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JULY 2020
VOL. 78 • NO. 7
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MATERIALS EVALUATION

JULY 2020
VOLUME 78 • NUMBER 7

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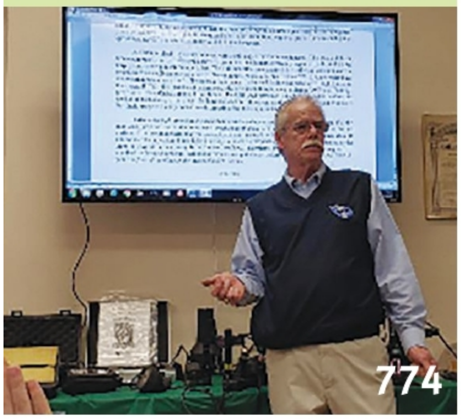
TECH FOCUS ISSUE: NDE 4.0

M·E departments

ASNT SCOPE



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RESOURCES

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MATERIALS EVALUATION

VOLUME 78 • NUMBER 7

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ASNT MISSION STATEMENT

ASNT exists to create a safer world by advancing scientific, engineering, and technical knowledge in the field of nondestructive testing.

Materials Evaluation is an archival journal in nondestructive testing/evaluation/inspection. The journal's technical articles are refereed by experts in their fields and the papers are abstracted by major technical abstracting services, including: *Aluminum Industry Abstracts; Applied Mechanics Review; Applied Science and Technology Index; Corrosion Abstracts; Current Contents Engineering, Computing, & Technology; Engineered Materials Abstracts; Engineering Index; Essential Science Indicators; Exploration and Production Health, Safety & Environment; INIS Atomindex; INSPEC (Engineering Village); International Petroleum Abstracts; ISMEC, Mechanical Engineering Abstracts; Materials Business File; PASCAL; Science Abstracts; Science Citation Index Expanded; Solid State and Superconductivity Abstracts; Transportation Research Information Services;* and *Web of Science.*

AMERICAN INSTITUTE OF NONDESTRUCTIVE TESTING

American Institute of Nondestructive Testing PURCHASES NEW TRAINING FACILITY

The American Institute of Nondestructive Testing has purchased a 21,600 sq. ft building which will be used to expand their training facility.

NDT TRAINING

The American Institute of Nondestructive Testing provides nondestructive testing training for major corporations, as well as offers a complete "Nondestructive Testing Technologies Certificate", vocational style training program for students across the country interested in entering into a rewarding career in Nondestructive Testing.

EXPANDED CAPABILITIES

The building will provide adequate space for the expansion of AINDT's training capabilities. The new campus will include a testing center, student lounge, additional classrooms, video production studio, welding equipment, among other items.

NEW FACILITY

"The new facility will allow us to expand our services to meet the needs of our clients." Said Don Booth CEO. "Adding additional equipment such as production studio, additional student amenities, and an improved testing center will make a positive impact on our students learning experience."

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PRESIDENT'Sletter

Vote!

> This month, voting starts for your 2020–2021 Board of Directors.

THIS MONTH, VOTING STARTS for your 2020–2021 Board of Directors. In order to be considered for a Board position, people started submitting their applications as early as last year. Next, the applications are reviewed by a subcommittee of the Board called the Selection Committee. The Selection Committee then makes its recommendation back to the Board for whom should be on the annual ballot. This process is usually finalized at the ASNT Research Symposium in March or April, but this year, for the first time, it was all performed remotely.

After review of the applications, the Selection Committee puts forth one name for Chairperson of the Board, President, and Vice President, and all qualified candidates for Secretary/Treasurer. That could be one individual or three individuals. This year is no different, as there are a few candidates for Secretary/Treasurer.

What is different about this year are the Director at Large candidates. Historically, the Selection Committee would submit up to three names for Director at Large, and then you, the member, could vote for up to or all three candidates, as there are always three openings every year. Because you, the member, vote for the Directors at Large, it has always been viewed as a "vote of the membership." However, if you, the member, are only given three choices and you can vote for all three, the question has come up as to whether this is a true "vote of the membership."

Because of this, the Board recently reviewed the policy that governs the number of candidates for Director at Large and decided that changes needed to be made. With that, I am pleased to announce that for the first time in our history (that I am aware of), the annual ballot will have more than three candidates for Director at Large. Therefore, this year will be the first year that is a true "vote of the membership" for Director at Large. I encourage everyone to read the bios of the candidates in order to make an informed decision about who you think will be the best people to serve on the Board of Directors. The bios are normally published in the June issue of *Materials Evaluation*, but this year they are online only and can be found at asnt.org/election.

In fact, this year marks a lot of firsts. We are in a global pandemic, which has forced everyone to rethink just about everything (including how much toilet paper to keep in stock). As ASNT President, I would normally be visiting and presenting at local sections, but I am now visiting sections virtually. This is not something I thought I would be doing, but honestly, it has made me more available to more local sections than I probably would have been if I had to travel. I do miss the one-on-one interactions with members, but so far, there has actually been more attendance at virtual meetings than at normal face-to-face meetings.

There have been several other firsts this year, such as webinars and virtual conferences, and all of our Board meetings since January have taken place through video conferencing. One other first I am very proud of is the New NDT Professional membership. As you may have heard me say (or read in a previous letter), I have issued a presidential challenge to have every member get one person to sign up for this membership. I wanted to give you an update, and I must say that this membership is off to a great start. It became available 1 April and by 29 May—59 days later—we added 55 people, with 45 people being brand-new members of the Society. I personally want to thank everyone who has accepted my challenge.

Lastly, as people are going back to work, we are still in unprecedented times, so be safe, stay healthy, and hopefully, we will be able to see one another at a conference soon.

MICHAEL V. MCGLOIN
2019–2020 ASNT President
president@asnt.org

DIRECTOR'S letter

ASNT Learning Opportunities

"There are so many opportunities to develop professional knowledge..."

OVER THE PAST SEVERAL MONTHS, I have been describing the ASNT Member Value Framework. This month, the focus is on learning opportunities, the third member value stream. In actuality, based on member feedback, I believe learning opportunities are the number-one reason NDT professionals look to ASNT.

ASNT was founded on the idea that its core purpose was "advancing scientific engineering and technical knowledge in the field of nondestructive testing through education." Over the Society's 75-plus years, ASNT has provided a wide range of learning opportunities, and recently, the Board of Directors approved the expansion of ASNT's learning programs into new digital formats.

You may have noticed our new series of live webinars hosted on the ASNT Learn website. Our webinars bring the knowledge of industry leaders to you at an extremely reasonable price ($49 for members). ASNT webinars are interactive, including opportunities for questions and answers. They are offered monthly in the Innovations in NDT series, which addresses interesting new NDT technologies or methodologies. ASNT is collaborating with the Nondestructive Testing Management Association in our newest webinar series, Management of NDT, which addresses challenges organizations face in managing the NDT function. We are also pleased to announce the release of our third webinar series, Applications of NDT, which focuses on practical applications of NDT. Professionals now have three unique learning opportunities to choose from each month. All webinars are recorded and archived on ASNT Learn.

ASNT is adding microcourses to its online learning portfolio. These web-based courses are short, one-hour focused learning modules, and can be completed on demand. Current topics include optimizing MT process controls, enhancing MFL of storage tanks, and the benefits of 3D modeling for VT measurement. These modules are interactive and include an assessment; successful completion earns a certificate. Look for the list of microcourse topics to expand every month.

ASNT is in discussions with a leading online NDT course provider to make their portfolio available to our members at discounted pricing. The courses, varying in length from 8 to 40 hours, will be accessed through ASNT Learn, and completion—just like all other ASNT Learn activities—will be tracked in your membership record.

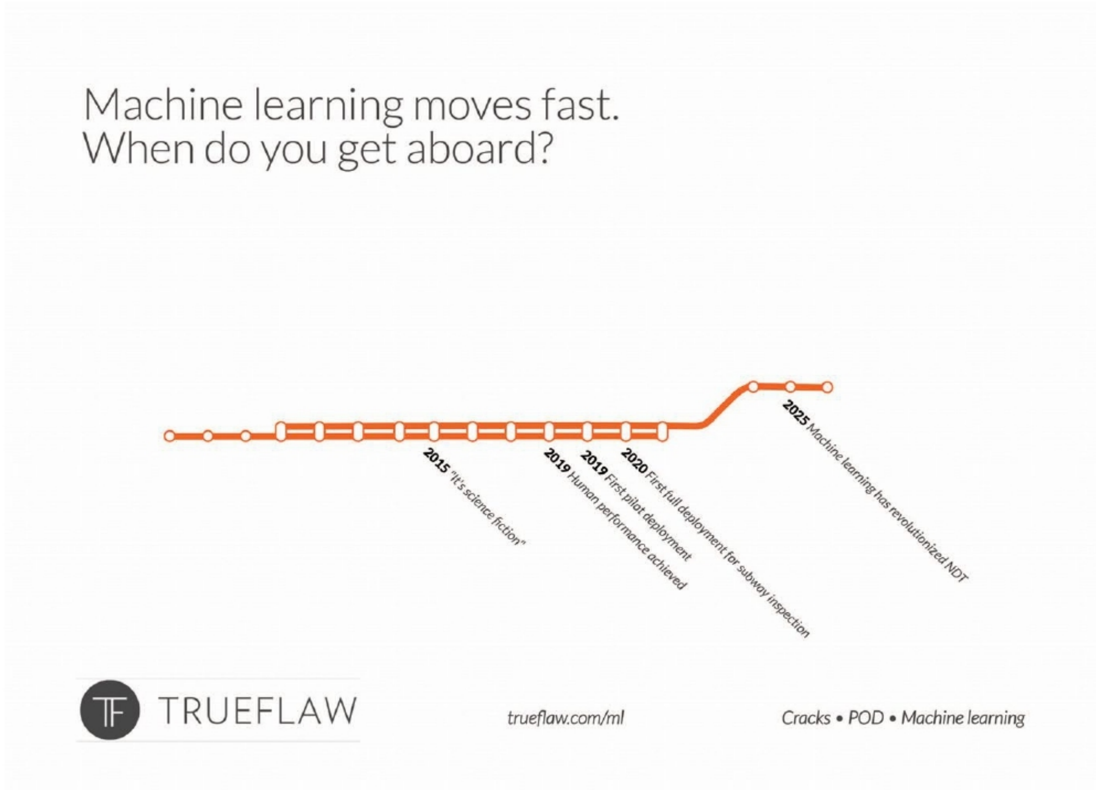
ASNT sections also provide learning opportunities through monthly meetings. ASNT will be producing a new Section Workshop Series of half- and full-day workshops. ASNT will develop the content and train the presenters, and sections will organize the event locally. We believe this new collaboration will provide great learning opportunities for our members.

ASNT Events offers extensive learning opportunities through keynote presentations, technical sessions, and post-conference short courses, which are half- or full-day seminars. In addition to learning, members can earn recertification points. ASNT now offers recorded conference sessions on demand through ASNT Learn. Many are available at no cost to members.

ASNT Refresher Courses are in-person training events offered in Columbus, Ohio, near the International Service Center. Unfortunately, we had to cancel our spring and summer sessions due to the pandemic, but the good news is we are working to make these courses available online beginning later this summer. We will be using the same course content and the same excellent instructors. Participants will complete work over a period of four weeks by attending live presentations online and completing work offline at a time convenient to them. Watch for further announcements on this exciting program!

There are so many opportunities for members to learn and develop professional knowledge and skills that we cannot address them all here. Please visit ASNT Learn at asnt.org to see all of the learning programs available to you.

NEAL J. COUTURE, CAE
ASNT Executive Director
ncouture@asnt.org



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2019 Human performance achieved
2019 First pilot deployment
2020 First full deployment for subway inspection
2025 Machine learning has revolutionized NDT
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FOCUSletter

NDE 4.0

WELCOME TO THE *MATERIALS EVALUATION* technical focus issue on NDE 4.0. It is truly an honor and privilege to serve as the guest editor for this special issue, the first ever on nondestructive evaluation (NDE) in the fourth industrial revolution across all technical publications.

NDE 4.0 is a confluence of Industry 4.0 technologies with traditional NDE methods. Digital technologies and physical inspection methods continue to evolve, mostly independently and sometimes interdependently. When combined using digital twins that capture and leverage data directly from the manufacturing process to in-service maintenance, we can optimize prescriptive maintenance for the safety and longevity of an asset and feed the relevant data back for design improvements.

NDE cannot be left behind as every industrial sector enters the fourth revolution. The entire inspection community needs to transition to a new way of thinking by embracing the increased role of machines in every aspect of quality and safety assurance; by being willing to accept significant changes to technology, application, training, certification, and regulation; and by having a collaborative and "unlimited possibility" mindset. This issue is aimed at opening minds by scratching the surface of NDE 4.0 and triggering the community's conversations and activities, like a fire starter.

> "NDE cannot be left behind as every industrial sector enters the fourth revolution."

This issue strives to touch upon many of the starter topics—purpose and pursuit (Singh), challenges and opportunities (Meyendorf et al.), perceptions and reality (Vrana), and opportunities and threats (Schulenburg). Also included are papers focused on the oil and gas industry (Wassink et al.) and the machine intelligence discipline (Aldrin). The content is specifically targeted to bring awareness around the topic and its use case as well as early thinking, which is evolving rapidly into what will be frontline world-class research in the next decade. We expect this issue to have a very short shelf life, just like a fire starter. Other journals including *Research in Nondestructive Evaluation* (published by ASNT) and *Journal of Nondestructive Evaluation* (Springer), also plan to publish topical issues on NDE 4.0, bringing valuable research content very soon.

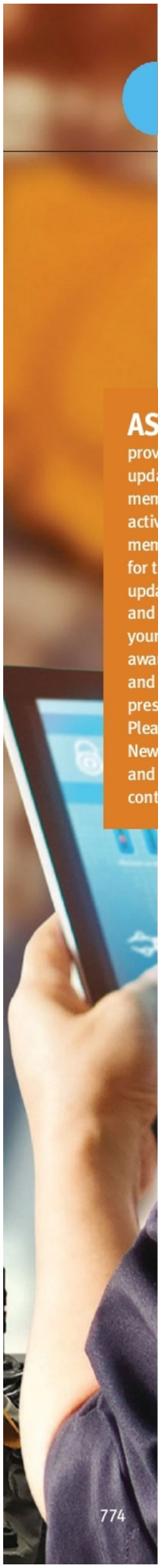
There has been a flurry of activities on NDE 4.0 over the last two years, mostly limited to a small group of thought leaders congregating at conferences and sharing research, applications, and a desire to come together. The German Society for Nondestructive Testing (DGZfP) committee, chaired by Bernd Valeske, was formed in June 2017 and is supported by 25 experts. They are focused on four items: interfaces in the Industrial Internet of Things, human-computer interaction, training, and additive manufacturing. The ASNT NDE 4.0 Committee, of which I am the chair, was formed in April 2019 and is supported by another 25 experts. The focus of this committee is to create a platform for knowledge exchange, endorse existing standards, and build a usable international resource directory. Another topic of concern is ethics as we consider the impact of decision-making machines. ASNT has been offering short courses, running full-day technical tracks, and facilitating panel discussions on the topic at annual conferences and research symposia. Norbert Meyendorf and colleagues are working to create a handbook of NDE 4.0. Johannes Vrana is organizing the first International Conference on NDE 4.0 in Munich, sponsored by DGZfP.

Watch the video
Welcome to the Technical Focus Issue on NDE 4.0

ASNT and DGZfP have recently launched efforts to align the global communities. An international ambassador program with key individuals from more than 10 active countries will meet virtually to share findings and exchange developments in their respective countries. This aligns with the upcoming ICNDT initiative on NDE 4.0 as well. We extend an open invitation to take part in the conversation around the acceleration of NDE 4.0 triggered by COVID-19.

Dear readers and leaders, please enjoy this special issue like a rising sun with a breath of fresh air and engage with NDE 4.0, as it brings abundant opportunities to all those who choose to embrace digital technologies and their valuable applications for a safer and more affordable world.

RIPI SINGH, PH.D.
Technical Focus Issue Editor
ripi@inspiringnext.com



ASNT SCOPE

ASNT Scope provides readers with updates on ASNT members, sections, and activities. We depend on member contributions for this section. Send updates, announcements, and photos regarding your Section, people, awardees, obituaries, and other updates to presaward@asnt.org. Please include Scope News in the subject line, and your name and contact information.

section news

Chicago

CHICAGO, ILLINOIS

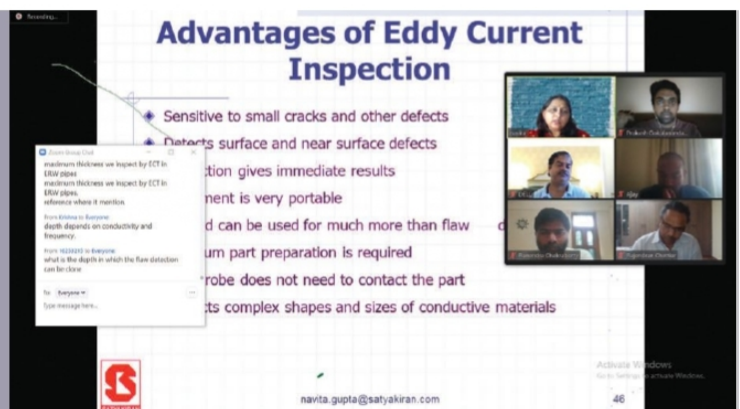
On 9 March, the Chicago Section participated in the Homewood Flossmoor High School career day. Over 50 professional organizations, private companies, and government agencies presented to more than 700 students.

Section members **Michael L. Kelley** of Olympus America Inc. and **Ronald R. Mika** highlighted the opportunities and benefits that a career in NDT can provide to high school graduates, such as ensuring the safety of society, providing opportunities for technical/professional growth, and affording personal financial security. Many discussions were held regarding the

Michael L. Kelley of Olympus America Inc. (left) and Ronald R. Mika of the Chicago Section exhibited at the Homewood Flossmoor High School career day.

SECTION HIGHLIGHT

The India Section successfully conducted its training program on eddy current testing via videoconferencing in May with around 220 members in attendance. The Section had the opportunity to have ASNT Director at Large and Regional Director, Region 19, Marwan F. Basrawi and Director at Large Sebastian Z. Fernandes attend the meeting.



The India Section hosted an eddy current training program virtually in May.

Golden Gate Section members and vendors at the Annual Vendor Fair 2020.

lower cost of the required education, quick entry into a vital field, opportunity to expand one's professional focus (for example, on different methods), and the prospect of secure employment over a career.

Golden Gate

SAN FRANCISCO, CALIFORNIA

The Golden Gate Section held its Annual Vendor Fair 2020 on 12 March at Embodied Wines in Livermore, California. A great time was had by all. The Section would like to thank all the vendors who provided raffle prizes and purchased a space, and to **Allison J. Wright** for providing prize-winning cookies.

India

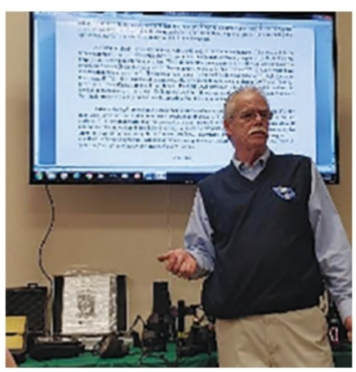
CHENNAI, INDIA

The India Section successfully conducted its training program on eddy current testing via videoconferencing in May with around 220 members in attendance. The Section had the opportunity to have Director at Large and Regional Director, Region 19, **Marwan F. Basrawi** and Director at Large **Sebastian Z. Fernandes** attend the meeting. The speaker was **Navita Gupta,** who gave a great presentation.

Metro NY/Northern New Jersey

ROCKVILLE CENTRE, NEW YORK

The Metro NY/Northern New Jersey Section met on 11 March in Freeport, New York, with 21 members and guests in attendance. The Section was awarded the bronze-level President's Award. **Tara M. Kavanaugh** presented the award to **Antionette (Toni) Y. Bailey** for being the driving force behind the revival of the Section. The Section would also like to



Section Vice Chair Edward P. Dukich presented on the evolution of the portable UV-A light at the Metro NY/Northern New Jersey Section meeting.

Society Notes

Readership Survey

Thank you to all our readers who completed the ASNT Periodicals Readership Survey that was conducted by ReadEx Research in March 2020. More than 13 000 surveys were distributed via email with a completion rate of nearly 19%. A summary of results will be presented in a future issue of *Materials Evaluation*. The winners of the $100 Visa gift cards were David Wright and Doug Corbett.

2020–2021 Election Notice

Meet the full slate of nominees and candidates by reading their biographies at asnt.org/election. Voting begins **1 July 2020**. All eligible voting members of the Society will receive an email from Intelliscan with instructions and a link to submit your ballot online. Eligible voting members who do not have an email address on file with ASNT will receive a ballot by mail. Voting closes 21 August 2020. Results will be posted on asnt.org no later than 1 September 2020.

Digital Imaging Conference Now Virtual

The Digital Imaging and Ultrasonics for NDT conference scheduled for **28–30 July 2020** will now be a virtual only conference. Please visit asnt.org/events to register.

Membership Dues Waiver

Of the concerns our members may be presently facing due to COVID-19, we do not want your ability to maintain your ASNT membership to be among them. If you're a member who has become unemployed as a result of the ongoing pandemic, you may be eligible for a hardship waiver of your dues for up to six months. Please call ASNT customer service at 1-800-222-2768 (1-614-274-6003) for assistance.

section news

congratulate Bailey on becoming their Regional Director (Region 2). Section Vice Chair **Edward (Ed) P. Dukich** presented on the evolution of the portable UV-A light with demonstrations of older model lights, bulbs, and filters including new LED light assemblies, LED UV replacement bulbs, and the newest flashlights. Demonstrations included the differences (advantages and disadvantages) between mercury vapor arc, high-intensity discharge, and LED bulbs. The presentation was fun, informative, and enjoyed by all.

North Alabama

HUNTSVILLE, ALABAMA

The North Alabama Section hosted a virtual meeting on 13 April. Participants included Section Secretary **Nathan Curtis**, Section Chair **Willie G. Finney, Jr.**, and Section Vice Chair **George K. Hodges**, as well as Section members **Richard Elvin Mitchell II** and **Roger Mainville**. The Section won a bronze-level President's Award for the third year in a row. The Section would like to thank all North Alabama Section members.

Northern New England

NEWINGTON, NEW HAMPSHIRE

The Northern New England Section held a virtual business meeting on 2 April. **Dana W. Wilson**, **William Hinton**, **Antonio (Tony) J. Maggio**, **Cleve B. Burbage III**, and **Lindsay A. Warner** were in attendance.

Pacific Northwest

SEATTLE, WASHINGTON

On 3 March the Pacific Northwest Section listened to **Robert D. Gessel** present on "Failure Investigation and Monitoring of Roof Transport Wheel Axles," with 17 members and guests in attendance. The presentation was about a local landmark, the T-Mobile Stadium. Gessel presented slides on the investigation that resulted after a wheel bearing broke on the retractable roof. The ultrasonic testing method was used to find the cracks in the axles. A shear wave examination was performed among the other bearings, which determined that there were additional bearings with similar defects. Overall, without having ultrasonic technology, finding hazardous defects like the one that caused the bearing to break would have been a much longer and more costly project.

Speaker Robert D. Gessel (left) received a speaker's gift from Pacific Northwest Section Vice Chair Tyler J. Young.

Rockford Stateline

ROCKFORD, ILLINOIS

The Rockford Stateline Section and Chicago Section held a joint virtual technical meeting on 14 April with 18 members and guests in attendance. The guest speaker for the evening was NDT Team Leader **Gary E. Mathias** of The Modal Shop Inc., located in Cincinnati, Ohio. Mathias presented on "The Basics of the Resonant Acoustic Method per *ASTM E2001*." The talk was centered on the ASTM standard and how the resonant acoustic technique can be applied. Mathias first gave an overview of the theory and how the process works, and then showed a number of applications across a wide spectrum of industries. Rockford Stateline Section Chair **Joel A. Mohnacky** of Collins Aerospace orchestrated the meeting and facilitated the question and answer period.

Western New York

BUFFALO, NEW YORK

The Western New York Section hosted an online meeting on 24 March. The schedule for meetings and programs for the coming year were discussed. With the current COVID-19 crisis, the Section decided to schedule an online meeting for May with **Chuck Hellier** as the speaker.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awards & honors


Hussein M. Sadek


Marybeth N. Miceli


Allison J. Wright

Charles N. Sherlock Meritorious Service Recognition

The Charles N. Sherlock Meritorious Service Recognition provides acknowledgment for an individual's outstanding voluntary service to the Society, through single or aggregate activities, though not necessarily in any single year. In 2004, the award was renamed in honor of its first recipient, Charles N. Sherlock.

2020 winner Hussein M. Sadek is the president and founder of TCI Inc., a consulting company that provides nondestructive testing (NDT) consulting, inspection, and training services. A member of ASNT since 1979 (Charlotte Section), Sadek is an ASNT Regional Director, Region 5. He is an active member of the Business and Finance Committee, chair of the Nonfinancial Recognition Committee, and a member of the Certification Management Council and chair of the Electromagnetic Testing (ET) Committee.

Sadek served on the ASNT Board of Directors for two terms and was ASNT Past President/Chairperson of the Board from 1997–1999. He is also a past president and past board member of the Nondestructive Testing Management Association (NDTMA). Sadek holds an associate's degree in electrical engineering from Central Piedmont Community College and a B.S. in engineering technology from the University of North Carolina at Charlotte.

He holds a number of professional certifications, including PMP from the Project Management Institute, ASNT NDT Level III in ET and magnetic particle testing (MT); ACCP Professional Level III in MT; Corporate Level III in ET (ET, remote field testing, and alternating current field measurement), thermal/infrared (IR), magnetic flux leakage (MFL), MT, liquid penetrant testing (PT), ultrasonic testing (UT), and visual testing (VT); and is a certified infrared thermographer from the Infraspection Institute.

Sadek is a member of ASME, AWS, and NDTMA, and an advisory board member for the Central Piedmont Community College's NDT Technology Program. Sadek is an ASNT Fellow (class of 1991) and winner of the Philip D. Johnson Honorary Member Award (2009), the Robert C. McMaster Gold Medal (2013), and the George L. Pherigo Tutorial Citation Award (2016). He also received a Meritorious Service Award from the Charlotte Section (2009).

Sadek has presented many papers on various NDT techniques and applications domestically and internationally. He is the author of ASNT's *Electromagnetic Testing Classroom Training Book*, the Electromagnetic Testing Student Package, the Electromagnetic Testing Instructor Package, and *Programmed Instruction Series: Electromagnetic Testing*.

Recognition for the Advancement of Women in NDT

The Advancement of Women in NDT Recognition acknowledges individuals or organizations who encourage women to enter and thrive in the field of NDT, either through creation and/or implementation of programs that provide educational or career advancement opportunities in NDT that may not otherwise be available to women, or through leading by example of how women can not only have a career in NDT, but also contribute greatly to NDT, ASNT, and creating a safer world.

2020 winner Marybeth N. Miceli is the cofounder and a principal of the We-NDT Marketing Network, which publishes NDTnow.com. Miceli is also the president of Miceli Infrastructure Consulting, a company she founded in 2010 to help owners and emerging structural health monitoring (SHM) and NDT technology providers work together to solve some of the biggest challenges in the infrastructure industry.

Miceli has over 25 years' experience in NDT, SHM, and testing of civil infrastructure. She is a chartered engineer through the British Institute of Non-Destructive Testing (BINDT) and a materials science engineer by education with a background in structures, NDE, technology commercialization, failure analysis, quality assurance, SHM, and transportation engineering, working on projects from the George Washington Bridge to the NY Mets Stadium to the Empire State Building antenna to various bridges around the world. Miceli has consulted for DHS and various transportation agencies and is a member of the FHWA NDT Research Working Group.

Miceli has served two three-year terms as a Director at Large on ASNT's Board of Directors, as chair of the Section Operations Council (SOC), as chair of the Infrastructure Committee, and currently serves as the chair of the Women in NDT Committee. She is the youngest member ever to be named a fellow of ASNT. Miceli also currently serves on the NDTMA Board of Directors and the *ASTM E07.10* committee, and is an invited member of ISHMII. She also serves on the National Academy of Sciences' TRB Committee on Testing of Transportation Structures.

Specific to women in NDT, Miceli's contributions include the creation of the Advancement of Women in NDT Recognition, contributing to special issues of *Materials Evaluation* focusing on women in NDT, creation of the Women in NDT LinkedIn Group, and creation of the Outreach Division under SOC and the Women in NDT committee within it. The ASNT Greater Los Angeles Section named a women's scholarship after her as well.

Miceli obtained her M.S. from Virginia Tech, where she developed inspection protocol for infrared thermography of in-situ FRP bridge decks, and her B.S. from Johns Hopkins University (JHU), where she worked with acoustic microscopy of ceramics and eddy current testing of bicycle cranks and engine cylinder liners. During her time at JHU, she interned at the FHWA's NDE Validation Center.

Miceli has appeared on Modern Marvels, Fox News, Fox's Morning Show with Mike and Juliet, WNBC, ABC.com, and CBS-KDKA, as well as in *USA Today*, *CNN Money*, and the *Wall Street Journal*, among others. Miceli is a social media pioneer in the NDT field and created and produced the social media–based NDT awareness campaign #whyiNDT on various platforms.

2020 winner Allison J. Wright is a senior nondestructive inspection (NDI) engineer for NDT Solutions and works from a home office in Fremont, California. Her career began at Spirit AeroSystems in Wichita, Kansas, as a summer intern, and she returned full-time after graduating with a bachelor of science degree in aerospace engineering and a minor in nondestructive evaluation (NDE) from Iowa State University. At Spirit AeroSystems, Wright supported new programs and contracted research and development projects. While working at Spirit, Wright earned her master of science degree in operations management from Friends University. Wright moved to California in 2017 and joined NDT Solutions, where she provides technical expertise about NDI as a consulting engineer.

Wright helped create an official Spirit process document for the design of NDI standards. By creating this process, she helped designers become more aware of how their designs affect NDI. While working on a difficult inspection, Wright invented a technique for inspecting the interior of aircraft stringers using a mobile inspection device. The first patent for this device was granted in 2015, and a second patent was granted in 2016.

Wright has held several leadership positions within the Wichita and Santa Clara Valley (SCV) Professional Society of Women Engineers (SWE) sections, including being the Wichita section president in FY12 and FY13 and the SCV vice president of career development in FY19. For the Santa Clara Valley section, Wright was placed in charge of the FY19 scholarship program where she helped streamline the application and judging process for scholarship program.

Wright has also held several leadership positions for SWE at the national level, most notably as the chair-elect of the Program Development Grant Committee for FY19. She was the FY16 Region i lieutenant governor. Wright has presented at multiple SWE conferences and is a frequent volunteer for "Invent it. Build it."

In addition to SWE activities, Wright is a frequent volunteer with the Girl Scouts. For several years in Wichita, she led a special-interest troop of girls who competed each year in a local robotics competition. The troop met year-round to introduce the girls to STEM topics and to generate excitement about careers in STEM fields. In California, Wright is the leader of the South Bay Gold Award committee, which oversees the highest achievement awards given by the Girl Scouts of the Northern California Council. She has also coauthored multiple blog posts about the Gold Award for the council, which have been shared by other Girl Scout councils across the country.

Wright has a passion for STEM outreach and is deeply involved in her community through a variety of activities. Her efforts are inspired by her passion for engineering and for developing that passion in the next generation of students. Wright lives with her husband, Alex, and their train-loving son, Henry, along with a varying number of foster kitties. When she's not volunteering, she enjoys hiking, reading, baking, and decorating (and eating!) cakes.

Each month, *ME* highlights selected honorees from the most recent ASNT award programs. The department also features background on the highlighted award, plus announcements of award applications, award winners, and deadline information.

awards & honors

ASNT Award Winners

Complete information on all awards is available on the ASNT website at asnt.org. Other 2020 ASNT award winners may be announced at a later date in the Awards & Honors pages in *Materials Evaluation*.

The American Society for Nondestructive Testing (ASNT) is pleased to announce the following award winners. These award winners will be recognized at the 2020 ASNT Annual Conference in Orlando, Florida.

50-Year Member Recognition

The recipients of the 2020 50-Year Member Recognition are **James S. Borucki**, **Joseph L. Rose**, Ph.D., and **George A. Matzkanin**.

ASNT Fellow

The 2020 class of ASNT Fellows is **Sebastian Z. Fernandes**, **Claude L. Going, Jr.**, **David P. Harvey**, **Alexander Leybovich**, **Yi-Cheng (Peter) Pan**, Ph.D., and **Albert M. Wenzig, Jr.**

Advancement of Active Military and Veterans in NDT Recognition

The winner of the 2020 Advancement of Active Military and Veterans in NDT Recognition is **Kevin W. McKinley**.

Advancement of Women in NDT Recognition

The winners of the 2020 Advancement of Women in NDT Recognition are **Marybeth N. Miceli** and **Allison J. Wright**.

Charles N. Sherlock Meritorious Service Recognition

The winner of the 2020 Charles N. Sherlock Meritorious Service Recognition is **Hussein M. Sadek**.

Engineering Undergraduate Scholarship

The winners of the 2020 Engineering Undergraduate Scholarship are **Zach Rodely** and **Stetson Watkins**.

Faculty Grant

The winners of the 2020 ASNT Faculty Grant are **Parisa Shokouhi**, Ph.D., of Pennsylvania State University, based on her proposal for "Revitalizing EMCH/MATSE 440 Nondestructive Evaluation of Flaws: Integration of Hands-On and Virtual Laboratory Modules & NDE for Additive Manufacturing"; and **Xuan (Peter) Zhu**, Ph.D., of University of Utah, based on his proposal for "Development of a Course Module in Machine Learning for Nondestructive Testing at the University of Utah."

Fellowship Award

The winners of the 2020 ASNT Fellowship Award are **Iowa State University** (Hantang Qin, Ph.D., advisor; Zhan Zhang, advisor; Xiao Zhang, student); **New Mexico State University** (Ehsan Dehghan-Niri, Ph.D., advisor; Sina Zamen, student); **Southern Illinois University Carbondale** (Tsuchin [Philip] Chu, Ph.D., advisor; Merrill Dennison, student); **University of Maryland** (Mohammad Modarres, advisor; Seyed Foad Karimian, student); and **University of Pittsburgh** (Piervincenzo Rizzo, Ph.D., advisor; Andrew Bunger, Ph.D., advisor; Yuhui Zeng, student).

George C. Wheeler Excellence in Personnel Certification Recognition

The winners of the 2020 George C. Wheeler Excellence in Personnel Certification Recognition are **Robert A. Feole** and **Danny L. Keck**.

George L. Pherigo Tutorial Citation

The winner of the 2020 George L. Pherigo Tutorial Citation is **Robert E. Cameron**.

Lester/Mehl Honor Lecture

The recipient of the 2020 Lester/Mehl Honor Lecture is **Henrique L. Reis**.

Lou DiValerio Technician of the Year

The Lou DiValerio Technician of the Year Recognition was not awarded in 2020.

Mentoring Award

The winners of the 2020 Mentoring Award are **Scott P. Cargill**, **John (Jack) C. Duke, Jr.**, Ph.D., **Roger W. Engelbart**, **Roman Maev**, Ph.D., and **William Scott Rose**.

Outstanding Paper Award

The winners of the 2020 Outstanding Paper Award for *Materials Evaluation* are **Joseph T. Case**, **Shant Kenderian**, Ph.D., and **Yong M. Kim** for the paper titled "*Orion* Heat Shield Bond Quality Inspection: Developing a Technique," published in *Materials Evaluation*, Vol. 77, No. 1, January 2019, pp. 83–93.

The winner of the 2020 Outstanding Paper Award for *RNDE* is **Kanji Ono** for the paper titled "Critical Examination of Ultrasonic Transducer Characteristics and Calibration Methods," published in *RNDE*, Vol. 30, No. 1, 2019, pp. 19–64.

Philip D. Johnson Honorary Member Recognition

The winner of the 2020 Philip D. Johnson Honorary Member Recognition is **Roger W. Engelbart**.

Research Recognition for Innovation

The winner of the 2020 Research Recognition for Innovation is **Neil J. Goldfine**, Ph.D.

Research Recognition for Sustained Excellence

The winner of the 2020 Research Recognition for Sustained Excellence is **Lalita Udpa**, Ph.D.

Robert B. Oliver Scholarship

The Robert B. Oliver Scholarship was not awarded in 2020.

Robert C. McMaster Gold Medal

The winners of the 2020 Robert C. McMaster Gold Medal are **John (Jack) C. Duke, Jr.**, Ph.D., and **William (Bill) F. Via, Jr.**

Student Travel Grant

The winners of the 2020 Student Travel Grant are **Maggie Baechle, Merrill Dennison, Saman Farhangdoust, Seyed Foad Karimian, Ogheneovo Idolor, Elliott W. Jost, Jinsun Lee, Stylianos Livadiotis, Milad Mehrkash, Ali Mirala, Swathi Muthyala Ramesh, Hamidreza Nemati Noghlebari, Jameson Secrist, Mehrdad Shafiei Dizaji, M.D. Shahjahan Hossain, Survesh Shrestha, Ryan J. Spencer, Marshall Vaccaro, Sina Zamen,** and **Xingxing Zou.**

William Via Bridge NDT Lifetime Service Recognition

The winner of the 2020 William Via Bridge NDT Lifetime Service Recognition is **Glenn A. Washer**, Ph.D.

Young NDT Professional Recognition

The winner of the 2020 Young NDT Professional Award is **Christopher Michael Kube**, Ph.D.

New ASNT Certificate Holders

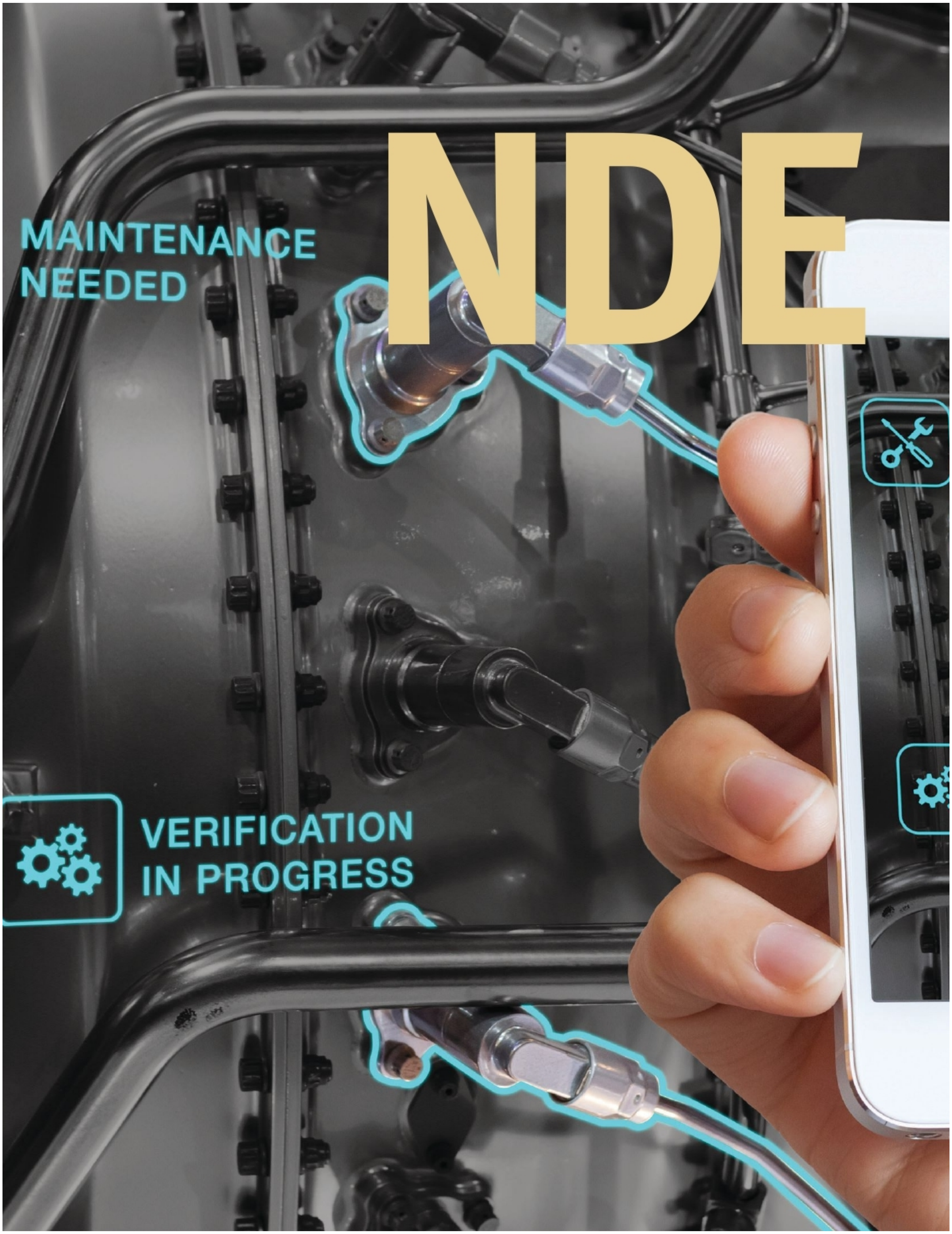
Below are personnel who have recently obtained their initial ASNT certifications. This list includes new certificate holders who were added to the ASNT database through 1 June 2020. Each certificate holder's current certification information can be found on the ASNT website at asnt.org/certlist.

ACCP Level II CWI

Chong Keun Ahn
Clay Allen
Mohamed Ibrahim Amer
Alex Anderson
Kyle Anderson
Daniel A. Azlin
Joel Backus
Philip Barker
Robert Bevilacqua
Darrell Boling
Rodney Bolton
Jordan Bouey
Andrew N. Bowman
Gordon W. Canning
Davide Carbonaio
Shih Yen Chen
Connor N. Childs
Dongjin Choi
Kevin Clark
Brian Collins
Michael Cook
Anthony Cornejo
Mark Degenstein
Alexander DeHart
Stevie Dehart
David A. Diaz
Anton Xose Diaz Gomez
Richard Dixon
Ryan Doyel
Kurt T. Drabold
Ibrahim Elbhiry
Jeffrey Erwin
Luis Gerardo Garcia Cortes
Phuntsok S. Gawatsang
George Gemmell
Kyle Gradert
Tom Greene
William R. Gunn, Jr.
Benjamin Harris
Daniel Hervatin
Paul Holler
Huoo-Ching Hsu
Ya Chi Huang
Daniel Ike
Barry Jennings
Jung Ju Kim
Joseph Kirkendall
In Soo Lee
Tae Ju Lee
Yu Jen Lin
David Logue
Francisco Lopez
Jared Maez
Jimmy Mayberry
Christopher McCray
George Moore
Enrique Munoz
Brian Nell
Christopher Ortlepp
Calvin Pepper
Michael Quade
Ryan Ridenour
Michael Sheehan
Tony D. Silva
Dane Alexander St. Cyr
Jim Strunk
Wister Todd
Michael Vaughn
Miguel Angel Vazquez Flores
Nicholas Virbitsky
Jordan Warner
Frank S. Williams
Shih Chou Yang
Tomas Zapata Miranda

ASNT NDT Level III

Brian Bulgrin
Damon Dichler
Jeremy C. Grass
Hyun Ki Hong
Jeffrey Jay House
YongCheol Kim
Christopher Kring
Jun Hyoung Lee
Kendall McClendon
Michael Olivo
Jong Ho Park
Austin M. Picano
Junyu Qu


NDE
MAINTENANCE NEEDED
VERIFICATION IN PROGRESS

4.0

Purpose and Pursuit of NDE 4.0

by Ripi Singh

This article is intended to outline the purpose of NDE 4.0 (the why?) and bring awareness to the newly developed ISO standard on innovation management as a possible tool set to successfully pursue NDE 4.0 (the how?). Over the last couple of years, the nondestructive evaluation (NDE) community has come to appreciate the fourth industrial revolution, which was defined by the Germans as "Plattform Industrie 4.0" (Industry 4.0), and its implication to the inspection world in terms of NDE, which we refer to as "NDE 4.0" (BMWi 2020; Meyendorf et al. 2017; Vaidya et al. 2018; Singh 2018, 2019). NDE 4.0 is the digitalization of NDE systems resulting from the confluence of current NDE systems with Industry 4.0 technologies. Subsequent to the definition of Industry 4.0, the Science and Technology Basic Plan (Government of Japan 2015) defined the term "Society 5.0," which in some sense defines the purpose of Industry 4.0. It calls for the application of technology in a manner that concurrently brings both economic development and solutions to social problems. It ensues technology for the sake of society and not just for business reasons. Along very similar lines, the purpose of NDE 4.0 can be defined as "Safety 5.0: to concurrently enhance safety and bring economic value to stakeholders."

Such a purposeful pursuit is not easy. Challenges associated with technology development and adaption must be addressed. The thought leaders of the NDE community are coming together to create platforms for awareness and knowledge exchange and are confident that the suite of NDE 4.0 technologies themselves will help with the adaption of other pieces. An interesting paradigm, with no precedence from the previous three industrial revolutions.

On the same timeline, in 2013 an international community of experts from 45 nations embarked on developing standards for innovation management with a keen acknowledgment of this revolution. A significant milestone was recently achieved with the publication of *ISO 56002* (ISO 2019), which provides guidance for the establishment, implementation, maintenance, and continual improvement of an innovation management system for use in all established organizations. Although this ISO standard does not explicitly call out the fourth industrial revolution as the driving force, it has been written to help any organization work through a rapidly changing business context. It has the strength to enable companies to successfully pursue a purposeful NDE 4.0.

prescriptive maintenance, repairs, and overhauls over the lifetime of an asset, and even feed the big data back to the original equipment manufacturer (OEM) for design improvements.

The four design principles of Industry 4.0 (Hermann et al. 2016) have been interpreted for NDE application as (Singh 2019):

- Interoperability: the ability of instruments, sensors, devices, inspection equipment, and people to connect and communicate with one another via the Internet of Things (IoT).
- Information transparency: the ability of information systems to create a virtual or augmented reality (VR/AR) of physical anomalies by enriching digital artifact models with sensor data.

NDE 4.0 can be defined as a cyber-physical NDE system–a confluence of Industry 4.0 technologies with traditional NDE methods.

- Technical assistance: (1) artificial intelligence (AI) capability to support humans by aggregating and visualizing information comprehensively for making informed decisions; and (2) robotics using cyber-physical systems to support inspectors with tasks that are unpleasant, exhausting, or unsafe.
- Decentralized decisions: the ability of automated cyber-physical systems to make decisions on their own and perform tasks independently. Only in the case of exceptions, interferences, or conflicting goals are tasks delegated to a higher-level inspector.

Quick Recap of NDE Revolutions

If we look at the evolution of NDE in terms of the recognized industrial revolutions, NDE 1.0 is considered inspection based on human senses (visual, hearing, touch, smell) with some schedule and evaluation criterion. NDE 2.0 started when analog instruments and methods began to provide amplification and even the ability to look beyond the line of sight. NDE 3.0 was marked by the advent of digital technologies for signal processing and visualization. In this article, we have aligned these with themes behind industrial revolutions, although exact changeover cannot be as precisely identified as the application of steam power (Industry 1.0), electricity (Industry 2.0), and computers (Industry 3.0).

NDE 4.0 can be defined as a cyber-physical NDE system—a confluence of Industry 4.0 technologies with traditional physical NDE methods. Within the context of the physical–digital–physical loop of NDE 4.0, we have seen digital technologies and physical methods continuing to evolve, mostly independently and sometimes interdependently. The real power is in the concurrent design of inspection systems through an appreciation of digital twins, with the ability to capture and leverage data directly from the materials and manufacturing process to usage and in-service maintenance, across multiple assets, to optimize

Currently, the depot maintenance of an aircraft involves a predetermined schedule for maintenance, repair, and overhaul of an asset with parts repaired or replaced based on manual inspections, stored in inventory, guided by written instructions, judgments made by a team of skilled personnel, and data captured electronically in a knowledge base for offline analytics. A depot maintenance scenario of the future as projected by Deloitte (Vitale et al. 2018) presents some very interesting opportunities. Imagine that the depot begins "all and only" necessary activities before the asset arrives: AR guides the crew's activities on the asset upon arrival; advanced scheduling orchestrates acquisition of spares/repairs; intelligent workflow optimizes the downtime; components are tagged with real-time performance data; robots begin performing inspections with better probability of detection (POD); AI looks at the correlations to data from other assets and creates prescriptive analytics; 3D printing (additive manufacturing) is brought in to help with missing spares and special tools; and soon the asset is all set to go back to service—safer, faster, and cheaper. All of these technologies work like an orchestra serving the purpose.

The connectivity providing speed, economic benefits, and enhanced safety is what differentiates NDE 4.0 from our current state of the art. System-level integration has the potential of becoming a platform, where applications can evolve to rapidly and continuously make inspection more reliable. Not necessarily direct, but think about how a smartphone—with the integration of Wi-Fi, mobile data, a processor, memory, GPS, a camera, an HD display, and a couple of other sensors—has completely changed the world within 10 years in ways that were not originally conceived. Did you ever think that phone could be a compass, plus a stud finder, gauss meter, sound Db meter, and light meter, all in one? Such is the exponential power of digital-physical integration. There is so much to emerge that I can't predict most of it. And whatever I can, might be wrong. And that is where having a purpose and process to pursue becomes highly relevant.

The Purpose: Safety 5.0

Assuring safety is the number-one motivation behind inspection and maintenance. Everybody wants the system to function reliably, whether it is an air, water, or ground transportation vehicle, a material or energy manufacturing plant, a bridge or building, or an appliance or piece of equipment. Everyone wants safety for all the customers, users, stakeholders, operators, and construction and maintenance crews, as well as for the inspectors. This is why we engage in the business of NDE.

To begin with, most digital systems offer a clear advantage over traditional systems in terms of accuracy and speed. However, a significant contribution of a cyber-physical NDE system (NDE 4.0) stems from better control over human factors. This leads to a more reliable inspection system with more consistent POD from inspection to inspection (see Figure 1). This improved and dependable POD provides enhanced safety and enables the optimization of inspection programs, reducing the lifetime operating cost of an asset. The structured management of lifetime digital data, like a digital twin, opens up an additional economic opportunity to asset manufacturers and operators.

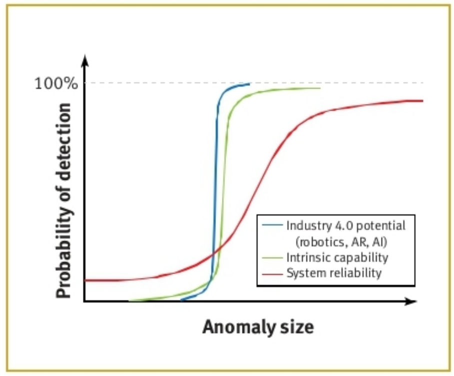


Figure 1. Industry 4.0 technologies have the potential to move system reliability closer to intrinsic capability, and even go beyond, making the POD curve rise up steeply toward the 100% mark.

Key questions we must ask include:

- What safety issues can NDE 4.0 address or create?
- How far and broad should we go with safety and economic impact?
- How many ways are there to deliver business value through fleet-wide lifetime data synthesis and digital-physical integration?

The possibilities for cyber-physical confluence using various sensory systems provide numerous opportunities (Vitale et al. 2018). Let's dig deeper into the application of NDE 4.0 technologies to both enhance safety and bring economic value to stakeholders, with an underlying emphasis that the two need not be mutually exclusive.

- Robotics and automation improve safety through dependable POD by virtue of reducing human factors and increasing precise execution. In addition, robots can protect the inspector from risks associated with confined spaces and hazardous areas.
- AR improves visualization of anomalies, leading to faster and more reliable interpretation; provides step-by-step instructions digitally layered over the physical asset to inform maintenance processes; and provides a possibility to engage OEMs and experts remotely.
- AI has the potential to significantly reduce false calls through data correlations and increase the accuracy of diagnoses, conduct root cause analysis of asset failures, enable continuous improvement in physical processes and automation, and more that we cannot comprehend today. AI ability in prescriptive and predictive maintenance is expected to be superior to human judgement.

An intermediate step could be intelligence augmentation, as discussed in an accompanying paper in this issue (Aldrin 2020).

- The IoT makes remote monitoring and remote decision making so much easier and faster (even in real time). In fact, it can open up new business models and value propositions around services and data monetization.
- "Big data" and AI can help identify complicated patterns and opportunities for improvement in the design and manufacturing of subsequent product variants.
- AI combined with digital image processing provides an opportunity to see anomalies currently not possible with visual, liquid penetrant, or magnetic particle testing methods. This conjecture is based on research reported by Hosny et al. (2018).
- AI combined with digital signal processing provides an opportunity to see anomalies currently not possible with methods such as acoustic emission testing.
- Additive manufacturing (AM) enables real-time adaptation of sensor systems for desired application, rapid manufacture of scarce/obsolete spare parts, and compression of the lead time needed for materials. As of now, we may not be able to create new sensors on the fly, but we can certainly improvise existing capability on the move, such as for naval ships or space stations. Another aspect of NDE 4.0 will be the insertion of inspection technology within AM devices to actively control the manufacturing quality.

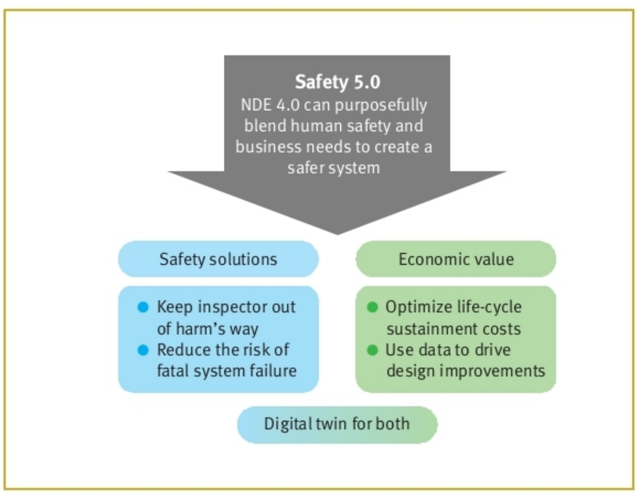


Figure 2. Safety 5.0 as a value proposition for NDE 4.0.

- Mobile devices have absorbed a large number of basic components (such as data processor, memory, video camera, display, two-way audio-video communication, data network, and so on), which allows NDE technology developers to focus their attention on sensors and data processing algorithms, making it a lot more affordable to create new inspection equipment or upgrade existing systems.

All of these possibilities have been opening up a whole new paradigm, where NDE 4.0 provides an opportunity to advance all three objectives—quality (safety), speed, and cost—as compared to the traditional perspective, where you can choose only two out of the three. That is why it is called the next revolution.

Another aspect to appreciate is that the revolution is not a discrete event that happens overnight. These technologies all emerge independently and then interdependently, until one day we begin to realize a very different value proposition.

NDE 4.0 opens up the possibility of asset-customized prescriptive maintenance, which can significantly improve the value we derive from the Data Analytics Maturity Model, originally proposed by Gartner in 2012 and summarized below:

- Level 1: Descriptive (What happened?)
- Level 2: Diagnostics (Why did it happen?)
- Level 3: Predictive (What will happen?)
- Level 4: Prescriptive (What should we do?)
- Level 5: Cognitive (What don't we know?)

This combination of stakeholder safety and economic value can be summarized under a single term: Safety 5.0. Safety 5.0, as illustrated in Figure 2, is similar to the definition of Society 5.0, which brings economic value and social benefits through cyber-physical confluence.

Challenges and Pursuit

Purposeful pursuit of NDE 4.0 for Safety 5.0 has its challenges, pretty much from all aspects, given the nature of multiple simultaneous disruptions. Visible challenges that can be listed, assessed, and addressed are related to technology, talent, and processes. Some of the more intangible ones include culture change and leadership mindset. And, on top of these, we need to prepare for the challenges that are completely unknown at this time, perhaps associated with the changing role of human interaction with cyber-physical systems. The good news is that Industry 4.0 also comes with solutions to many of the challenges it creates. Let's explore some of these along with opportunities to successfully overcome them.

First, the technology standardization around data connectivity, exchange, security, analytics, synthesis,

The need and speed for learning in the fourth revolution is an order of magnitude larger than the previous revolution.

and interpretation is still evolving. In fact, some argue that continuous change is the new normal. The underlying technology may just always stay in a state of continuous flux. The German Society for Nondestructive Testing (DGZfP) is making a serious effort toward standardization or acceptance thereof with sources from the IT industry for data exchange protocol (Vrana 2020). Soon, we will come to accept either HL7, OPC UA, or another variant better suited for NDE, because this acceptance is a cornerstone for the industrial success of NDE 4.0, just like in the third revolution, when the community adapted HTML in 1990–1991 to enable the explosive growth of the Internet, originally born in 1969. Let's accept that there is help available within the Industry 4.0 technology suite. The 5G network is expected to address the challenge of bandwidth. Blockchain could provide the required level of data security, and AI/machine learning is emerging to handle the vast amounts of data stored in digital twins over the lifespan of thousands of similar assets. For example, let's say an airline is operating a fleet of 520 airplanes of four different types from the same manufacturer, with a common undercarriage design and a baseline computer model. There is a digital twin for each serial number, tracking the inspection and usage data on top of as-manufactured information. Data analysis now makes it possible for the airline to derive information and trends based on all assets. In fact, if connected to the airplane's OEM, it is possible to look across multiple airline operators. Such a capability provides an opportunity for enhanced safety and economic savings in proactive maintenance.

Second, the organizations need a whole new skill set—skills involving information and communication technologies (ICT, not just IT), coworking with intelligent systems (desktop as well as industrial cobots, or "collective robots"), and more importantly, the willingness to accept that what you know today will likely be obsolete before you can establish yourself as an expert. The need and speed for learning in the fourth revolution is an order of magnitude larger than the previous revolution. Employers and employees both need to embrace learning and development as a shared, continual investment. While operators will need training on technology, managers will need to get on top of the processes, and leadership ought to explore new business models. The ability to rapidly learn and develop new skills will be key. From within Industry 4.0, AI is reducing the need for technical training, AR is enhancing training experience, and cobots can be programmed in real time for on-the-job execution.

Third, companies need a slightly different leadership mindset. Competitive forces are unpredictable. Technology is rapidly changing. Communication needs to be in real time. This means that hierarchical organizational structures are detrimental to the adaption of Industry 4.0, and leaders need to free up the decision-making process. Peripheral vision and leadership agility, transparency, and connectivity are absolutely necessary to thrive in this era of volatility, uncertainty, complexity, and ambiguity, defined as "VUCA" by Bennis and Nanus (1985). We routinely witness the death of companies that flourished prior to digitization but were slow to adapt. Having a leadership mindset is one area where just simply adopting Industry 4.0 technologies will not help in addressing the challenge. Self-awareness and mindfulness are key for leadership going forward. A good fraction of business leaders will fail the test of time.

Fourth, once leadership prepares itself for the transformation, they need to change the culture. Basic principles of physics come into play here. Adaption of new systems requires leaders to address the fear of failure to deliver on expectation (inertia) and resistance to change (friction). Leadership ought to define a clear value proposition (lubrication) and sponsor learning and technology projects (energy) to sustain transformation (momentum). The traditional business culture seeks a traditional return on investment analysis before investing. When working through the newest revolution, the traditional analysis does not work. You need to account for the cost of not investing, which at times could be as high as bankruptcy.

At the time of finalizing this special issue, the world was in the grip of the COVID-19 pandemic, which forced millions to work remotely from home or other locations that permitted social distancing (at least 1.8 m [6 ft] apart) and engage in contactless operations. All trainings and meetings had gone virtual. Anything that could be done remotely was done that way. As of June 2020, it was still too early to analyze how many businesses and jobs were saved by the cyber-physical technologies that constitute Industry 4.0. But there is certainly an enhanced appreciation of the role of digitalization in a robust and resilient workplace. AM, AI, AR, and remote operations have all proven their value in the health care sector. In the coming years, I expect management will use lessons from the COVID-19 pandemic to build business cases in pursuit of Industry 4.0 and NDE 4.0.

NDE thought leaders are coming together to create knowledge platforms for guidance on this topic. There is a range of activities being pursued jointly by DGZfP and ASNT for general awareness and early acceptance of the topic. These include the formation of committees, technical publications, and conferences. However, individual companies need to manage their risk of adaption and investment through some dependable process (Singh 2018, 2019). The best practices in innovation management are now emerging through a series of ISO standards (ISO 2019) that captures global expertise on the subject. My service on *ISO/TC 279*, as one of the US delegates to the *ISO 56000* series, gives me the confidence that these will enable the evolution of purposeful NDE 4.0.

Role of ISO in Support of NDE 4.0

The *ISO 56000* series of standards brings best practices in innovation management to the public and can be used for the conception, development, validation, and pursuit of purposeful NDE 4.0 applications. The intended benefits of these standards in the context of NDE 4.0 development process, include the following:

Market Benefits:

- Provide guidance on how an organization can fulfill unmet inspection and safety needs.
- Enhance the competitiveness of organizations, NDE products, and inspection services.
- Lead to the easier acceptance of global inspection products.
- Reduce time to market for new inspection equipment.

Cultural Benefits:

- Open the mind to accept new NDE equipment, techniques, and business models.
- Promote the growth of an NDE 4.0 culture with a global safety objective.
- Facilitate necessary partnerships across NDE and IT expertise.
- Implement social responsibility while developing new NDE tools and methods.

Organizational Benefits:

- Save costs and reduce risk in developing NDE 4.0 through standard processes.
- Increase the ability to make decisions (test and try, fail fast) and the capability to take reasonable risks, while facing the challenges and uncertainty associated with NDE 4.0.
- Evaluate the progress of the organization and identify and share good practices in innovation management.
- Share a globally accepted "common language" for innovation management and perhaps develop a common language for NDE 4.0.

The following provides a quick overview of what is in store with the new series of *ISO 56000* standards and their relevance to NDE 4.0.

ISO 56000:2020 – Fundamentals and Vocabulary (published in February 2020)

This document describes the fundamental concepts, principles, and vocabulary of innovation management and its systematic implementation. Innovation is defined as "new or changed entity, realizing or redistributing value."

The eight innovation management principles behind the *ISO 56000* series are: (1) realization of value; (2) future-focused leaders; (3) strategic direction; (4) culture; (5) exploiting insights; (6) managing uncertainty; (7) adaptable structures; and (8) systems approach.

The four principles of NDE 4.0, defined earlier, already conform with these innovation management principles. The task of terminology specific to NDE 4.0 has been taken on by the ASNT committee, and the committee will adapt whatever definitions have been published in this document.

ISO 56002:2019 – Innovation Management System – Guidance (published in July 2019)

This document provides guidance for the establishment, implementation, maintenance, and continual improvement of an innovation management system for use in all established organizations. It is applicable to NDT equipment manufacturers, service providers, training houses, and asset owners responsible for infrastructure safety. All of the guidance within this document is generic and intended to be applicable to all types of organizations, regardless of type, sector, or size; all types of innovations (for example, product, service, process, model, and method), ranging from incremental to radical; and all types of approaches (for example, internal and open innovation and user-, market-, technology-, and design-driven innovation activities).

This is an overarching document that integrates all of the remaining *ISO 56003-08* documents on innovation, which refer and eventually feed into one another for successful execution. It does not describe detailed activities within the organization, but rather provides guidance at a general level. It does not prescribe any requirements or specific tools or methods for innovation activities. This intent makes the application as broad as possible, including NDE 4.0, which also subjects the user to differences in understanding and interpretation. It is directly relevant, providing some level of understanding of the overlap across the fundamentals of NDE and basics of innovation.

ISO 56003:2019 – Tools and Methods for Innovation Partnership (published in February 2019)

This document provides guidance for innovation partnerships. It describes the innovation partnership framework and provides sample corresponding tools to use to decide whether to enter an innovation partnership and describes how to evaluate and select partners and how to manage the partner interactions.

Since NDE 4.0 requires serious collaborative activity across those who understand the physics of inspection systems and those who can connect them digitally, this standard is of value to innovation partnerships. It starts with a gap analysis, followed by the identification, and engagement, of potential innovation partners and the governance of their interaction. The document addresses the essence of an innovation partnership required for NDE 4.0, where all parties must mutually benefit from working together in the context of the purpose defined above.

ISO/TR 56004:2019 – Innovation Management Assessment (published in February 2019)

This document will help the user understand why it is beneficial to carry out an innovation management assessment (IMA), what to assess, how to carry out the IMA, and how to maximize the resulting benefits, which are universally applicable.

This document is labeled as ISO/TR (Technical Report), and contains information of a different kind from the standard ISO publication. It may include data obtained from a survey, for example, or from an informative report, or information of the perceived "state of the art."

This standard can be used to assess and prepare an organization for the NDE 4.0 journey. Together with *ISO 56002*, it is a "must use and conform" document with some level of interpretation.

ISO 56005 – Intellectual Property Management (to be published by November 2020)

This standard proposes guidelines for supporting intellectual property (IP) within innovation management. It aims at addressing the following topics concerning IP management at strategic and operational levels: creating an IP strategy to support innovation in an organization; establishing IP management in the innovation process; and applying IP tools and methods in the innovation process.

NDE 4.0 is a fertile ground for innovation and the creation of new IP. In general, any dependable existing IP management system is likely to be adequate. If not, then this document is of use; otherwise, a cross reference might be enough.

ISO 56006 – Strategic Intelligence Management (to be published by November 2020)

This standard is a part of the innovation management system; and through planning, deployment, measurement, and continual improvement, it provides guidance to organizations on how to develop and provide intelligence to top management, enabling decisions on the vision, mission, strategy, and innovation activities of the organization.

Once again, at this time NDE 4.0 is still in the realm of "blue ocean strategy" (Kim and Mauborgne 2015), where the market boundaries and industry structure are not a given and can be constructed by the actions and beliefs of industry players. In general, any dependable existing strategic intelligence management system is likely to be adequate. If not, then this document can be referred to. The fundamental model is the data–information–knowledge–intelligence cycle. And this needs to be applied to marketplace insight (consumers, competitors, and regulators) and PESTEL trends (Albu 2014). The integration and interpretation of knowledge to generate intelligence is somewhat of an art, and you cannot completely depend upon *ISO 56006*. Hence, this standard should be used with caution.

ISO 56007 – Idea Management (to be published in 2022)

Ideas have the ability to make incremental improvements in the efficiency of an organization, up to prompting a reevaluation of its entire business model. This standard provides guidelines for the management of ideas: the people who have them and the benefits they bring. It aims to address idea management at both the strategic and operational level through the culture and leadership of an organization, including opportunity and risk management, intrapreneurship, problem-solving, and tools and methods for managing creativity and ideas.

This standard supports the innovation management system introduced in *ISO 56002*, and is absolutely necessary for NDE 4.0. Since the actual processes and techniques are still being discussed, it is too early for me to comment on its total relevance. However, some parts of the content are likely to have a strong influence on the successful outcome of the NDE 4.0 journey. Also, there are not many good books available on ideation. This document is expected to bring value to any aspect of a functioning organization.

ISO 56008 – Innovation Operation Measurements and Metrics (to be published in 2023)

This standard will provide guidance for the definition, implementation, evaluation, and further improvement of the measurements necessary to effectively manage innovation operations in an organization. This standard will provide guidance at a general level; specifically, the selection of indicators to measure the progress of innovation activities and the performance of the innovation portfolio.

Technical teams are excited about the intellectual and qualitative possibilities of NDE 4.0, but business leaders will likely struggle with the ability to track and quantify the projected success of such an initiative for some time. There are only a handful of innovation metrics, and companies that have successfully innovated have figured out the art, rather than the math, of relevant metrics. Once again, it is too early for me to comment on this standard's applicability.

The most popular financial metric is revenue generated from products and services that did not exist three years ago. From an NDE 4.0 perspective, look at it as a technology approach that serves existing business metrics at the top level. At the second level, one can include metrics that help quantify Safety 5.0—improved safety/reliability (POD) and economic value.

Going Forward

NDE 4.0 is the way to go, given the nature of the digital transformation taking place all around us. It includes the confluence of digital and physical technologies for assuring the safety of infrastructure, assets, and inspectors, as well as creating economic value for business owners, operators, OEMs, and service providers. All of this is quite possible, considering the new opportunities associated with disruptive technologies and how thought leaders are coming together to guide the industry.

For some, innovation is a process; for others, it is a skill or a competency; and for many, it is just an outcome of creative activity. Very soon, ISO standards will put that debate to rest, along with providing highly valuable guidance on execution, with relevance to the emergence of NDE 4.0.

Just like in previous revolutions, we again have three options going into the fourth revolution. We can embrace purposeful NDE 4.0 for Safety 5.0, leveraging *ISO 56000* guidelines; adapt to the changes brought on us by Industry 4.0 and eventually hope to evolve; or ignore it, and plan to retire or exit the business.

What is your choice? ◐

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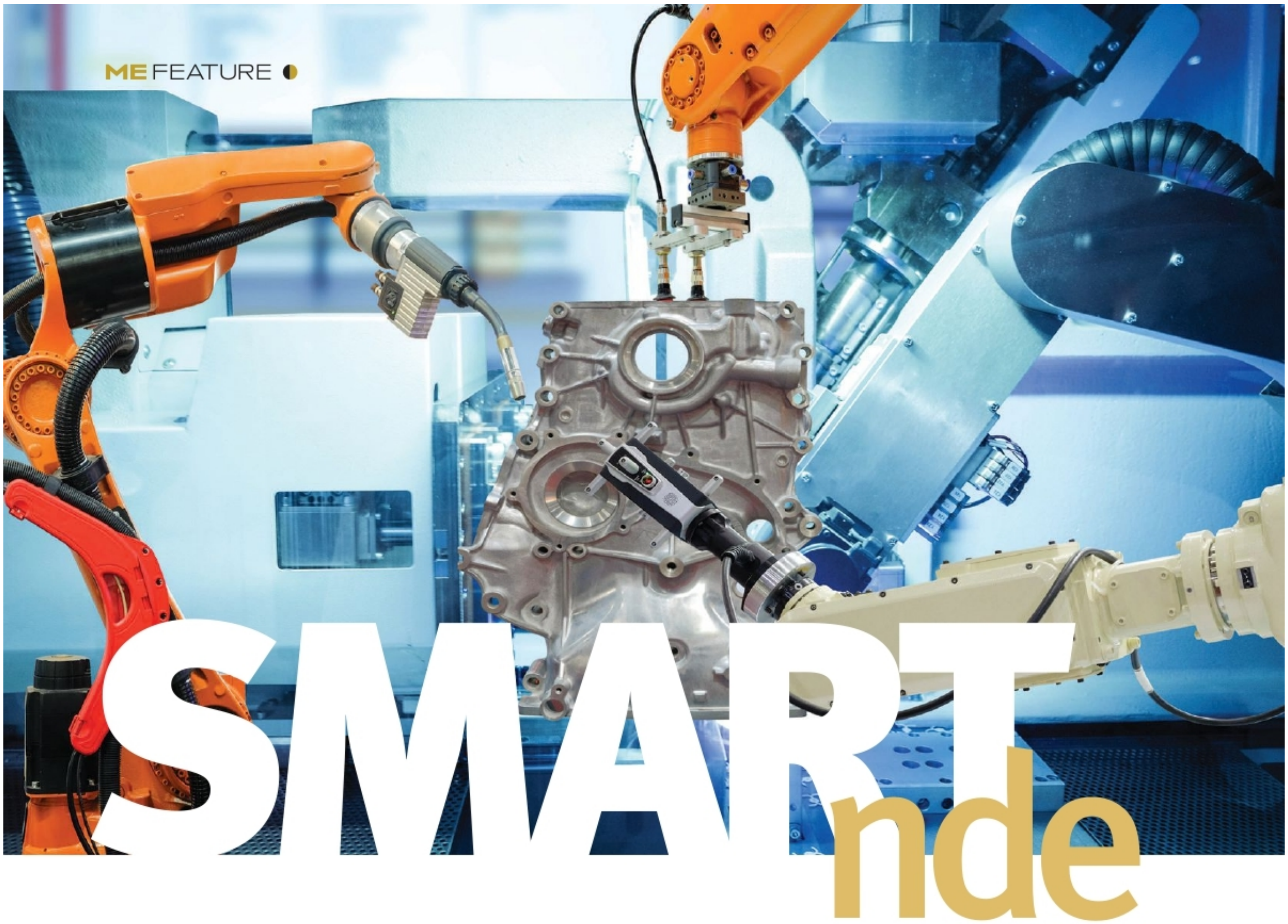

NDE 4.0 in Manufacturing: Challenges and Opportunities for NDE in the 21st Century

by Norbert G. Meyendorf, Peter Heilmann, and Leonard J. Bond

Industry 4.0 and the ability to tailor individual components to specific customer needs will significantly impact the way we need to provide nondestructive testing (NDT) inspections. We now call this NDE 4.0. This does not necessarily mean that we will develop a new type of nondestructive evaluation (NDE); however, we will have to prepare or adapt our current techniques for integration into the cyber-controlled production process by networking with the machines and materials used during manufacturing. The ability to produce individual parts tailored to specific customer needs will result in a paradigm shift between industrial quality management and NDE. The following paper will discuss the challenges and opportunities that the NDE industry will face in today's age, which the authors have named the "age of artificial intelligence." This is characterized by "digitalization" and moving toward an exponential convergence of atoms, bits, qubits, neurons, and genes. Artificial intelligence will potentially be the key to creating smart machines with the ability to make smart decisions on their own while working side by side in a partnership with humans.

Introduction

The concept of "NDE 4.0" was introduced at the 2017 SPIE symposium "Smart Structures and Nondestructive Evaluation" in the plenary presentation titled "NDE for the 21st Century: Industry 4.0 Requires NDE 4.0" (Meyendorf 2017). Meyendorf discussed how various revolutions in technology have impacted the development of NDE and outlined the opportunities and challenges he envisioned for NDE in the new industrial area of Industry 4.0. These concepts have inspired forward-looking discussions, and some significant activities have now been initiated to move these concepts forward. This paper is intended to contribute further to these discussions and to present the developing ideas of the authors.

In its simplest form, NDT is almost as old as mankind. Testing could involve listening to the cracking of a bent tree branch or the response to knocking on a nutshell to determine if it is hollow; this eventually evolved into a simple acoustic emission testing inspection that involved tapping a pot or a visual examination to assess aesthetic quality. Testing became a way to check on the quality of workmanship during the 19th century and began to evolve from about 1870 into what is now called NDE.

At the beginning of industrialization, steam power replaced human and animal muscle power for many tasks, and products were simply inspected randomly by using human senses, but such testing was found to be inadequate when new technologies were produced and items such as boilers failed.

The basic idea for providing a nondestructive test for quality has not changed a lot since the first industrial revolution and up until the last decade of the 20th century; however, the instrumentation we use and the way we apply the techniques now depend upon more complex technology and industrialization. In recent years, the basic idea has evolved from inspecting to minimize the occurrence of discontinuities, to life concepts such as damage tolerance. With more advanced equipment, we can now look for smaller and hidden anomalies and plan inspection intervals based on estimated damage growth rates so as to assure safety. As advancing technologies seek to push materials to their performance limits, NDE becomes a risk-management tool. Fundamentally, this philosophical approach of risk management becomes a more active and real-time function with NDE 4.0.

Advances in science have provided the NDT community with a diverse range of new tools and capabilities. Looking through transparent or opaque objects was possible before the discovery of X-rays. However, with the availability of X- and gamma rays, we extended the applicable wavelength range of electromagnetic radiation beyond what was available by using light. This advancement allowed the user to look through materials that were not optically transparent. The development of sonar and then ultrasonic NDT extended the range of frequencies that were available beyond human hearing and to a range above 20 kHz. This involves shorter wavelengths and therefore allows better local resolution. Such ultrasonic testing (UT) is now seen as just part of an acoustic spectrum that includes applications in surface acoustic wave devices for electronics and exploration seismology. NDT now also utilizes technologies that employ heat (thermal inspections), light and electromagnetic waves (visual, liquid penetrant, magnetic particle, X-ray, and eddy current techniques), and sound (acoustic emission and ultrasonic) in all their various forms (Ahmad and Bond 2018). Looking forward, we can now talk about NDE 4.0, which does not mean that we invent a new NDE technique, but rather that we make the capabilities of NDE available in new implementations to meet upcoming challenges and to prepare for the mid-21st century.

NDE and Progress in Industry

Major innovations in technology can be seen in Figure 1, which provides a simple timeline for the history of technology. In the 19th and into the early 20th century

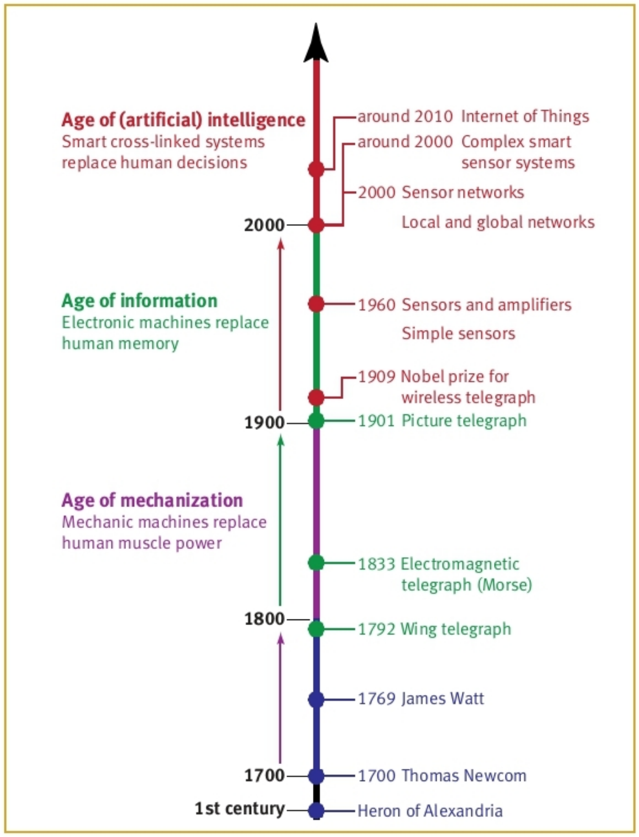

Figure 1. An attempt to characterize the 19th, 20th, and 21st centuries by showing typical innovations in technology. This does not completely correlate to the recognized industrial revolutions (see Table 1). It illustrates that important innovations have often been made many years ahead (some of them cannot be exactly dated). It is the authors' opinion that smart machines that have the ability to learn, solve complex tasks, and make decisions on their own or work with humans "hand in hand" will be the key technology of the future.

TABLE 1
Impact of industrial revolutions on NDE*

Industrial revolution	NDT/NDE	NDE techniques introduced
1st (1750–1850) • Mechanization • Replacement of muscle power • Unique components	1.0 • Using human senses for random inspection	• Visual tesing • Acoustic emission techniques
2nd (1850–1960) • Mass production • Assembly lines • Electrical energy • Identical components	2.0 • Enhancing detectability of human senses (for instance, for surface-breaking cracks) • 100% manual inspection of selected safety relevant parts	• Liquid penetrant testing • Magnetic particle testing
3rd (1960–today) • Automation • Electronic control and data processing • Multifunctional microelectronic systems	3.0 • Using physical effects, radiation, or fields to detect discontinuities, measure material properties • Manual or automated inspection • 100% inspection of large quantities of parts	• Radiographic tesing • Ultrasonic testing • Electromagnetic testing
4th (next) • Cyber-physical systems • Learning and decision-making machines • Individual custom-tailored components	4.0 • Use of cyber-physical systems (cloud computing, Internet of Things, modeling) • Continuous monitoring of manufacturing processes or components in service • Large-volume data files (3D images)	• Computed tomography • Phased array ultrasonic testing • Optics • Thermal/infrared testing • Terahertz

*adapted from Meyendorf (2017)

(1800–1950s), machines replaced muscle power (humans or animals), initially using the steam engine and then later electric and gasoline engines. These changes enabled a significant increase in productivity, and this period of history is well known as the Industrial Revolution. We can characterize this time period as the "age of mechanization" and call it Industry 1.0. During this time, NDT was characterized by techniques that used human senses (visual/sound) and then simple techniques to enhance the signals that can be detected by humans (including liquid penetrant testing and magnetic particle testing).

The 20th century is considered to be the "age of information." The Nobel Prize in Physics 1909 was awarded jointly to Guglielmo Marconi and Karl Ferdinand Braun in recognition of their contributions to the development of wireless telegraphy (Nobel Foundation 1967). It subsequently took 100 years for this first step to evolve into today's cellphones and global telecommunication. However, the fundamental capabilities needed to enable this age were electricity and later electronic machines (computers), which became tools used to supplement the capabilities of the human brain. In manufacturing, these developments began with the application of electricity to what created the first physical network and the introduction of conveyer techniques, which established mass production (Industry 2.0). In the second half of the last century, mass production was improved further by the introduction of electronic-controlled and automated production (Industry 3.0). This prompted the need for reliable NDE to provide 100% inspection for large quantities of parts and the quantification of NDE performance using probability of detection (POD). With the development of electronics and portable computers, it was also possible to develop automated inspection techniques and increasingly replace analog instruments with digital ones. This was essential in enabling various advancements in UT, such as phased array UT (PAUT), that we use today. There were corresponding advances in most NDE technologies. Both X-ray and electromagnetic testing techniques where pushed forward by developing new sensors and data analysis procedures, including image processing and computed tomography (CT) (Thompson and Chimenti 1980–2019).

What Comes Next?

It is the authors' opinion that the next 50 to 100 years will be characterized by increasing capabilities to collect and manage digitized data, which are produced by various forms of big-data processing and artificial intelligence. These changes will be represented by:

- Digitizing of all (or much) of our information, which can be stored effectively forever.
- Information networks that allow not only real-time telecommunication, but also remote control of processes and activities anywhere in the world.
- Smart robots that can interact with humans, including much beyond keyboard control.
- Machines that have the ability to learn and make decisions on their own.
- Exponential convergence of atoms, bits, qubits, neurons, and genes, which also includes the merging of cyber-physical and biological systems.

Due to the continuous increase of the miniaturization of electronic circuits (successfully described by Gordon Moore as "Moore's Law"—the observation that the number of transistors in a dense integrated circuit will double about every two years [Moore 1965]), together with a significant decrease in the price and energy consumption of circuits, it can be expected that there will be computers that have the computational power of the human brain within just a few years. Already, a lot of human functions and decisions can be replaced by computers; however, in the future, advanced "smart" devices will be able to learn and adapt or respond to new situations. Machines will become "smart" with decision-making capability, if not sentient. In NDE this means, for example, that there is the potential (for at least some routine inspections) to have the initial characterizations of parts and potentially initial data evaluations performed by smart inspection robots. Such smart robots can then potentially enable new applications; for example, allow for operation in harsh environments. These capabilities can even be controlled remotely from anywhere in the world. Such advances don't mean that we will not need NDE inspectors in the future, but tools will be available that can remove some of the tedium of routine tasks, such as viewing X-rays or C-scans, and enable the smart technology to focus the inspector's attention to anomalies identified automatically, improve POD, and give senior inspectors (who are often a scarce resource) the time needed to address higher-level review and even reinspection tasks.

Introducing smart NDE to the new industrial age will require the NDE community to make techniques ready for use in advanced manufacturing and the new approaches in production, by using the capabilities that will become available with new cyber-physical techniques. In the following sections, two aspects of these changes will be discussed.

Develop NDE Techniques Ready for the New Age of Smart Production

The fourth industrial revolution (Industry 4.0) is driven by trends that bring together collaborative advanced manufacturing networks (networks of advanced manufacturing devices controlled by computers) and combining them into a physical-digital environment.

This new age is characterized by the "smart factory." This means that there is communication among the machines and between the products and machines. This new manufacturing philosophy and technology potentially enables the production of customized individual parts; for example, by use of 3D printing/additive manufacturing. We can then potentially, for some applications, say goodbye to conveyor belts and traditional mass production. Each component or small batch can then potentially be individually tailored to meet the specific requests of the customer and be manufactured on demand, which will also impact inventory and production logistics. Such a change will impact the entire value chain from raw materials to end use, including through to recovery/recycling (circular economy), and with these changes, advances in design and manufacturing, including customization, will also impact business and support functions (such as supply chain and sales).

For next-generation quality management (QM), this requires a paradigm shift. Until today, we used established optimized process chains. QM is characterized by statistical process control, statistical quality planning, and commonly the destructive testing of random samples combined with NDE, particularly for higher-value items. Such NDE has always been an integral part of QM in specific high-technology industries, such as aviation, energy production, and transportation. In the future, the trend is moving toward production "on demand" with the delivery of customer-configured objects produced by additive and subtractive manufacturing technologies in combination. This step change in manufacturing requires a new paradigm for quality assurance with capabilities that employ integrated intelligence and self-learning/teaching smart systems. Statistics-based random destructive testing is simply not possible for many small-batch additive products. "Sample sets" may consist of just one item, and it can be both unique and an item of high value (Wunderlich 2016). As smart manufacturing evolves, there will be a need for 100% NDE inspection for many cases where parts are safety critical. Such new manufacturing techniques will also require new approaches and implementations of NDE methods. For example, if metallic or ceramic parts are created in a 3D printer, the material's microstructure and volumetric defects like microcracks or microporosity are mostly unknown. It becomes necessary to provide material state awareness/characterization, including obtaining such data in process, as microfeatures can potentially harm the integrity of the part. This is different from the present situation, where the starting materials and products and end products can be characterized before or to some degree after fabrication, and then again after different process steps like heat treatments.

To meet these needs, some challenges that must be solved are:

- Real-time monitoring of the manufacturing process, by detecting thermal and acoustic emissions that can be related to the position of where the emission occurred.
- High-resolution volumetric NDE techniques, like X-ray, CT, or acoustic microscopy. For nonmetallic and transparent or opaque parts, both optical or gigahertz techniques might be considered.
- 3D volumetric characterization of the whole part; for example, taking density or elastic modulus measurements and mapping the grain structure.

NDE strategies are based on experience gained through making repeated measurements on similar objects and understanding the types of discontinuities, their significance and impact on performance, and the responses they produce when using sensors and instruments to look for the anomalies. Determination of a POD strategy is most useful for assessing the performance of an inspection involving a larger number of similar objects (Meyendorf et al. 2017b). The challenge becomes the need to address quality assurance and maintainability for unique structures and components, such as those increasingly produced by additive manufacturing.

In a Frost & Sullivan report (Kimbara 2015), the author made the following predictions:

- The current business model for NDT inspection services is increasingly coming under threat and will change over the next few years.
- While historically innovation has been incremental in the NDT industry, going forward the model will be disruptive innovation.
- Organizations need to adapt and embrace the disruptive business ecosystem to be relevant in 10 years' time (note: this statement was written in 2015!).

The NDE community needs to look at how best to enable the inspection of complex and unique components, and make the ability and experience of the senior inspectors (Level IIIs) locally available at remote locations. This might be able to happen in conjunction with using modeling capabilities ("digital twins") and providing remote viewing; for example, when performing ultrasonic inspection and interpretation of results (Meyendorf et al. 2017a). The ability to enable and move toward this future will be supported by

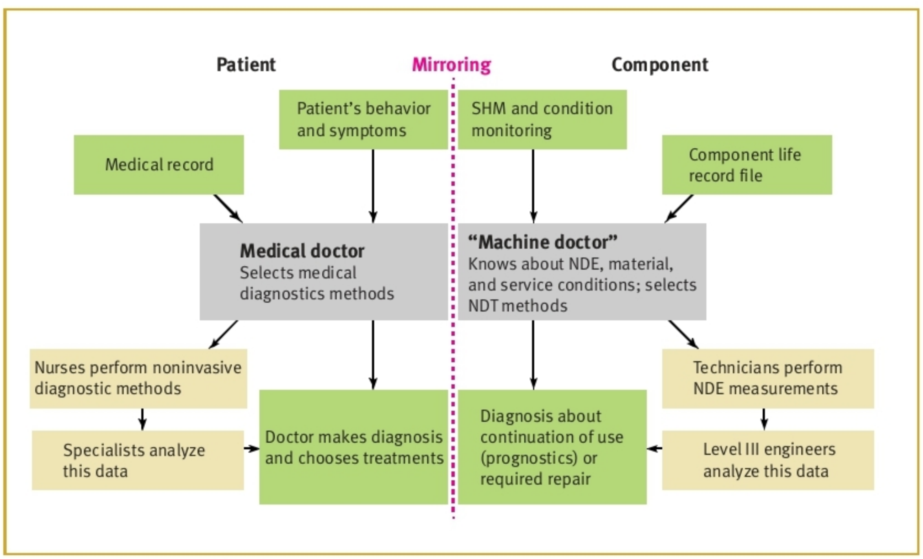

Figure 2. Learning from medicine (adapted from Meyendorf et al. 2017).

innovation management systems such as *ISO 56000*. The inspection of unique components will require well-trained specialists that not only understand the NDE methods and inspection requirements, but also the materials and components to be inspected. The human factor and their related skill sets will need to be developed so as to significantly enhance the reliability of NDE results.

If a specialist is not locally available, remote NDE can be utilized. "Tele-NDE" has been demonstrated, in a simple form, previously by the authors by using standard telecommunication software and PC-attachable UT instruments (Meyendorf 2017). Increasing bandwidth and 5G networks will potentially better facilitate the telepresence of NDE.

This inspection of novel individual parts made using advanced manufacturing will also challenge how NDE is organized. There needs to be a fundamental change, which can be inspired by the changes already seen in medicine where diagnostics is always geared toward the individual. However, this requires an excellent trained specialist, which is made available by an increasing use of telecommunication or tele-NDE. In Figure 2, this is seen in a concept called the "machine doctor," who could be an NDE specialist or small team, who has expertise in the materials, design, and loading conditions of the components. This will require capabilities and expertise that go beyond those found in a typical Level III. The needed workforce development will be a major challenge. NDE 4.0 will disrupt the skill sets required by Level III inspectors: not only will it require the incorporation of "digital" skills, but also the addition of a much wider multidisciplinary engineering skill set.

Use of the New Cyber-Physical Techniques in NDE

New smart and remote technologies can impact and improve NDE in several different ways. The Internet of Things (IoT) potentially allows the networking of all machines and products. These networks can include NDE tools. NDE inspection has to be integrated into the manufacturing process for individual custom products. For process planning, designing/optimizing, and assessing inspectability, NDE modeling will be essential in applying digital twins.

Modern advanced sensor networks and measurement tools create a tremendous amount of data. This could be, for example, the continuous measurement data created by the next generation of structural health monitoring (SHM) systems or the 3D volume data created by X-ray, CT, or PAUT.

Cloud computing potentially enables capabilities to safely store, organize, and analyze the various NDE and parts-related data. Smart robots and intelligent self-learning machines could be used to assist inspectors and support decisions in ways that go beyond the typical inspector's skill set. A growing database of NDE data will help to improve the decision-making process, supported by deep learning algorithms.

It is important that these NDE data are seen as an "item of value." Saving NDE, SHM, and operational data, organizing them by creating new NDE databases, and linking the data to CAD data can have significant benefits for the service teams. NDE and SHM data need to be linked and provide data that can be related to standards (Figure 3).

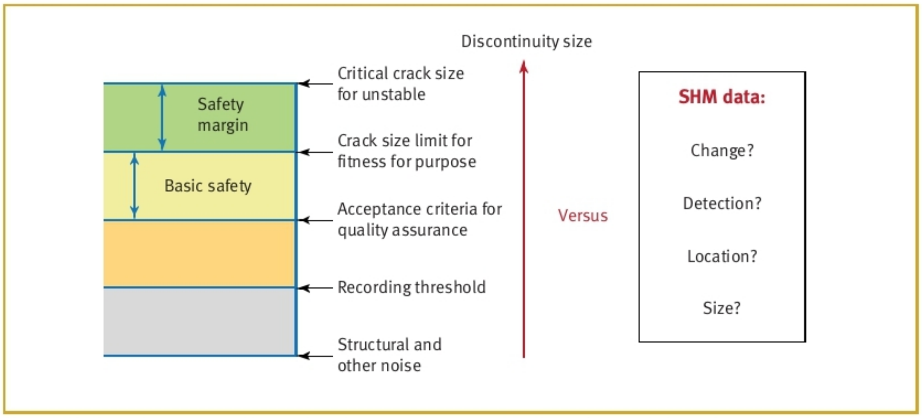

Figure 3. Schematic showing relationship between crack size and NDT acceptance criteria (adapted from Bond and Meyendorf 2019).

These ideas are not new, but today advanced computers give us the capability to apply them in near real time and do so cost effectively.

The development of NDE/SHM databases will provide the following benefits for service and quality management teams:

- Graphic planning and improved control of project processes, and subsequently a quicker overview of planned activities and results from activities that have been carried out.
- CAD linking for equipment data and automatic access to assigned CAD drawings.
- Comfortable implementation of inspections with a modular inspection and evaluation system (MIES) and importing of NDE data, such as X-ray radiographs, into protocols.
- Documentation and archiving of activities and work results.
- User-specific access to data and functions with intuitive operation using a graphic user interface.
- Quick access combined with a high level of data security.

Such a system would include standard software (such as word processing, spreadsheet analysis, and graphics) and enable graphic and statistical presentation of the imported measurement data.

An example for such a system is the inspection and revision management system (IRMS). The basic idea is to support all the necessary process steps in connection with inspection and revision metrics at power plants, chemical plants, and other industrial facilities based on a modular design, going beyond process limits.

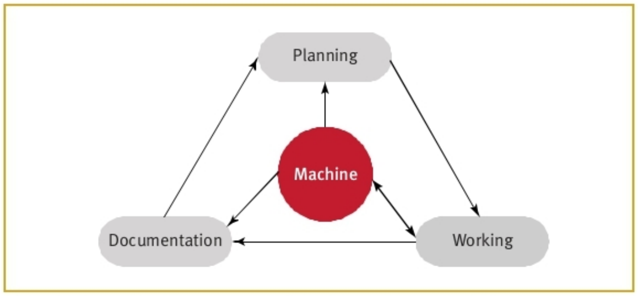

Figure 4. Integration of all processes in the inspection and revision management system (IRMS).

An IRMS approach that was developed approximately 10 years ago is presented in Figure 4. This system integrated all necessary processing steps based on the organizational processing diagram of the documents and data, beginning with the planning of activities to their evaluation, documentation, and archiving. In today's world, the "working box" has sensors and can adapt. Actions can deviate from original plans within an intended plan. Such planning can become very different from current methods—it includes objectives, constraints, and space for flexibility, in addition to defined activities and timelines.

An integrated MIES enables the complete integration of all activities—for example, by including the computer-supported processing of ultrasound, eddy current, and visual inspections with videoscopy and endoscopy. Simultaneously, machine parameters and inspection results are directly transferred to the MIES modules. In such an approach, the processing of raw NDE data is supported. An example of this is scanned X-ray images with IQIs compared to measured geometric details.

A CAD interface allows the linking of NDE results to CAD. Processed elements are then found in linked CAD documents and highlighted. The CAD documents can be processed online. Including process modeling, for example, along with thermal cycles and solidification sequences in welding might be a future step in obtaining information of value to make assessments for advanced NDE.

An interesting and related tool, which is used for prognostics, is stress analysis. Appropriate analysis and images for stress analysis can be automatically generated for processed elements and then be imported into CAD documents. These concepts for

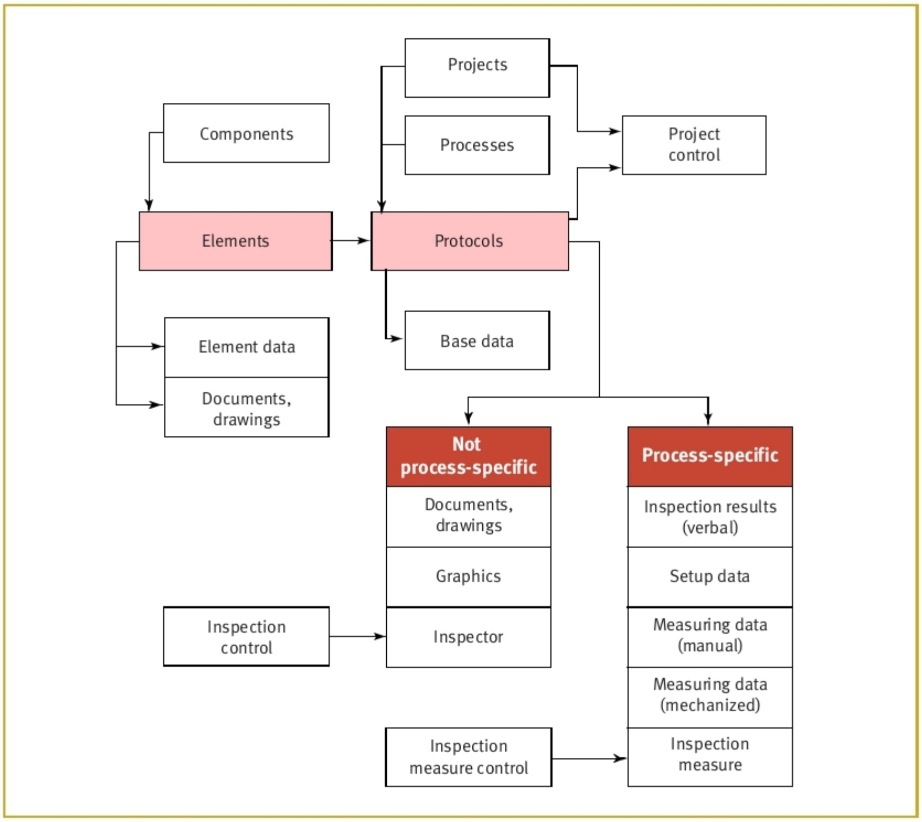

Figure 5. Concept for data processing in the inspection and revision management system (IRMS).

data processing are depicted in the schematic given in Figure 5.

These ideas are not new, but today advanced computers give us the capability to apply them in near real time and do so cost effectively. Even better, there is an increasing capability with widely available electronic devices (such as tablet computers and smartphones) and WLAN, which means that service teams can potentially gain access to these data almost anywhere on the globe and at any time.

Commonly available communication devices (such as tablet computers and smartphones) incorporate various sensors in the form of cameras, microphones, vibration sensors, and accelerometers. Other smartphone-attachable tools are now available for purchase such as IR cameras (FLIR Systems 2017), terahertz arrays (Boyle 2012), and eddy current transducers (Mook and Simonin 2008), and these units can be potentially used for NDE. The use of these tools is almost as simple as downloading an app from an app store and attaching the necessary device to the phone. That is literally everything that is necessary for a person to start taking measurements.

With the availability of smartphones and tablets, the whole world's accumulated knowledge (which is a large amount of data) can potentially, with the right software tools, become available to anyone at any time and in any place. For the younger generation, this technology is intuitive, and they possess a natural flair for it. Merging the highly specialized knowledge of NDE techniques with today's technology will open a new market for NDE (Meyendorf 2018). These new handheld devices will be applied to make NDE more available and affordable for everybody. As a benefit of these new technologies, product inspection at home can become an additional part of monitoring a product through its life cycle. This type of integration into everyday life has the potential to significantly

NDE has the capability to be integrated into the new smart production process by networking with machines and materials...

increase the rate of acceptance of NDE 4.0 within the wider NDE and engineering communities by solving new inspection problems, which can then become part of everyday service activities.

Conclusions

Industry 4.0 and the ability to tailor the assessment of individual components to meet customer needs will significantly impact the way we ensure quality, safety, and reliability and provide NDT inspections. NDE has the capability to be integrated into the new smart production process by networking with the machines and materials used during manufacturing. This will result in a paradigm shift between industrial QM and NDE. Classical concepts applied to quality assurance, which are statistics-based and employ the comparison of multiple similar components, will not be applicable in a world of unique products and additive manufacturing, which utilize limited production runs and individual product designs. The resulting changes required for the delivery of quality will raise the importance and needed skill sets for those engaged in NDE delivery. It will be critical to address workforce needs, but it can be expected that such changes will be a major challenge. To be successful in this new world, it will be necessary to have specialists available to make the best possible decisions based on the available NDE results along with prior knowledge of the materials/components and the service/loading conditions. This will require the incorporation of "digital" and also the addition of multidisciplinary engineering skills.

The following bullets summarize what, in the authors' opinion, will characterize NDE for the mid-21st century:

- The internet will enable remote real-time monitoring of structure integrity.
- Tele-NDE will enhance the reliable inspection of unique components.
- Fast 3D imaging techniques (X-ray, CT, and PAUT) will create big data that has to be handled and analyzed.
- Creating NDE databases, managing a component's lifetime files, and handling big data will create value and present significant benefits for quality management.
- Smart robots and drones will assist inspectors in performing NDE in harsh and hard-to-access environments by automated or remote NDE.
- NDE modeling will support inspection, planning, and interpretation of results.
- Digital twins will include NDE in design/planning and in the interpretation of data based on modeling.
- 3D printing will require new NDE techniques and concepts for the reliable inspection of unique components.

Smartphones and tablets make NDE available to anybody. By making low-cost sensing available, this can create new markets for NDE and enable inspection at home. This can become an additional component of monitoring throughout the life cycle of some products (Meyendorf 2018). We perceive two supplementing trajectories of evolution for the field, which may be perceived as moving in opposite directions: (1) the increased sophistication and specialization of NDE technologies and equipment, including the development of multipurpose, multimethod devices (for example, ET/UT in a single unit); and (2) the "democratization" of NDE to the general public with devices that may be attached to smartphones. Example applications could include thermal imaging of failing electric/electronic equipment or a low-cost "sniffer" that can detect leaks in air-conditioning equipment.

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CITATION

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PRODUCT gallery

Infrared Blackbody System

Santa Barbara Infrared Inc. (SBIR), a manufacturer of advanced infrared and electro-optical test hardware for medical, aerospace, and defense applications, has introduced the Nightingale Body Temperature Reference (BTR) Blackbody System developed for COVID-19 testing.

The innovative blackbody system provides a highly stable, uniform, low-cost, and easy-to-operate thermal source for the detection of human body temperatures. Specially designed for use in thermal imaging body-temperature screening systems, SBIR has developed this system to work utilizing a convenient, viewable, thermal reference area for infrared camera systems.

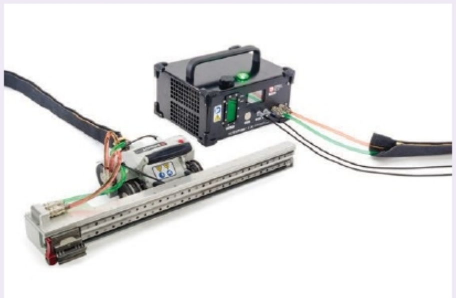
Santa Barbara Infrared Inc.
Santa Barbara, California
sbir.com

Automated Measurement Station

GOM has introduced a mobile measuring station with a collaborative robot. Equipped with a motorized rotation table and powerful software, including a virtual measuring room, the GOM ScanCobot offers an easy entry into automated 3D measurement technology. The measuring station is combined with GOM's precise ATOS Core 3D measuring system.

GOM ScanCobot, with dimensions of 975 mm × 755 mm and a working height of 1000 mm, requires only a small space. The system is very flexible at the same time—the installed wheels allow users to easily move it to the next location. GOM ScanCobot is equipped with the current GOM inspection software, including the Kiosk Interface.

GOM GmbH
Braunschweig, Germany
gom.com



Automated Corrosion Mapping Tool

JIREH has developed an automated corrosion mapping solution capable of operating on surfaces up to 350 °C (662 °F). Duty cycling is not required with the SKOOT • HT (high temperature), thanks to its cooling system. Coolant flows to the crawler and 600 mm (24 in.) raster arm, allowing UT inspection on surfaces with temperatures as high as 350 °C (662 °F). The remote handheld controller allows the programming of precise raster paths as well as variable-speed control of the SKOOT system. Magnetic wheels allow scanning on ferrous surfaces, while specially designed cable management protects and organizes hoses and cables.

JIREH Industries
Edmonton, Alberta, Canada
jireh.com

Pipe Inspection Gauge

Designed to internally scan pipeline walls for condition assessment using patented broadband electromagnetic (BEM™) technology, these pipe inspection gauges (PIGs) are capable of operating in pipes with a wide range of diameters. A primary use is for the inspection of cast iron cement lined (CICL) gas mains at lengths of up to 305 m (1000 ft). To maximize value, the majority of BEM components are universal to suit a range of BEM internal and external scanning tools. A PIG trailer houses the electronics, power, and pneumatics for remote engagement/disengagement of the multisensor antennae to the pipe wall.

Rock Solid Group
Tullamarine Victoria, Australia
rocksolidgroup.com.au

Automated System

By using Delphin's ProfiSignal Klicks intuitive programming language and "sequencer" module, users can create their own process control programs without having to learn how to program on their own. Laboratory engineers are then able to automate their own experiments. The created process program is easy to comprehend, amend, and maintain. For accurate data measurement, Delphin hardware is equipped with measurement inputs and analog and digital outputs. Experiments can be set up, started, and analyzed from a PC workstation. Process control is created using the Klicks automation software.

CAS DataLoggers Inc.
Chesterland, Ohio
dataloggerinc.com

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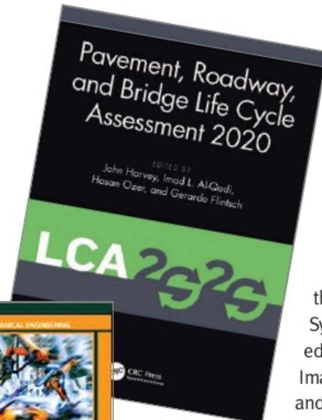

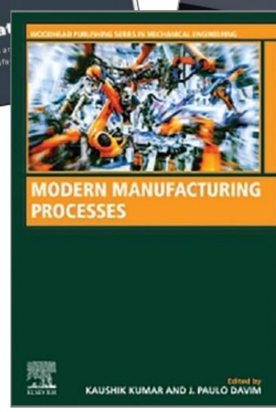

AM Focus eBook

3dpbm, a provider of news, analysis, and specialized content for the additive manufacturing (AM) space, has published the fourth edition of the company's AM Focus eBook series *Advanced Materials: How Cutting Edge Materials Are Shaping the Future of Additive Manufacturing*. The latest publication spotlights a far-reaching and fascinating topic within the AM industry: advanced materials. The latest edition addresses the cutting edge of AM materials today: technical ceramics, continuous fiber-filled composites, refractory metals, and high-performance polymers. Applications include the aerospace, automotive, defense, medical, electronics, and dental industries, among others.
3dprintingmedia.network

Modern Manufacturing Processes Book

Elsevier has published *Modern Manufacturing Processes*, edited by Kaushik Kumar and J. Paulo Davim. This book draws on the latest international research on traditional and nontraditional practices, to provide valuable advice on the digitization and automation of the manufacturing industry. In addition to providing technical details for the correct implementation of the latest tools and practices, impacts on productivity and design quality are also examined. The thorough classification of manufacturing processes will help readers to decide which technology is most effective for their requirements, and comparisons between modern and traditional methods will clarify the case for upgrading. This comprehensive assessment of technologies will include additive manufacturing and Industry 4.0, as well as hybrid methods where exceptional results have been gained through the use of traditional technology.
elsevier.com

Proceedings of the International Symposium on Pavement

CRC Press has published *Pavement, Roadway, and Bridge Life Cycle Assessment 2020* from the Proceedings of the International Symposium on Pavement, edited by John Harvey, Imad L. Al-Qadi, Hasan Ozer, and Gerardo Flintsch. An increasing number of agencies, academic institutes, and governmental and industrial bodies are embracing the principles of sustainability in managing their activities. Life cycle assessment (LCA) is an approach developed to provide decision support regarding the environmental impact of industrial processes and products. LCA is a field with ongoing research, development, and improvement, and is being implemented worldwide, particularly in the areas of pavement, roadways, and bridges.
routledge.com

Write Us

New Media Submissions

New Media features newly published books, websites, videos, and other publications that cover NDT products or the NDT community, and is an excellent way to reach readers who are active in the NDT industry. *Materials Evaluation* welcomes press releases and photos. Send contributions to cschaurer@asnt.org.


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INDUSTRY news

A DGZfP subcommittee recently met at VisiConsult to discuss OPC United Architecture.

DGZfP Forms Joint Working Group for Industry 4.0

The DGZfP (German Society for Nondestructive Testing), headquartered in Berlin, Germany, organizes sponsorships in science and research and facilitates communication between these groups. Its subcommittee "Interfaces, Documentation, Data Safety, Storage, and Filing" is part of the new Committee ZfP (NDT) 4.0, and its members recently met at VisiConsult, a manufacturer of X-ray systems headquartered in Stockelsdorf, Germany, for two days.

The central topic of the meeting was developing a standardized method for exchanging data using OPC Unified Architecture. Members of the subcommittee agreed to work actively to form a joint working group of the OPC Foundation, headquartered in Scottsdale, Arizona, and the VDMA (German Association of Machine Manufacturers), headquartered in Frankfurt, Germany. This joint working group will act on behalf of DGZfP and will work on an OPC companion specification for the area of nondestructive testing. This specification is meant to further enhance the Industry 4.0 concept. Other topics like DICONDE and alternatives were discussed as well.

Spectronics Makes UV Sanitation Products to Fight COVID-19

Spectronics Corp., headquartered in Westbury, New York, has strengthened its manufacturing of UV-C germicidal products. Due to the spread of COVID-19, citizens are taking extra precautions to disinfect frequently touched surfaces.

Spectronics Corp. has been a manufacturer of UV sanitization, fluorescent inspection, and other UV applications for over 64 years. The company has recently released UV-C (shortwave ultraviolet light) and UVGI (ultraviolet germicidal irradiation) products. Due to the recent lack of masks, hospitals are looking for ways to disinfect and reuse masks for health care workers. Spectronics offers two models of UVGI sanitizing cabinets—one model sanitizes up to three N95 masks and the other sanitizes up to six N95 masks. As well as the cabinets, Spectronics has products that utilize UV-C light to eliminate 90% to up to 99% of microorganisms on the surfaces of products used daily, such as mobile devices.

State officials also contacted Spectronics owner Jon Cooper regarding the need for hand sanitizer. This interest gave him the opportunity to retrofit a section of the plant to switch from the production of fluorescent dyes to hand sanitizer. The spray-bottle hand sanitizer will be the next product to be released by Spectronics in its sanitization line.

Write Us

Seeking NDT Heroes

Are you an NDT company or individual who has shifted your focus to helping out in the current global pandemic? If so, we'd like to know! Please contact the editor, Jill Ross, at jross@asnt.org.

Call for Papers

7th US–Japan NDT Symposium

Wailola Beach Marriot Resort, Waikoloa, HI

ASNT and JSNDI are soliciting abstracts for the 7th US–Japan NDT Joint Symposium to be held in Waikoloa, Hawaii, on 5–9 July 2021. Categories include aerospace, aging infrastructure, applications of artificial intelligence and the Internet of Things, automated NDE, biomechanics, certification criteria, composites, condition monitoring, future direction and possibilities in NDE, guided wave ultrasonics, health monitoring, laser ultrasound, materials characterization, measurement analysis, NDE advancements toward technology transfer, NDE advances in radiology, NDE developments for transportation systems, NDE in manufacturing processes, NDE modeling and signal processing, NDE of infrastructure, neutron radiography, nonlinear ultrasonic, oil and gas, performance-based NDT, probability of detection, prognostic tools for NDE, safety and reliability, and synergies within ND.

Deadline: 30 October 2020
Submit: asnt.org/events

International Conference on NDE 4.0

Munich, Germany

Abstracts are currently being solicited for the first International Conference on NDE 4.0 to take place 26–28 April 2022. This conference is devoted to promoting a broad exchange on all subjects regarding NDE 4.0. The conference provides a unique opportunity for users, scientists, equipment suppliers, and others. Presentations considering the use of Industry 4.0 emerging technologies for NDE/NDT; the use of NDE data for the Industrial Internet of Things and Industry 4.0; and human considerations for NDE 4.0 environments will be most welcome.

Submit: conference.nde40.com


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STANDARDSupdate

The Standards Update department focuses on standards, codes, recommended practices, and other documents used by NDT professionals. This department reports every few months on new publications, draft work currently in process, and the status of standards development. This month's installment focuses on current work in American National Standards and ISO Draft International Standards.

American National Draft Standards

Project Initiation

ANSI procedures require notification by ANSI-accredited standards developers of the initiation and scope of activities expected to result in new or revised American National Standards. The following is a list of proposed actions and new standards that have been received recently from accredited standards developers. To view information about additional standards for which a project initiation notification has been submitted, and to search approved American National Standards, please visit nssn.org, which is a database of standards information. Note that this database is not exhaustive.

- *BSR/AWS D1.1/D1.1M-202x, Structural Welding Code – Steel*. This is a revision of *ANSI/AWS D1.1/D1.1M-2019*. This code covers the welding requirements for any type of welded structure made from the commonly used carbon and low-alloy constructional steels. Clauses 1 through 11 constitute a body of rules for the regulation of welding in steel construction. There are eight normative and eleven informative annexes in this code. A commentary of the code is included with the document.
- *BSR/ICC 1205-202x, Standard for Off-Site Construction: Inspection and Regulatory Compliance*. This is a new standard to address the inspection, approval, and regulatory compliance of off-site residential and commercial construction components and their assembly and completion at the final building site. This includes permitting, in-plant and on-site final inspections, third-party inspections, and the role of industrialized building departments, state modular programs, and the authority having jurisdiction. Off-site construction includes componentized, panelized, and modularized elements. This standard will not apply to HUD manufactured housing.
- *BSR N43.17-202x, Radiation Safety for Personnel Security Screening Systems Using X-ray or Gamma Radiation*. This is a revision of *ANSI N43.17-2009 (R2018)* and applies to the manufacture and operation of security screening systems that use X-rays, gamma radiation, or both, in which individuals are intentionally exposed to this ionizing radiation. Does not address neutron-based systems. The standard provides requirements specific to the ionizing radiation safety aspects of both the design and operation of these systems. It does not include electrical safety guidelines or any other safety, performance, or use considerations outside of the realm of radiation safety.
- *BSR/ASME MUS-2-202x, Use of Crawler/Ground Robotics for Inspection*. This is a new standard. This document provides guidelines and requirements for the utilization of crawlers/ground robotics to safely and reliably perform inspections and examinations of fixed equipment including pressure vessels, tanks, piping systems, and other components considered part of critical infrastructure.

Call for Comment on Proposals Listed

The public comment period has passed for the following draft American National Standards, which are currently in review.

- *BSR/AWS D14.6/D14.6M-202x, Specification for Welding of Rotating Elements of Equipment*. This is a revision of *ANSI/AWS D14.6/D14.6M-2012*. This standard establishes material and workmanship standards for manufacturers, fabricators, repair organizations, purchasers, and owner/operators of rotating equipment that are fabricated or repaired by welding. Included are sections defining process qualifications, operator qualifications, quality control, inspection requirements, and repair requirements.
- *BSR/AWS D14.9/D14.9M-202x, Specification for the Welding of Hydraulic Cylinders*. This is a revision of *ANSI/AWS D14.9/D14.9M-2012*. This specification provides standards for the design and manufacture of pressure-containing welded joints and structural welded joints used in the manufacture of hydraulic cylinders. The manufacturer's responsibilities are presented as they relate to the welding practices that have been proven successful within the industry in the production of hydraulic cylinders. Included are sections defining welding procedure qualification, welder

STANDARDSupdate

performance qualification, workmanship, and quality requirements as well as inspection requirements and repair requirements.

- *BSR/ASNT CP 189-202x, Qualification and Certification of Nondestructive Testing Personnel*. This is a revision, redesignation, and consolidation of *ANSI/ASNT CP-189-2016, ANSI/ASNT CP-189-2016, Addenda 2018*. This standard applies to personnel whose specific tasks or jobs require appropriate knowledge of the technical principles underlying nondestructive testing (NDT) methods for which they have responsibilities within the scope of their employment. These specific tasks or jobs include, but are not limited to, performing, specifying, reviewing, monitoring, supervising, and evaluating NDT work.
- *BSR/AWS D17.3/D17.3M-202x, Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*. This is a revision of *ANSI/AWS D17.3/D17.3M-2016*. This specification covers the general requirements for the friction stir welding of aluminum alloys for aerospace applications. It includes the requirements for weldment design, qualification of personnel and procedures, fabrication, and inspection.
- *BSR/ASME B31.1-202x, Power Piping*. This is a revision of *ANSI/ASME B31.1-2018*. This code prescribes the minimum requirements for the design, materials, fabrication, erection, test, and inspection of power and auxiliary service piping systems for electric generation station, industrial and institutional plants, central and district heating plants, and district heating systems.
- *BSR/ASME BPVC Section XI-202x, Section XI Rules for Inservice Inspection of Nuclear Power Plant Components*. This is a revision of *ANSI/ASME BPVC Section XI-2019*. Division 1 provides requirements for in-service inspection and testing of light-water-cooled nuclear power plants. The requirements identify the areas subject to inspection; responsibilities; provisions for accessibility and inspectability; examination methods and procedures; personnel qualifications; frequency of inspection; record keeping and report requirements; procedures for evaluation of inspection results and subsequent disposition of results of evaluations; and repair/replacement activity requirements, including procurement, design, welding, brazing, defect removal, fabrication, installation, examination, and pressure testing. Division 2 provides the requirements for the creation of the reliability and integrity management (RIM) program for all types of nuclear power plants.

ISO Draft International Standards

The following are standards that the International Organization for Standardization (ISO) is considering for approval. The proposals have received substantial support within the technical committee that developed them and are now being circulated to ISO members for comment and vote. Readers interested in reviewing or commenting on these standards should order copies from ANSI.

- *ISO/DIS 22290, Non-destructive testing – Infrared thermographic testing – Thermoelastic stress measuring method – General Principles*. This standard is under development. It will provide general principles of the thermoelastic stress measuring method of infrared thermographic testing in the field of industrial nondestructive testing.

Call for Candidates

ASNT Research Council Seeks RNDE Editor-in-Chief

The American Society for Nondestructive Testing (ASNT) is seeking a new Editor-in-Chief for *Research in Nondestructive Evaluation* (*RNDE*). Published by Taylor & Francis Group, *RNDE* is the influential research journal of ASNT. More information about the journal can be found on www.rnde.org.

The successful candidate will replace Professor John (Jack) C. Duke, Jr., who ends his editorial term with the closure of the 2020 volume. The Editor-in-Chief appointment is for a five-year term, beginning 1 January 2021. The Editor-in-Chief works with the Editorial Board, ASNT Research Council, *RNDE* Committee, and Taylor & Francis in developing the journal.

Candidates are expected to have a broad and proven record of published influential research in the field of nondestructive evaluation, as well as previous experience in scientific publishing. The successful candidate will show a strong interest in developing and promoting the journal and will also possess the interpersonal skills needed to work closely together with a team of associate technical editors and ASNT publication staff.

Applicants should submit a cover letter no longer than two pages summarizing qualifications and experience, a curriculum vitae, a list of publications, two letters of support, a statement of interest of up to 500 words stating the nominee's vision for the journal, and a letter of support from the applicant's employer.

Questions and applications should be emailed to the Director of Publications at tkervina@asnt.org and to the Research Council Chair at yi.pan@emerson.com. Applications received by 31 July 2020 will receive full consideration.

Additional information on this position can be found at asnt.org/MajorSiteSections/Publications/Periodicals/RNDE/Editor_In_Chief_Submissions.


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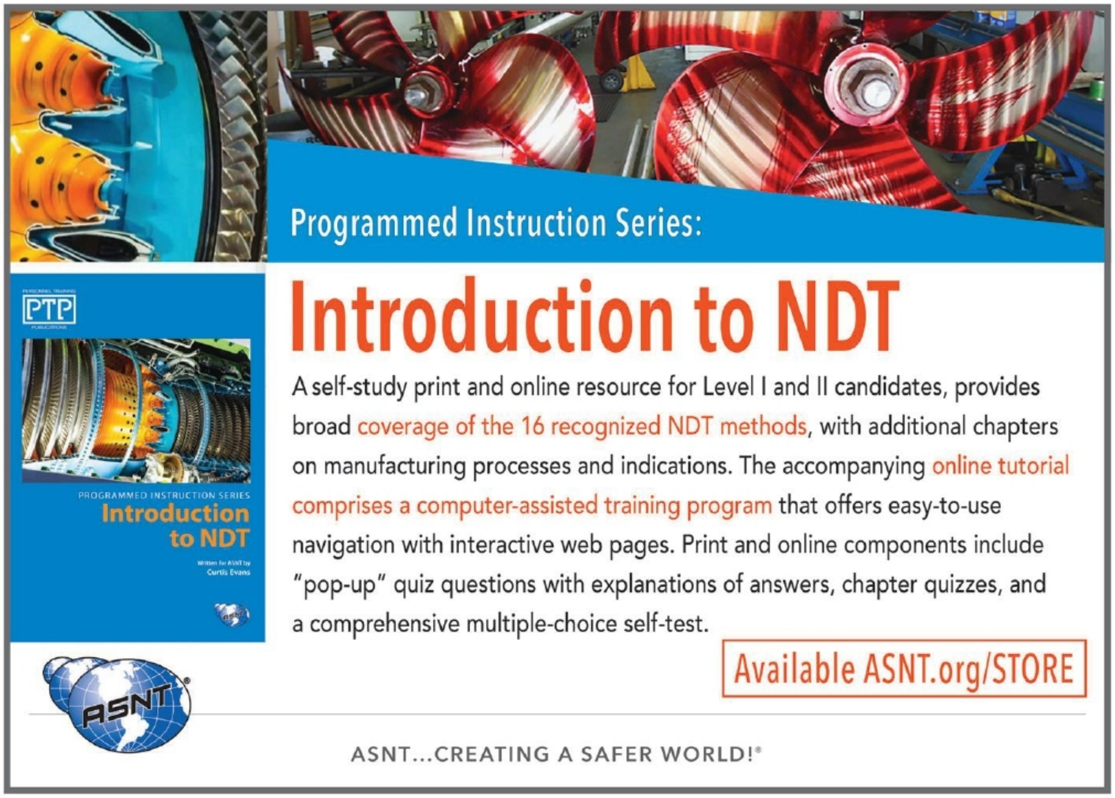
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NEWpatents

ROBERT E. SHANNON
Associate Technical Editor

US 10488371

Nondestructive inspection using thermoacoustic imagery system (A.M. Finn, A. Surana, M.O. Williams, E.A. Bernal, and O. Erdinc)

This patent relates to a nondestructive thermoacoustic imagery system for prognostics and health management, preventative maintenance, and repair of gas turbine engine parts. Manufactured components may incur defects or imperfections during manufacturing or suffer wear and incur defects during operation and thus are periodically inspected. Some defects are caused by delaminations or the improper bonding of composite structures, which may be detected by thermoacoustic techniques (also known as vibroacoustic, vibrothermography, thermosonic, or sonic infrared techniques) wherein vibration of the component induces localized heating at defect locations. The heating is detected by an infrared camera. Typically, the imagery is reviewed manually for the detection of defects. These reviews are tedious, time consuming, imprecise, and may be prone to errors. More recently, automated statistical analysis has been performed for crack detection using rapid exterior heating of a component and infrared imaging. For instance, pulsed thermography, in which a very short intense flash of light heats a component, has been used to show thermal conductivity of a coating. These techniques, however, require external heating of the component, which may not be applicable to composite material components.

This technique uses an ultrasonic excitation source to induce elastic waves in the component such that each single frequency of excitation is converted into a broad band of frequencies that are particular to resonant frequencies of the component. This vibrational energy is dissipated through conversion into heat due to friction or plastic deformation at defects in the component. A thermal signature is then observed with the thermography system. The amount of heat generated depends on the frequency and position of the excitation source and the size, shape, orientation, and depth of the dissipation site, as well as the excitation power level. Particular to this patent, a model of the component is stored in the component database to be registered to the thermal signature to provide structural information for location-dependent analysis. The model stored in the component database may be an as-designed model, an as-built model, a previous condition model, a model derived from the current thermal signature, and variations thereof for each component. In one example, the model may be a statistical distribution of pixel values from the thermal signature as constrained by the internal structure. Pixel values that fall outside of $+/- 3\sigma$ of the mean are considered anomalous. If the anomalous pixels spatially cluster relative to the internal structure, a defect is determined to be present. The internal structure is registered to a thermal signature via the model of the component. The registration may make use of edges of the component and the model to scale, rotate, and/or translate the model to orient with respect to the component to elucidate the internal structure for automated reasoning about the location of potential defects. The automated reasoning may include geometry-specific algorithms for the detection of defects. The registration may include a random sample consensus (RANSAC) algorithm based on computed features where the features may include SIFT, SURF, ASIFT, other SIFT variants, Harris Corner features, SUSAN, FAST, a phase correlation, a normalized cross-correlation, GLOH, BRIEF, CenSure/STAR, ORB, and the like.

The thermal signature is then compared with the model to initialize or constrain the detection of defects in the thermal signature to only the relevant predetermined area of the component, such as that defined by the internal structure. That is, the internal structure from the model is used to influence the detection of defects, particularly where the defect manifests as a "distorted pattern" in the thermographic image. This may be based on, for example, initialization of an active contour shape determination, a geometric restriction for predetermined areas over which statistical characterization is performed as priors in a Bayesian estimation, or another technique that limits portions of the thermographic image based on the model. In one example, a defect may be detected because it appears at a particular location with respect to the rigid internal structure, whereas an identical thermal signature defect that is not adjacent to the internal structure may be ignored.

Other examples include the detection of defects by performing a geometry-dependent analysis, comparing the thermal signature to the model (which delineates the internal structure), a pixel segmentation of the thermal signature compared to the model, a statistical analysis of predetermined areas of the thermal signature, and the like. Or, detection may be performed by a deep learning classifier trained from available data, such as a library of user-characterized defect examples. Deep learning is the process of training or adjusting the weights of a deep neural network. In an embodiment, the deep neural network is a deep convolutional neural network. Deep convolutional neural

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networks are trained by presenting an error map or partial error map to an input layer and a defect/no-defect label to an output layer. The training of a deep convolutional network proceeds layer-wise and does not require a label until the output layer is trained. The weights of the deep network's layers are adapted, typically by a stochastic gradient descent algorithm, to produce a correct classification. The deep learning training may use solely partially labeled data, solely fully labeled data, or solely implicitly labeled data, or may use unlabeled data for initial or partial training with only a final training on labeled data.

The nondestructive thermoacoustic imagery system facilitates automated visual inspection, which reduces costs incurred from faulty human visual inspection; reduces turn-backs from subsequent inspector disagreement; reduces dependence on increasingly scarce skilled inspectors; reduces inspection time and cost; increases inspector efficiency; and gathers machine-readable data on component condition for repair scheduling, life estimation, redesign, and training.

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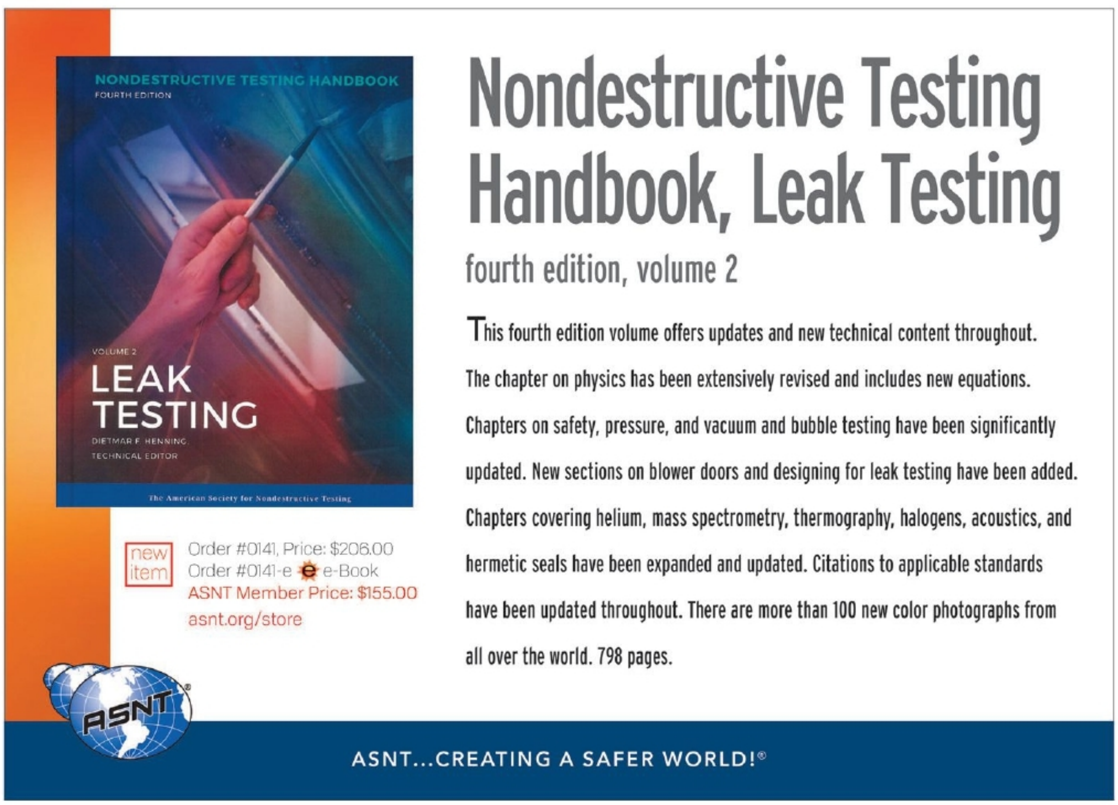
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Milan Tool Corp. (Cleveland, OH)
MIR Engineering (Tangerang, Indonesia)
MISTRAS Group Inc. (Princeton Junction, NJ)
Mitchell Laboratories (Pico Rivera, CA)
Modal Shop Inc. (Cincinnati, OH)
Moraine Valley Community College (Palos Hills, IL)
Mountain Pressure Testing (Longview, TX)
moviTherm (Irvine, CA)
MPM Products Inc. (Ontario, CA)
MR Chemie GmbH (Unna, Germany)
Mytechnic MRO (Istanbul, Turkey)

N

Nafto Serv (Istanbul, Turkey)
Nanovision Technology Beijing Co. Ltd. (Beijing, China)
Naya Engineering Services (Basra, Iraq)
NDE Professionals Inc. (Portland, OR)
NDE Solutions LLC (Bryan, TX)
NDT & Corrosion Control Services (Dammam, Saudi Arabia)
NDT Classroom Inc. (Buffalo, NY)
NDT Innovations Inc. (The Woodlands, TX)
NDT Level 3 Partners LLC (Saint Charles, MO)
NDT Power Ltd. (Port Harcourt, Nigeria)
NDT Seals Inc. (Houston, TX)
NDT Solutions (New Richmond, WI)
NDT Spot Inc. (Houston, TX)
NDT Supply.com Inc. (Lenexa, KS)
NDT Systems Inc. (Huntington Beach, CA)
NDT Testing Srl (Odobesti, Romania)
NDT Texas LLC (Houston, TX)
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Neill Aircraft Co. (Long Beach, CA)
Nepal Institute of NDT Resources Pvt Ltd. (Kathmandu, Nepal)
New Tech Systems (Mansfield, TX)
Newco Inc. (Florence, SC)
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Nextant Aerospace (Cleveland, OH)
NextNDT (San Jose, CA)
Nexxis Technologies USA Corp. (Webster, TX)
NiGSA Energy Services Ltd. (Lagos, Nigeria)
Nikon Metrology (Brighton, MI)
Non Destructive Evaluation International (Indian Trail, NC)
Non Destructive Testing Quality Ltd. (Moscow, Russia)
Nondestructive Inspection Service Inc. (Hurricane, WV)
North Star Imaging Inc. (Rogers, MN)
Northeast Testing and Manufacturing LLC (Beverly, MA)
Northwest Inspection (Kennewick, WA)
NOVA Geotechnical & Inspection Services (Las Vegas, NV)
NOVO DR Ltd. (Petah Tikva, Israel)
Novosound Ltd. (Lanarkshire, United Kingdom)
NXTNdT Inc. (North Adams, MA)

O

Ocean Corp. (Houston, TX)
Oceaneering International Asset Integrity (Houston, TX)
Oceanscan USA (Houston, TX)
OcerT Training & Consulting Ltd. (Jiading New City, China)
Ogden Weber Applied Technical College (Ogden, UT)
OGTC Pvt. Ltd. (Islamabad, Pakistan)
Ohio CAT (Broadview Heights, OH)
Oilfield Equipment Marketing Inc. (San Antonio, TX)
OKOS Solutions LLC (Manassas, VA)
Olympus America Inc. (Waltham, MA)
Orbit Industries Inc. (Cleveland, OH)
Overall Solutions (Arequipa, Peru)

P

Pac Testing Services Ltd. (Port Harcourt, Nigeria)
Pacific High Technology Services Co. Ltd. (Yangon, Myanmar)
Pacific Imaging LLC (Irvine, CA)
Pacsess (Bremen, Germany)
Palmetto Integrity Services LLC (Cheraw, SC)
Paragon NDT LLC (Wichita, KS)
Parker Research Corp. (Dunedin, FL)
PdM Consultores Internacional S.R.L. (Cartago, Costa Rica)
Peak NDT (Derby, United Kingdom)
Pennsylvania College of Technology (Williamsport, PA)
Penta Oil Services (Tripoli, Libya)
Performance Review Institute (Warrendale, PA)
Petro Base Ltd. (Richmond, TX)
PetroKnowledge (Masdar City, United Arab Emirates)
Petroleum Industrial Training Services (Thiruvananthapuram, India)
Petrolift International (Cairo, Egypt)
PetroScanalog International Ltd. (Port Harcourt, Nigeria)
Pfinder KG (Boeblingen, Germany)
PH Tool Reference Standards (Pipersville, PA)
Phased Array Co. (West Chester, OH)
PHATECO Technical Services Joint Stock Co. (Hai Phong City, Vietnam)
Phoenix Inspection Systems Ltd. (Warrington, United Kingdom)
Phoenix LLC (Monona, WI)
Pine (Windsor, NJ)
Pinnacle X-Ray Solutions (Suwanee, GA)
PM Testing Laboratory Inc. (Fife, WA)
Portsmouth Naval Shipyard (Portsmouth, NH)
Prakasa Spectro Cast Pvt. Ltd. (Vijayawada, India)
Premier Tubular Inspection Services Pte. Ltd. (Karachi, Pakistan)
Premium Inspection Co. (Bakersfield, CA)
Principia Inspecciones S.A.C. (Lima, Peru)
PRL Industries Inc. (Cornwall, PA)
Proceq (Aliquippa, PA)
PROMAG Technologies Development Ltd. (New Taipei, Taiwan)
Provident Energy Services (Fort Collins, CO)
PSSI NDT (Houston, TX)
PT Radiant Utama Interinsco Tbk. (Jakarta Selatan, Indonesia)
Pyromet Film Recycling (Aston, PA)

Q

QA Systems Pte. Ltd. (Singapore, Singapore)
QSA Global Inc. (Baton Rouge, LA)
Q-Sea Corp. (Tampa, FL)
Qualis NDT (San Gabriel, CA)
Quality Control Council US (Kansas City, KS)
Quality Equipment Distributors Inc. (Orchard Park, NY)
Quality NDE Ltd. (Mercier, Canada)
Quality Professional (Riyadh, Saudi Arabia)
Quality Testing Services Inc. (Linden, NJ)
Qualtech NDE (Karachi, Pakistan)

R

Raasyahan Sdn Bhd (Kuala Belait, Brunei)
RAD Source NDT (Lawrenceville, GA)
RADAC – Radiographic Accessories Ltd. (Newton Aycliffe, United Kingdom)
Radalytica (Praha, Czech Republic)
Radiago Work Solutions Pvt Ltd. (Navi Mumbai, India)
Radiografias EEE S.A. de C.V. (Salamanca, Mexico)
R-CON NDT Inc. (Menomonie, WI)
Redi Inspection Services (Evanston, WY)
Refined Inspection Services (Houston, TX)
Reinhart & Associates Inc. (Austin, TX)
REL Inc. (Calumet, MI)
Resources Unlimited Co. USA (Carlsbad, CA)
Rig Solution Engineering (Cairo, Egypt)
Rigaku Analytical Devices (Wilmington, MA)
Ritec Inc. (Warwick, RI)
Rohmann Eddy Current Instruments & Systems (Spartanburg, SC)
Rosen (Shah Alam, Malaysia)
Royal Crown (Basra, Iraq)
rtw ROENTGEN-TECHNIK (Neuenhagen, Germany)
Russell NDE Systems Inc. (Edmonton, Canada)

S

SAI Global (Chicago, IL)
Sarl 3MECS Engineering & Consulting Services (Laghouat, Algeria)
ScanMaster IRT Inc. (Greenville, SC)
ScanTech Instruments Inc. (Longview, TX)
School of Applied Non Destructive Examination (Boksburg, South Africa)
SCI Control & Inspeccion (Ajalvir, Spain)
SciAps Inc. (Woburn, MA)

SE International Inc. (Summertown, TN)
SEAL Aviation (Hollywood, FL)
Seikowave (Lexington, KY)
Sensor Networks (Boalsburg, PA)
Setcore Arabia Petroleum Services (Dammam, Saudi Arabia)
Shandong HTS NDT Technology Co. Ltd. (Jinan City, China)
Shanghai Puxian Mechanical Technology Co. Ltd. (Shanghai, China)
Shanghai QiJi Inspection Technology Co. (Shanghai, China)
Shenzhen Firstrank Industrial Development Co. Ltd. (Shenzhen, China)
Sherwin Inc. (South Gate, CA)
Shueze Marine Services Ltd. (Eleme Port Harcourt, Nigera)
Sidat Inspecciones (Cuautitlan, Mexico)
Siemens Energy Inc. (Mount Pleasant, PA)
Siemens Gamesa Renewable Energy (Sarriguren, Spain)
SignalNDT (Goleta, CA)
Signature TechnicAir (Greensboro, NC)
Silean (Tremonton, UT)
Siruk Ltd. (Port-Harcourt, Nigera)
SIUI (Shantou, China)
SME (Plymouth, MI)
SMEC Automation Pvt Ltd. (Cochin, India)
Snell Group (Barre, VT)
Soaring High Inc. (Islamabad, Pakistan)
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Sonaxis SA (Besancon, France)
Sonic Systems International (Houston, TX)
SONOTEC (Islandia, NY)
Sound NDT Solutions (Conroe, TX)
Source Production & Equipment Co. Inc. (Saint Rose, LA)
Southern Inspection Services (Chennai, India)
Southwest Research Institute (San Antonio, TX)
Sowela Technical Community College (Lake Charles, LA)
Sowsco Inspection Services Ltd. (Port Harcourt, Nigeria)
Sparrows (Bridge of Don Aberdeen, United Kingdom)
Spartan College of Aeronautics & Technology (Tulsa, OK)
Special Oilfield Services Co. LLC (Ruwi, Oman)
Specpro (Hollywood, FL)
Spellman High Voltage Electronics Corp. (Hauppauge, NY)
Stanley Inspection (Tulsa, OK)
Stegman Inspection Services Inc. (Troy, MI)

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Being a part of the Society links your business to the worldwide NDT community and puts your business on the front lines of the industry. To learn more about becoming an ASNT Partner, see the Membership section of the ASNT website at **asnt.org**.

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Surehand Inc. (Morgan Hill, CA)
Surialke Marketing and Industrial Services Ltd. (Oropouche, Trinidad and Tobago)
Suzhou Phaserise Technology (Suzhou, China)
System One (Cheswick, PA)

T

Talcyon Pte. Ltd. (Singapore, Singapore)
TCR Arabia Co. Ltd. (Dammam, Saudi Arabia)
TEAM Industrial Services (Alvin, TX)
Tech Service Products Inc. (Harahan, LA)
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Technicon Engineering Services (Fresno, CA)
Technisonic Research Inc. (Fairfield, CT)
Technology Design Ltd. (Winsford, United Kingdom)
Technoparts (Hollywood, FL)
Techshore Inspection Services (Cochin, India)
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Telops Inc. (Quebec, Canada)
Tesco Corp. (Kanagawa, Japan)
Test Equipment Distributors LLC (Troy, MI)
Testex Inc. (Pittsburgh, PA)
Testia (Toulouse, France)
Testing Equipment Specialist Team Co. (Dammam, Saudi Arabia)
Texas Research International (Austin, TX)
The Lloyd Co. (Houston, TX)
Thermal Wave Imaging Inc (Madison Heights, MI)
Thermographie GG Inc. (Granby, Canada)
Tian Jin ORD Engineering Inspection Technology Co. Ltd. (Tian Jin, China)
Tisa Lifeboats & LA Services S.A. (Colon, Panama)
Topscan Inspections Ltd. (Port Harcout, Nigeria)
Torab Engineering Consultancy Co. (Alexandria, Egypt)
Toray Industries America Inc. (New York, NY)
Total NDT LLC (Longview, TX)
Transportation Technology Center Inc. (Pueblo, CO)
Trident Refit Facility (Kings Bay, GA)
Trikon Technologies Inc. (Vaudreuil-Dorion, Canada)
Tru Amp Corp. (Jackson, MS)
Tsukuba Technology Co. Ltd. (Tsukuba, Japan)
Tubecare International (Doha, Qatar)
Tubestar Oil and Gas Services (Al Khobar, Saudi Arabia)
Tuboser Oilfield Inspection Services (Sfax, Tunisia)
Tulsa Welding School (Tulsa, OK)
Turbo Nondestructive Testing Inc. (Houston, TX)

U

ULSO TECH Co. Ltd. (Xing Tai He Bei, China)
Ultrasonic Sciences Ltd. (Aldershot, United Kingdom)
Universal Inspection Co. Ltd. (Jubail, Saudi Arabia)
University of South Wales (Cardiff, United Kingdom)
UniWest (Pasco, WA)
US Army Yuma Proving Ground (Yuma, AZ)
U-Sonix Inspection Solutions Pvt Ltd. (Chennai, India)
UT Quality (Edmonton, Canada)
UTEX Scientific Instruments Inc. (Mississauga, Canada)

V

VAAL University of Technology (Vanderbijlpark, South Africa)
Valley Inspection Service Inc. (Allentown, PA)
Vandergriff Technologies NDT Services (Haltom City, TX)
Varex Imaging (Salt Lake City, UT)
Vector TUB GmbH (Hattingen NRW, Germany)
Velosi (B) Sdn Bhd (Kuala Belait, Brunei)
Velosi (M) Sdn Bhd (Petaling Jaya, Malaysia)
Venom Technologies & Inspection Services LLC (Houston, TX)
Verasonics Inc. (Kirkland, WA)
Verda (Sfax, Tunisia)
Verichek Technical Services Inc. (Bethel Park, PA)
Veriphase (Birmingham, AL)
Vermon NDT (Walhalla, SC)
Versa Integrity Group (Sulphur, LA)
Vidisco USA (Arlington, VA)
ViewTech Borescopes (Traverse City, MI)
Virgin Galactic (Mojave, CA)
VisiConsult X-Ray Systems & Solutions GmbH (Stockelsdorf, Germany)
Vision Financial Group Inc. (Pittsburgh, PA)
VJ Technologies Inc. (Bohemia, NY)
Volume Graphics Inc. (Charlotte, NC)
Volunteer NDT Corp. (Chattanooga, TN)

W

Walt Disney World Co. (Lake Buena Vista, FL)
Warren Associates (Pittsburgh, PA)
Washita Valley Enterprises Inc. (Oklahoma City, OK)
Waygate Technologies (Greenville, SC)
We-NDT (Minden, NV)
WesDyne AMDATA (Windsor, CT)
Willick Engineering Co. Inc. (Santa Fe Springs, CA)
Winstonson and Sons Nigeria Ltd. (Effurun Warri, Nigeria)
World Testing Inc. (Mount Juliet, TN)
World Wide Nondestructive Testing LLC (Land O'Lakes, FL)
Wuhan Zhongzhen Huachuang Technology Co. Ltd. (Wuhan, China)

X

XCEL A Crossbridge Group Co. (Clifton, KS)
Xplore Edutech (Ernakulam, India)
X-Ray Associates LLC (San Dimas, CA)
X-Scan Imaging Corp. (San Jose, CA)

Y

YXLON (Hudson, OH)

Z

Zamil Inspection and Contracting (Ad Dammam, Saudi Arabia)
Zetec Inc. (Snoqualmie, WA)
Zitadel Ltd. (Port Harcourt, Nigeria)

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Coming Soon
Order 2073

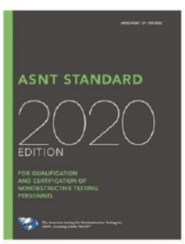
Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing

Recommended Practice No. SNT-TC-1A provides guidelines for employers to establish in-house certification programs for the qualification and certification of NDT personnel. It provides the educational, experience, and training recommendations for each NDT method.

Coming Soon
Order 2823

ANSI/ASNT CP-105: ASNT Standard Topical Outlines for Qualification of Nondestructive Testing Personnel, 2020

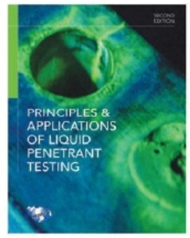
ANSI/ASNT CP-105 specifies the body of knowledge to be used as part of a training program qualifying and certifying NDT personnel. It applies to personnel whose tasks or jobs require knowledge of the technical principles underlying the NDT methods for which they have responsibility.



Coming Soon
Order 2511

ANSI/ASNT CP-189: ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, 2020

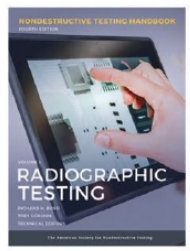
ANSI/ASNT CP-189 (2020) is an ANSI standard that establishes the minimum requirements for the qualification and certification of NDT and PdM personnel. It includes the minimum training, education, and experience requirements, as well as criteria for documenting qualifications and certification.



new item
Order 2204

Principles and Applications of Liquid Penetrant Testing: A Classroom Training Text
second edition

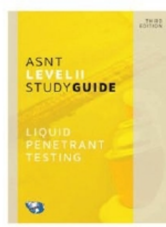
This book was updated to cover the current basic penetrant process requirements, systems and materials, application and removal, types of developers, inspection equipment, and personnel requirements. Intended for technicians who do not need all of the technical data contained in other publications, it is recommended for classroom training, self-instruction, and as a reference.



new item
Order 0144
eBook 0144e

Nondestructive Testing Handbook, Radiographic Testing,
fourth edition, volume 3

This Radiographic Testing Handbook offers revised and expanded content throughout, with over 150 new color images. A chapter on neutron radiography has been added, as well as new technical information on digital imaging, data processing, and digital image reconstruction. All attenuation tables have been recalculated. 768 pages.



new item
Order 6101

ASNT Level II Study Guide: Liquid Penetrant Testing,
third edition

This Study Guide presents fundamental information to assist the candidate in preparing for a Level II PT examination. Many expanded chapters to cover the body of knowledge in CP-105 (2016). Updated industry specifications (ASTM, AMS, ASME, etc.) Material has been added to recognize Type III dual-mode penetrant.

ASNT...CREATING A SAFER WORLD!®

Personnel Training Publications (PTP) Classroom Training Series

PTP Series available in complete six method set: PT, MT, UT, ET, RT, and VT. Each volume covers Level I and Level II.

Liquid Penetrant Testing (PT) Instructor Package and Student Package, second edition

Instructor Package Order 1650

Liquid Penetrant Testing Instructor Package focuses on the fundamentals for Levels I and II. Includes: Instructor Lecture Guide; quizzes with answer keys for each section; online access to a downloadable PowerPoint® lecture with more than 175 slides which can be customized for classroom use; and Liquid Penetrant Testing Classroom Training Book. Multiple-choice questions align with ASNT PT examinations.

Student Package Order 1660

Liquid Penetrant Testing Student Package focuses on the fundamentals for Levels I and II. The package includes: Student Guide; quizzes for each section; and Liquid Penetrant Testing Classroom Training Book.

Visual Testing (VT) Instructor Package and Student Package

Instructor Package Order 1655

Visual Testing (VT) Instructor Package focuses on the fundamentals for Levels I and II. The multimedia Instructor Package includes: Visual Testing Classroom Training Book, PowerPoint® lecture on USB Flash drive, Quizzes with answer keys for each lecture, and Instructor Guide to PowerPoint® lecture.

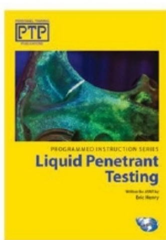
Student Package Order 1665

Visual Testing (VT) Student Package focuses on the fundamentals for Levels I and II. The Student Package includes: Student guide to PowerPoint® lecture, Visual Testing Classroom Training Book, and Quizzes.

PTP Programmed Instruction Series is a **self-study resource** for Level I and II candidates.

Available in complete five method set: PT, MT, UT, ET, and RT. Each volume covers Level I and Level II.

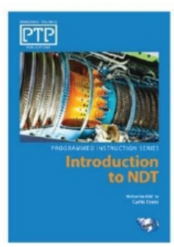
Liquid Penetrant Testing



A self-study resource for Level I and II candidates, Liquid Penetrant Testing provides in-depth, coverage of liquid penetrant testing (PT) theory, principles, and applications. Topics are sequenced based on the body of knowledge in ANSI/ASNT CP-105 (2016).

Order 1534

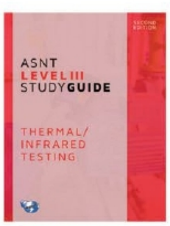
Introduction to NDT



A self-study resource for Level I and II candidates, Programmed Instruction Series: Introduction to NDT provides in-depth, up-to-date coverage of the 16 recognized nondestructive testing (NDT) methods, covering theory, principles, and applications. It features chapter previews and summaries, quiz questions with explanations of answers, and a self-test. The online component contains a training program that offers easy-to-use navigation with interactive pages and review questions.

new item Order 1530

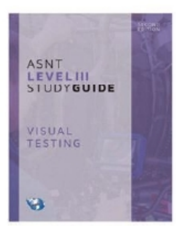
ASNT Level III Study Guide: Thermal/Infrared Testing, second edition



Order 2265

This Study Guide was extensively revised and updated to better cover the training outlines in CP-105. Written to assist the Level III candidate preparing for the thermal/infrared testing exam.

ASNT Level III Study Guide: Visual Testing, second edition



Order 2263

This Study Guide was extensively revised and updated to better cover the training outlines in CP-105. New and expanded content includes lighting, imaging fundamentals, test object characteristics, VT techniques, remote VT equipment, as well as codes and standards.

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calendar

meetings

Meetings are events at which paper and/or poster presentations are made and recent developments in technology, research and development are discussed by those in attendance. These are generally sponsored by academic or professional technical associations. The sponsor is the same as the contact except where noted.

For ASNT meetings and events (highlighted in red) contact the ASNT Conference Department, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518; 1-800-222-2768 or 1-614-274-6003; email conferences@asnt.org.

PLEASE NOTE: ***Materials Evaluation*'s Calendar** department is derived from information sent to our offices by the sponsoring organizations. ASNT staff is not responsible for collecting or verifying the information contained herein: for more information on meetings or courses, please contact the sponsoring organization. The Calendar copy deadline is the first of the month, two months prior to the issue date: for example, 1 August for the October journal. Send your organization's information by email to the *Materials Evaluation* Assistant Editor at cschaurer@asnt.org. Information in the Calendar runs for three months at a time. ASNT reserves the right to reject event listings for any reason. Listings will be edited to conform to ASNT's editorial style.

2020

29–30 JUL
Digital Imaging and Ultrasonics for NDT, Virtual Conference. Contact: ASNT.

19 AUG
NDE/NDT Structural Materials Technology for Highways and Bridges, Virtual Conference. Contact: ASNT.

10–13 NOV
ASNT Annual Conference, Disney's Coronado Springs Resort, Lake Buena Vista, FL. Contact: ASNT.

8–10 DEC
Gulf Nondestructive Testing Expo Dubai, Dubai Parks and Resorts, Dubai, United Arab Emirates. Contact: ASNT United Arab Emirates Section; email info@emeraldeventsme.com; gndtexpo.com.

2021

3–5 FEB
International Chemical and Petroleum Industry Inspection Technology (ICPIIT) Conference, Sugar Land Marriott Town Square, Sugar Land, TX. Contact: ASNT.

26–29 APR
ASNT Research Symposium, Westin Westminster, Westminster, CO. Contact: ASNT.

31 MAY–4 JUN
20th WCNDT 2020, Incheon, Korea. Contact: Korean Society for Nondestructive Testing; +82 27570981; email secretariat@wcndt2020.com; wcndt2020.com.

5–9 JUL
7th US-Japan NDT Symposium, Waikoloa Beach Marriott Resort & Spa, Waikoloa, HI. Contact: ASNT.

4–8 OCT
European NDT & CM, Prague, Czech Republic. Contact: Guarant International; email endtcm21@guarant.cz; endtcm21.com; or guarant.com.

15–18 NOV
ASNT Annual Conference, Renaissance Phoenix Downtown, Phoenix, AZ. Contact: ASNT.

2022

26–28 APR
International Conference on NDE 4.0, Munich, Germany. Contact: German Society for Non-Destructive Testing; email tagungen@dgzfp.de; conference.nde40.com.

6–10 JUN
13th ECNDT, Lisbon, Portugal. Contact: AIM Group International – Lisbon Office; email ecndt2022@aimgroup.eu; ecndt2022.org.

courses

Courses are events where participants are instructed in the technologies and methodologies of a particular technical area and which generally conclude with the student being evaluated to determine the student's retention of the material presented. These events often offer some form of course credit or continuing education units to those participants successfully completing the course. For ASNT refresher courses, visit asnt.org/refresher.

ASNT neither approves nor disapproves of any program or training course claiming to meet the recommendations of ASNT's *Recommended Practice No. SNT-TC-1A*. The following are contacts for only those organizations that offer public courses listed in this month's Calendar.

The following courses are listed without necessarily giving their full titles.

Acoustic Emission Testing

13–17 JUL
Level I/II, Milan, Italy. ETS.

27–31 SEP
SHM through AE Testing, Milan, Italy. ETS.

8–10 SEP
AE for Scientists & Engineers, Princeton Junction, NJ. Mistras East.

14–18 SEP
Level I/II, Milan, Italy. ETS.

21–25 SEP
Level I/II, Milan, Italy. ETS.

Electromagnetic Testing

30 JUL–3 AUG
Level II, Bangalore, India. Trinity.

3–7 AUG
Level I, Atlanta, GA. ATS.
Level II, New London, CT. Hellier New London.

4–6 AUG
Refresher Level II, San Antonio, TX. BRL.

10–14 AUG
Level II, Atlanta, GA. ATS.

17–21 AUG
Eddy Current Level I, San Antonio, TX. BRL.

24–28 AUG
Eddy Current Level I, Brea, CA. Test.
Eddy Current Level II, San Antonio, TX. BRL.

27–31 AUG
Level II, Bangalore, India. Trinity.

31 AUG–2 SEP
Eddy Current Array, Houston, TX. Hellier Houston.

calendar

Electromagnetic Testing, cont.

31 AUG–4 SEP
Eddy Current Level II, Brea, CA. Test.

1–3 SEP
Refresher Level II, San Antonio, TX. BRL.

14–18 SEP
Eddy Current Level I, Anaheim, CA. Hellier Anaheim.
Eddy Current Level I, Houston, TX. Hellier Houston.

21–25 SEP
Eddy Current Level II, Anaheim, CA. Hellier Anaheim.
Eddy Current Level II, Houston, TX. Hellier Houston.

24–28 SEP
Level II, Bangalore, India. Trinity.

28 SEP–2 OCT
Eddy Current Level I, New London, CT. Hellier New London.

Leak Testing

20–24 JUL
Helium LT for Engineers, Milan, Italy. ETS.

3–7 AUG
Mass Spectrometer Level I/II, Orlando, FL. LTS.

10–14 AUG
PCMT Level I/II, BT Level I/II, and Level III Preparation, Orlando, FL. LTS.

14–18 SEP
Pressure Change Measurement Level I/II, Orlando, FL. LTS.

17–21 SEP
Helium LT for Engineers, Milan, Italy. ETS.

21–24 SEP
LT for Engineers, Orlando, FL. LTS.

Liquid Penetrant Testing

13–14 JUL
Level I/II, Greenville, SC. PQT.

13–16 JUL
NAS410, Atlanta, GA. ATS.

20–23 JUL
Level I/II, Kent, WA. Mistras Northwest.

22–23 JUL
Level II, Bangalore, India. Trinity.

23–24 JUL
Level I/II, Anaheim, CA. Hellier Anaheim.
Level I/II (*SNT-TC-1A*), Brea, CA. Test.

Course Contacts

The following are contacts for only those organizations that offer public courses listed in this month's Calendar.

Atlantic: Atlantic NDT Training; Gary L. Chapman; Branford, CT; 1-203-481-4041; atlanticndttraining.com.

ATS: Applied Technical Services; Lisa Henry; Marietta, GA; 1-888-287-5227; email lhenry@atslab.com; atslab.com/training.

BRL: BRL Consultants Inc.; San Antonio, TX 78216; 1-210-341-3442; email info@brlconsultants.com; brlconsultants.com.

CodeWest: CodeWest; Teresa Benton; Houston, TX; 1-281-392-4540; email tbenton@codewest.com; codewest.com.

ETS: ETS Sistemi Industriali Srl.; Alberto Monici; Brugherio (MB), Italy; +39 039877790; email a.monici@etssistemi.it; etssistemi.it.

Fujifilm: Fujifilm NDT Training Services; James Molinaro; Valhalla, NY; 1-864-437-9780; email fnacndttraining@fujifilm.com or james.molinaro@fujifilm.com; fujifilmndttraining.com

Hellier Anaheim: Hellier; Sharyl McGloin; Anaheim, CA; 1-714-956-2274; email smcgloin@hellierndt.com; hellierndt.com.

Hellier Houston: Hellier; Heather Monclova; Houston, TX; 1-281-873-0980; email hmonclova@hellierndt.com; hellierndt.com.

Hellier New London: Hellier; Jan Mahoney; New London, CT; 1-860-437-1003; email jmahoney@hellierndt.com; hellierndt.com.

Kraft: Kraft Technology Resources LLC; Karl E. Kraft; Tiki Island, TX; 1-405-819-7786; email kraftndt@aol.com; ndtbootcamp.com.

LTS: Leak Testing Specialists Inc.; Cyndi Reid; Orlando, FL 32822; 1-407-737-6415; email cyndi.reid@leaktestingspec.com; leaktestingspec.com.

Mistras Central: Mistras Group Inc.; Billy Reiter; Heath, OH; 1-740-788-9188 X26; email billy.reiter@mistrasgroup.com; mistrasgroup.com.

Mistras East: Mistras Group Inc.; Christina Librandy; Princeton Junction, NJ; 1-609-716-4000; email christina.librandy@mistrasgroup.com; mistrasgroup.com.

Mistras Northwest: Mistras Group Inc.; Mike Campbell; Kent, WA; 1-206-764-8123; email training.seattle@mistrasgroup.com; mistrasgroup.com.

Moraine: Moraine Valley Community College; Palos Hills, IL; 1-708-974-5735; email ccce@morainevalley.edu; morainevalley.edu/ccce/community-partner/career-training/nondestructive-testing/.

MPM: MPM Products Inc.; Jeri Matza; Ontario, CA; 1-918-740-0290; email jerimatza@mpmproducts.com; mpmproducts.com.

NPI: NDE Professionals Inc.; Portland, OR; 1-503-287-5255; email training@qnpi.com; ndeprofessionals.com.

PQT: PQT Services (Plumstead Training); Kim Rosa; Greenville, SC; 1-864-292-1115; email krosa@atslab.com; pqt.net.

Snell: The Snell Group; Jim Fritz, Barre, VT; 1-802-479-7100; email jfritz@thesnellgroup.com; thesnellgroup.com.

Test: Test NDT; Cathy Harvey; Brea, CA; 1-714-255-1500; email ndttrain@aol.com; testndt.com.

Trinity: Trinity Institute of NDT Technology; Ravi Kumar T. or Shiva Kumar R.; Bangalore, India; +91 9900929439 or +91 9844129439; email training@trinityndt.com; trinityndt.com.

WTTI: Welder Training and Testing Institute; Tracy Wiswesser; Allentown, PA; 1-800-223-9884; email tracy@wtti.com; wtti.edu.

3 AUG
Refresher Level II, San Antonio, TX. BRL.

3–4 AUG
Level I/II, Greenville, SC. PQT.
Level I/II, Jacksonville, FL. PQT.

3–6 AUG
***NAS 410*,** New London, CT. Hellier New London.

13–14 AUG
Level I/II, New London, CT. Hellier New London.

14–15 AUG
Level I/II, Houston, TX. Hellier Houston.

17–18 AUG
Level I/II, Atlanta, GA. ATS.

19–20 AUG
Level II, Bangalore, India. Trinity.

20–21 AUG
Level I/II, Allentown, PA. WTTI.

27–28 AUG
Level I/II, Anaheim, CA. Hellier Anaheim.

31 AUG
Refresher Level II, San Antonio, TX. BRL.

31 AUG–3 SEP
Level I/II (*NAS 410*), Anaheim, CA. Hellier Anaheim.

14–16 SEP
Level I/II, Palos Hills, IL. Moraine.

14–23 SEP
Level I/II, Palos Hills, IL. Moraine.

16–17 SEP
Level II, Bangalore, India. Trinity.

17–18 SEP
Level I/II, San Antonio, TX. BRL.

21–22 SEP
Level I/II, Atlanta, GA. ATS.
Level I/II, Greenville, SC. PQT.

21–23 SEP
Level I/II (*SNT-TC-1A*), Branford, CT. Atlantic.

21–24 SEP
Level I/II, Portland, OR. NPI.

24–25 SEP
Level I/II (*SNT-TC-1A*), Brea, CA. Test.

28 SEP–1 OCT
Liquid Penetrant (*NAS 410*), New London, CT. Hellier New London.

Magnetic Particle and Liquid Penetrant Testing

13–17 JUL
Level I/II, Greenville, SC. PQT.

3–7 AUG
Level I/II, Greenville, SC. PQT.
Level I/II, Jacksonville, FL. PQT.

17–21 AUG
Level I/II, Allentown, PA. WTTI.
Level I/II, Atlanta, GA. ATS.

21–25 SEP
Level I/II, Atlanta, GA. ATS.
Level I/II, Branford, CT. Atlantic.
Level I/II, Greenville, SC. PQT.
***SNT-TC-1A*,** Heath, OH. Mistras Central.

Magnetic Particle Testing

15–17 JUL
Level I/II, Greenville, SC. PQT.

20–21 JUL
Level II, Bangalore, India. Trinity.

20–22 JUL
Level I/II, Anaheim, CA. Hellier Anaheim.
Level I/II (*SNT-TC-1A*), Brea, CA. Test.

20–23 JUL
***NAS 410*,** Atlanta, GA. ATS.

5–7 AUG
Level I/II, Greenville, SC. PQT.
Level I/II, Jacksonville, FL. PQT.

10–12 AUG
Level I/II, New London, CT. Hellier New London.

11–13 AUG
Level I/II, Houston, TX. Hellier Houston.

17–18 AUG
Level II, Bangalore, India. Trinity.

17–19 AUG
Level I/II, Allentown, PA. WTTI.

17–20 AUG
Level I/II (*NAS 410*), Anaheim, CA. Hellier Anaheim.

calendar

Magnetic Particle Testing, cont.

19–21 AUG
Level I/II, Atlanta, GA. ATS.

24–26 AUG
Level I/II, Anaheim, CA. Hellier Anaheim.

24–27 AUG
Level I/II, Kent, WA. Mistras Northwest.

14–15 SEP
Level II, Bangalore, India. Trinity.

14–16 SEP
Level I/II, San Antonio, TX. BRL.

14–17 SEP
Level I/II, Portland, OR. NPI.

16–18 SEP
Level I/II, Palos Hills, IL. Moraine.

21–23 SEP
Level I/II (*SNT-TC-1A*), Brea, CA. Test.

22–25 SEP
Level I/II (*NAS 410*), New London, CT. Hellier New London.

23–25 SEP
Level I/II, Atlanta, GA. ATS.
Level I/II, Greenville, SC. PQT.
Level I/II (*SNT-TC-1A*), Branford, CT. Atlantic.

28–30 SEP
Level I/II, Anaheim, CA. Hellier Anaheim.
Level I/II, Houston, TX. Hellier Houston.

Radiographic Testing

13–15 JUL
Nonfilm Level I Transition, Atlanta, GA. ATS.

13–17 JUL
CR Level I, Atlanta, GA. ATS.
DR Level I, Atlanta, GA. ATS.
Level I Film, Atlanta, GA. ATS.
Nonfilm Level I, Atlanta, GA. ATS.
Nonfilm Level II Transition, Trumbull, CT. Fujifilm.
Radiation Health and Safety, Anaheim, CA. Hellier Anaheim.
Radiography Level II, Houston, TX. Hellier Houston.
RT Level II, New London, CT. Hellier New London.

20–24 JUL
Radiography Level I, Anaheim, CA. Hellier Anaheim.
RT Film Interpretation, Houston, TX. Hellier Houston.

20–29 JUL
Film/Nonfilm Level I, Atlanta, GA. ATS.

24–26 JUL
Level II, Bangalore, India. Trinity.

27–28 JUL
Radiation Safety Worker, Greenville, SC. PQT.

27–31 JUL
CR Level II, Atlanta, GA. ATS.
Digital Radiography Level I, Anaheim, CA. Hellier Anaheim.
DR Level II, Atlanta, GA. ATS.
Level II Film, Atlanta, GA. ATS.
Level II Nonfilm, Atlanta, GA. ATS.
Radiation Safety, Atlanta, GA. ATS.
Radiation Safety, Houston, TX. Hellier Houston.
Radiation Safety Officer, Greenville, SC. PQT.
Radiation Safety Radiographer, Greenville, SC. PQT.

27 JUL–5 AUG
Film/Nonfilm Level II, Atlanta, GA. ATS.

29–31 JUL
Radiation Safety Officer, Greenville, SC. PQT.

3–7 AUG
Level I, Heath, OH. Mistras Central.
Level I, Houston, TX. Hellier Houston.
Level II, Anaheim, CA. Hellier Anaheim.

10–14 AUG
Level II, Heath, OH. Mistras Central.
Level II/III Film to Nonfilm Transition Training DR, Tualatin, OR. MPM.
Nonfilm Level II Transition, Atlanta, GA. Fujifilm.
Radiation Safety, Anaheim, CA. Hellier Anaheim.
Radiation Safety, New London, CT. Hellier New London.
Radiation Safety (IRRSP Preparation), Brea, CA. Test.

11–15 AUG
Level II, Houston, TX. Hellier Houston.

17–21 AUG
CR Level I, Atlanta, GA. ATS.
CR Level I, Greenville, SC. PQT.
DR Level I, Atlanta, GA. ATS.
DR Level I, Greenville, SC. PQT.
Film Interpretation, Houston, TX. Hellier Houston.
Level I, Brea, CA. Test.
Level I, New London, CT. Hellier New London.
Level I Film, Atlanta, GA. ATS.
Level I Film, Greenville, SC. PQT.
Level I Nonfilm, Atlanta, GA. ATS.
Level I Nonfilm (*NAS 410*), Greenville, SC. PQT.
Nonfilm Level I Transition (*NAS 410*), Greenville, SC. PQT.

17–26 AUG
Film/Nonfilm Level I, Atlanta, GA. ATS.

21–23 AUG
Level II, Bangalore, India. Trinity.

24–28 AUG
CR Level II, Atlanta, GA. ATS.
CR Level II, Greenville, SC. PQT.
DR Level II, Atlanta, GA. ATS.
DR Level II, Greenville, SC. PQT.
Level II, Brea, CA. Test.
Level II, New London, CT. Hellier New London.
Level II Film, Atlanta, GA. ATS.
Level II Film, Greenville, SC. PQT.
Level II Nonfilm, Atlanta, GA. ATS.
Level II NonFilm (*NAS 410*), Greenville, SC. PQT.
Nonfilm Level II Transition (*NAS 410*), Greenville, SC. PQT.
Radiation Safety, Houston, TX. Hellier Houston.

31 AUG–4 SEP
Level I, Houston, TX. Hellier Houston.
Nonfilm Level II Transition, Atlanta, GA. ATS.

14–15 SEP
Radiation Safety Worker, Greenville, SC. PQT.

14–18 SEP
Level II, Houston, TX. Hellier Houston.
Nonfilm Level III Transition, Lake Forest, CA. Fujifilm.
Radiation Safety Officer, Greenville, SC. PQT.
Radiation Safety Radiographer, Greenville, SC. PQT.

16–18 SEP
Radiation Safety Officer, Greenville, SC. PQT.

18–20 SEP
Level II, Bangalore, India. Trinity.

21–25 SEP
CR Level I, Atlanta, GA. ATS.
DR Level I, Atlanta, GA. ATS.
Film Interpretation, Houston, TX. Hellier Houston.
Level I, Allentown, PA. WTTI.
Level I Film, Atlanta, GA. ATS.
Level I Nonfilm, Atlanta, GA. ATS.
Radiation Safety, Anaheim, CA. Hellier Anaheim.
Radiation Safety, Palos Hills, IL. Moraine.

21–30 SEP
Film/Nonfilm Level I, Atlanta, GA. ATS.

28 SEP–2 OCT
CR Level II, Atlanta, GA. ATS.
DR Level II, Atlanta, GA. ATS.
Level I, Anaheim, CA. Hellier Anaheim.
Level II Film, Atlanta, GA. ATS.
Level II Nonfilm, Atlanta, GA. ATS.
Radiation Safety, Houston, TX. Hellier Houston.
Radiation Safety (IRRSP Preparation), Brea, CA. Test.

28 SEP–7 OCT
Film/Nonfilm Level II, Atlanta, GA. ATS.

Thermal/Infrared Testing

13–17 JUL
Thermographic Applications Level I, Barre, VT. Snell.

17–21 AUG
Advanced Infrared Thermography Level II, Barre, VT. Snell.

24–28 AUG
Thermographic Applications Level I, Seattle, WA. Snell.

25–26 AUG
Infrared for Electrical Inspections, Minneapolis, MN. Snell.

14–18 SEP
Advanced Infrared Thermography Level II, Denver, CO. Snell.
Electric Motor Testing, Knoxville, TN. Snell.
Thermographic Applications Level I, Indianapolis, IN. Snell.
Thermographic Applications Level I, Denver, CO. Snell.

21–25 SEP
Advanced Infrared Thermography Level II, Dallas, TX. Snell.
Thermographic Applications Level I, Chicago (Palatine), IL. Snell.

22–23 SEP
Infrared for Electrical Inspections, Cleveland, OH. Snell.

29–30 SEP
Infrared for Electrical Inspections, Kansas City, MO. Snell.

Ultrasonic Testing

13–17 JUL
Level II, Atlanta, GA. ATS.
Level II, New London, CT. Hellier New London.
Level II, Portland, OR. NPI.
PAUT Composite Inspection, Brea, CA. Test.
Ultrasonic Phased Array Level II, Houston, TX. Hellier Houston.

14–16 JUL
Thickness, Heath, OH. Mistras Central.

15–19 JUL
Level II, Bangalore, India. Trinity.

16 JUL
Thickness, Digital Level II, San Antonio, TX. BRL.

20–24 JUL
Level I, Greenville, SC. PQT.
Level I, San Antonio, TX. BRL.
Level II, Allentown, PA. WTTI.
Longitudinal Level I, Palos Hills, IL. Moraine.
Weld Inspection/Flaw Detection and Sizing, Houston, TX. Hellier Houston.

21–23 JUL
Weld Inspection, Heath, OH. Mistras Central.

27–31 JUL
Level I, Anaheim, CA. Hellier Anaheim.
Level I, Brea, CA. Test.
Level I, Houston, TX. Hellier Houston.
Level II, Greenville, SC. PQT.
Level II, San Antonio, TX. BRL.

3–7 AUG
Level I, Atlanta, GA. ATS.
Level II, Anaheim, CA. Hellier Anaheim.
Level II, Brea, CA. Test.
Level II, Houston, TX. Hellier Houston.

6–7 AUG
Thickness, Digital Level II, San Antonio, TX. BRL.

10–14 AUG
Level II, Atlanta, GA. ATS.

11–15 AUG
PAUT Level I, Houston, TX. Hellier Houston.

11–16 AUG
Level II, Bangalore, India. Trinity.

13 AUG
Thickness, Digital Level II, San Antonio, TX. BRL.

17–21 AUG
Advanced Users Tomoview and Beamtool, Houston, TX. Hellier Houston.
PAUT Level II, Houston, TX. Hellier Houston.

24–28 AUG
Level I, Houston, TX. Hellier Houston.
Level II, New London, CT. Hellier New London.

31 AUG–4 SEP
Level I, Atlanta, GA. ATS.
Level I, Greenville, SC. PQT.
Level II, Houston, TX. Hellier Houston.

3–4 SEP
Thickness, Digital Level II, San Antonio, TX. BRL.

8–10 SEP
Thickness, Heath, OH. Mistras Central.

8–11 SEP
Level I, Brea, CA. Test.

9–11 SEP
Annex Q, Allentown, PA. WTTI.

9–13 SEP
Level II, Bangalore, India. Trinity.

11 SEP
Thickness, Digital Level II, San Antonio, TX. BRL.

14–18 SEP
Level II, Atlanta, GA. ATS.
Level II, Brea, CA. Test.
Level II, Greenville, SC. PQT.
PAUT Level I, Houston, TX. Hellier Houston.

21–25 SEP
Level I, San Antonio, TX. BRL.
PAUT Level II, Houston, TX. Hellier Houston.

28 SEP–2 OCT
Level I, Houston, TX. Hellier Houston.
Level II, San Antonio, TX. BRL.
Longitudinal Evaluation Level I, Palos Hills, IL. Moraine.

30 SEP–2 OCT
D1.1 and D1.5, Allentown, PA. WTTI.

Visual Testing

13–15 JUL
Level I/II, San Antonio, TX. BRL.

27–29 JUL
Level II, Bangalore, India. Trinity.

10–12 AUG
Level I/II, San Antonio, TX. BRL.

11–13 AUG
Level I/II, Greenville, SC. PQT.
Level I/II, Jacksonville, FL. PQT.

17–19 AUG
Level I/II, Houston, TX. Hellier Houston.

Online Education

The following are contacts for organizations offering online courses available any time. For course offerings and other information, please contact the organization.

AINDT: American Institute of Nondestructive Testing; Baxter, MN; 1-855-313-0325; instructor@trainingndt.com; trainingndt.com.

Chuck Hellier's NDT Classroom Inc.: William Cronberger; Buffalo, NY; 1-716-812-8165; email billc@ndtclassroom.com.

ETS Sistemi Industriali Srl.: Alberto Monici; Brugherio (MB), Italy; +39 039877790; email a.monici@etssistemi.it; etssistemi.it.

Global NDE Guru: S.B. Prasad; Houston, TX; 1-877-237-2858; email info@ndeguru.com or ndt@ndtcs.com; https://ndeguru.com.

Son Set Consultants Training LLC: Rick Gaffney; Owasso, OK; 1-918-633-0740; email sonsetconsultants@gmail.com; weld-procedure.com.

WorldSpec NDT Training, a division of Hellier NDT: Parker Ray; Houston, TX; 1-877-506-7773; email info@worldspec.org; worldspec.org.

calendar

Visual Testing, cont.

24–26 AUG
Level II, Bangalore, India. Trinity.

8–10 SEP
Level I/II, San Antonio, TX. BRL.

14–16 SEP
Level I/II, Anaheim, CA. Hellier Anaheim.

15–17 SEP
Level I/II, New London, CT. Hellier New London.

21–23 SEP
Level II, Bangalore, India. Trinity.

29 SEP–1 OCT
Level I/II, Portland, OR. NPI.

Short Courses/Topical Seminars

3–7 AUG
Auditing NDT Systems, Houston, TX. Hellier Houston.

10–14 AUG
API 1169, Houston, TX. CodeWest.

24–28 AUG
NDT Instructor Qualification & Development, Houston, TX. Hellier Houston.

24 AUG–3 SEP
API 510, Houston, TX. CodeWest.

14–18 SEP
Intro to NDT, New London, CT. Hellier New London.

21–25 SEP
Intro to NDT, Anaheim, CA. Hellier Anaheim.

Level III Examination Preparation/Refreshers

13–14 JUL
MT Level III, Brea, CA. Test.

13–17 JUL
Eddy Current Level III Refresher, Anaheim, CA. Hellier Anaheim.
UT Level III, Houston, TX.Kraft.
UT Level III Refresher, Houston, TX. Hellier Houston.

15–16 JUL
PT Level III, Brea, CA. Test.

20–24 JUL
Basic Level III, Houston, TX. Kraft.
Basic Level III Refresher, Houston, TX. Hellier Houston.
ET Level III Refresher, New London, CT. Hellier New London.
RT Level III Refresher, Houston, TX. Hellier Houston.

21–23 JUL
VT Level III Refresher, New London, CT. Hellier New London.

27–28 JUL
MT Level III Refresher, Houston, TX. Hellier Houston.

27–29 JUL
MT Level III, Houston, TX. Kraft.

29–30 JUL
PT Level III Refresher, Houston, TX. Hellier Houston.

29–31 JUL
PT Level III, Houston, TX. Kraft.

3–5 AUG
VT Level III Refresher, Houston, TX. Hellier Houston.

3–7 AUG
ASNT Basic Level III, Houston, TX. Hellier Houston.

10–11 AUG
MT Level III Refresher, Anaheim, CA. Hellier Anaheim.

10–12 AUG
ASNT UT Level III, Houston, TX. Hellier Houston.

10–14 AUG
PCMT Level I/II, BT Level I/II, and Level III Preparation, Orlando, FL. LTS.
RT Level II/III Film to Nonfilm Transition Training DR, Tualatin, OR. MPM.

12–13 AUG
PT Level III Refresher, Anaheim, CA. Hellier Anaheim.

13–14 AUG
ASNT MT Level III, Houston, TX. Hellier Houston.

17–21 AUG
Basic Level III Refresher, Anaheim, CA. Hellier Anaheim.
RT Level III Advanced Training DR, Tualatin, OR. MPM.

19–20 AUG
PT Level III, Greenville, SC. PQT.

19–21 AUG
Basic Level III, Greenville, SC. PQT.
MT Level III, Greenville, SC. PQT.
VT Level III, Greenville, SC. PQT.

24–26 AUG
ASNT RT Level III, Houston, TX. Hellier Houston.
ASNT VT Level III, Houston, TX. Hellier Houston.

27–28 AUG
ASNT PT Level III, Houston, TX. Hellier Houston.

31 AUG–4 SEP
UT Level III Refresher, Anaheim, CA. Hellier Anaheim.

31 AUG–1 SEP
PT Level III Refresher, New London, CT. Hellier New London.

2–3 SEP
MT Level III Refresher, New London, CT. Hellier New London.

9–11 SEP
VT Level III Refresher, Anaheim, CA. Hellier Anaheim.

14–18 SEP
Basic Level III Refresher, Houston, TX. Hellier Houston.
RT Level III Refresher, Anaheim, CA. Hellier Anaheim.

19–23 SEP
RT Level III, Greenville, SC. PQT.

21–25 SEP
Basic Level III Refresher, New London, CT. Hellier New London.
Infrared Best Practices Level III, Barre, VT. Snell.
UT Level III Refresher, Houston, TX. Hellier Houston.

28 SEP–2 OCT
ASNT Basic Level III, Houston, TX. Hellier Houston.
Eddy Current Level III Refresher, Anaheim, CA. Hellier Anaheim.
RT Level III Refresher, Houston, TX. Hellier Houston.

Calendar Entries

Please email all Calendar entries as soon as the information is available. While the Calendar runs only three months at a time, we encourage you to send us your meeting or course information as soon as you have it. The deadline for entries is the first of the month, two months prior to issue date (for example, the due date for the October issue is 1 August).

Send information by email, to the Assistant Editor, *Materials Evaluation*, cschaurer@asnt.org.

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NDE Perception and Emerging Reality: NDE 4.0 Value Extraction

by Johannes Vrana*

ABSTRACT

Up until recently, the industrial revolution was divided into three phases: (1) simple mechanization; (2) mass production; and (3) automation. Similarly, nondestructive evaluation (NDE) can be divided into three phases: (1) tools, such as lenses, sharpened the human senses; (2) the conversion of waves made the invisible visible by offering a "look" inside components; and (3) automation, digitization, and reconstruction enhanced the accuracy, speed, and ease of information sharing. During industrial development, although NDE has been decisively responsible for the quality of the manufactured goods and safety of operations, it has carried perceptions not commensurate with the value realized. Currently, industry leaders have been talking about a fourth revolution: the informatization, digitization, and networking of industrial production and the concurrent use of emerging technologies, such as artificial intelligence, augmented reality, and 5G networks. For NDE, this fourth revolution offers an unprecedented opportunity to address technical challenges and negative perceptions at the same time, leading to an enhanced appreciation of this significant discipline. The paper begins with a survey of professionals in the field to identify the perceptions surrounding NDE and moves on to demonstrate the value of integrating Industry 4.0 with NDE in the form of NDE 4.0 driven by connectivity and data mining. Building on that, this paper next presents the necessary basics and concepts, like semantic interoperability and the Industrial Internet of Things. Moreover, the key interfaces and data formats, like OPC UA and DIOCONDE, are discussed, and the International Data Spaces Association (IDSA), which goes one step further by ensuring data sovereignty, enabling data markets, and connecting the world, is introduced. The emerging reality of NDE 4.0 is that robust digital interfaces help create value, and statistical approaches combined with digital twins and threads help extract that value.

KEYWORDS: NDE 4.0, Industry 4.0, perception, AAS, digital twin, IIoT, OPC UA, DICOM, DICONDE, semantic interoperability

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Introduction

The term Industry 4.0 was created in 2011 and has led to an almost unmanageable number of activities over the past eight years (Kagermann et al. 2011). Thousands of people are working to make the dream of a networked industry come true, thanks to data transparency. As detailed later, data transparency is enabled by open standardized interfaces using semantic interoperability that allows easy, unhindered machine-readable data exchange between all machines, systems, and assets in industrial production and service. This enables, for example, users to reuse the data, to perform trend analyses, and to enable the use of artificial intelligence (AI). Therefore, data transparency is one of the cornerstones of Industry 4.0, both for data formats and for interfaces.

As an integral part of industrial production and operation, nondestructive evaluation (NDE) provides the quality assurance means required by industry. With the foundation of the German Society for NDE (DGZfP) committee "ZfP 4.0" in 2017, the American Society for Nondestructive Testing (ASNT) committee "NDE 4.0" in 2019, and the International

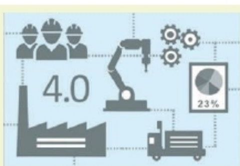
Committee for NDT (ICNDT) Specialist International Group "NDE 4.0" in 2019, the NDE industry reacted to developments in connection with Industry 4.0. In addition, the DGZfP subcommittee "Interfaces and Documentation for NDE 4.0" faces the challenge of defining the interfaces between NDE and industry in such a way that customers can process and interpret NDE results directly in their world (Vrana 2019b). The NDE sector will not succeed in giving the industry new interfaces. It is more reasonable to use Industry 4.0 interface developments and participate in the design in order to shape them for NDE requirements.

Watch the video
Welcome to the World of NDE 4.0

The Industrial Revolutions

The terms Industry 4.0, Industrial Internet of Things (IIoT), and digital factory are now ubiquitous, but what do they mean? Industry 4.0 is the fourth industrial revolution, the IIoT is one of the technologies that enables the connections necessary for the fourth revolution, and the digital or smart factory is the goal. The term "4.0" refers to the version numbering that is commonly used for software. The following is a brief overview of the four industrial revolutions (Table 1).

TABLE 1
The four industrial revolutions

Industrial revolutions		Revolutionary innovations	Key enablers	Technological basis	Leading country
 © Johann Jaritz	Handcrafting	n/a	Fire, tools	Muscle power	n/a
 © Wassily Frese	First industrial revolution	Simple mechanization	Steam engine, renewable energies	Coal, iron	England
	Second industrial revolution	New industries, mass production	Chemical and physical findings, production line	Electricity	Germany
	Third industrial revolution	Computers and automation	Digital technology, robots, drones	Microelectronics	United States
 © Franziska Vrana	Industry 4.0	Networking, data markets	Informatization, digitalization, networks, interfaces, digital communication, artificial intelligence, machine learning, 5G, quantum technologies	Software, computer science	?

The industrial revolution began in England in the second half of the 18th century and brought about change from handcrafted forms of production to the mechanization of production with steam engines or regenerative energy sources such as water.

The second industrial revolution was marked by the economic use of new chemical and physical knowledge and the beginning of new industries such as the chemical and pharmaceutical industries, electrical engineering, and mechanical engineering. It began at the end of the 19th century in Germany and led to the introduction of the assembly line (implemented in 1913 at Ford Motor Co.) and to new forms of industrial organization.

At the end of the 20th century, the development of microelectronics, digital technology, and computers ushered in the third industrial revolution, which allowed automated control of industrial production and revolutionized data processing in offices (for example, computers and laptops) as well as in private environments (for example, computers, mobile phones, and game consoles).

Watch the video
The Four Industrial Revolutions

All these developments were enabled by the emerging technologies of the particular period, were implemented to simplify industrial production, and allowed new and cheaper products. For example, the textile industry started during the first revolution and allowed everybody to afford clothing. However, multiple professions became unnecessary and working conditions were challenging. This, in the long run, resulted in the creation of trade unions, creating better and safer working conditions, more jobs, shorter workdays, longer life expectancies, and a higher living standard for everybody. The second and third revolutions helped to further build industries and made more products affordable (or enabled them, like a computer), but also made more professions and certain product categories unnecessary. However, in the long run, the second and third revolutions improved working and living conditions, created jobs, and resulted in a higher living standard, up to the point that a 40-hour work week and an expected lifetime of 80 years were now considered normal.

Watch the video
The Why of Industrie and NDE 4.0

New developments like informatization, digitization, digitalization, networking, and semantic interoperability (defined in the following paragraph) are changing/simplifying everybody's life and are enabling new products; for example, web mapping tools (like Google maps), self-driving vacuum cleaners or cars, intelligent virtual assistants (like Amazon's Alexa), cryptocurrencies (like bitcoin), and ridesharing companies (like Uber). New products like these can be seen as the first outcomes of the starting fourth industrial revolution.

The new developments are defined as follows:

- *Informatization* is the process by which information technologies, such as the world wide web and other communication technologies, have transformed economic and social relations to such an extent that cultural and economic barriers are minimized (Kluver 2000).
- *Digitization* is the transition from analog to digital.
- *Digitalization* is the process of using digitized information to simplify specific operations.
- *Networking* uses digital telecommunication networks for sharing resources between nodes, which are machines/assets/computers that use common wire-based or wireless telecommunication technologies. To allow straightforward communication between the nodes, it is best to use standard open interfaces. These interfaces will be discussed later in this paper.
- *Semantic interoperability* allows nodes to understand the received data and makes it machine readable.

The enablers for these developments, the emerging technologies of the fourth industrial revolution, include the following:

- new communication channels, such as 5G
- new computer technologies for evaluation, such as general-purpose computation on graphics processing units, single-board computers, special hardware for AI calculations, and quantum computers
- new ways to protect data from manipulation, such as quantum cryptography and blockchains

For example, consider the self-driving car. The car uses data from multiple sensors to determine its position and distance relative to other cars. Therefore, networks between all the sensors and the central computer must be established. By choosing open standardized interfaces, the car manufacturer only needs to implement the standard interface one time and afterward all sensors can be used. Moreover, due to semantic interoperability, the car knows that the sensor is measuring a distance and that it is located at the front of the car. In addition, the car obtains maps and traffic conditions from web mapping tools and gets information from the other cars in the vicinity, even if they were built by different manufacturers. All this combined information finally allows the car to map and travel to a predetermined waypoint.

This shows the necessity of standardized interfaces for all kinds of systems and sensors and ultimately leads to a situation where sensor manufacturers who insist on using their own proprietary interfaces will soon be out of business—even if they offer the best-suited sensor on the market.

A similar development occurs in industrial manufacturing. Manufacturing shops are starting to collect the data from all kinds of manufacturing and handling machines by installing sensors to monitor production and connecting enterprise resource planning and manufacturing execution systems to simplify, enhance, and secure industrial production in order to streamline supply chains and allow newer, cheaper, and safer products. In addition, the desire for these cyber-physical systems to make decisions independently is growing.

This results in the need for data transparency and the need for open standardized interfaces with semantic interoperability between all devices in the industry. To drive these developments, the term Industry 4.0 was created in the year 2011 (Kagermann et al. 2011). Within a very short time, especially in Germany, many projects and groups were created with the aim of standardizing development, like Platform Industrie 4.0 and the International Data Spaces Association (IDSA). Without them, the fourth industrial revolution cannot function. Similarly, the Industrial Internet Consortium (IIC) was established in the United States in 2014 to work on IIoT standards.

So, even from a hardware standpoint, the fourth industrial revolution uses the technical principles of the third revolution, but leads to a completely new transparency of information through the informatization, digitalization, and networking of all machines, equipment, sensors, and people in production and operation. Industry 4.0 enables feedback and "feedforward" loops to be established in production, the ability to determine trends through data analysis, and a better overview to be gained through visualization.

The first three industrial revolutions were declared by historians. The fourth, on the other hand, uses the term "4.0" to introduce it. For the reasons given previously, it might be appropriate to speak already of a fourth revolution. However, only history will show whether it is worthy of the name.

The Revolutions within NDE

Nondestructive testing (NDT) and NDE underwent a similar development compared to industry and can also be divided into four revolutions (Table 2). For the first industrial revolution, the basis was handcrafting that had developed over the millennia. For NDE, the basis is perception. Through their senses, people have been able to "test" objects for thousands of years. They looked at components and joints and smelled, felt, knocked on, and even tasted items to learn something about their condition and interior.

The first revolution, or the birth of NDT, took place partly through the introduction of tools that sharpened the human senses and partly through the standardization of testing procedures. Procedures (not necessarily in written form) made the results of the tests comparable, and tools such as lenses, colors, and stethoscopes improved detection capabilities. At the same time, industrialization also made it necessary to expand quality assurance measures.

The second revolution of NDE, like the second revolution of industry, is characterized by the use of physical and chemical knowledge and electricity. The transformation of electromagnetic or acoustic waves, which lie outside the range of human perception, into signals that can be interpreted by humans resulted in the ability to "look" into the components.

Parallel to industry, microelectronics, digital technology, and computers made the third revolution in NDT possible. Digital inspection equipment, such as X-ray detectors, digital ultrasonic testing (UT) and eddy current equipment, and digital cameras were developed, making it possible to automate inspection.

The fourth revolution could become the greatest for NDT, turning the entire business upside down. First, the Industry 4.0 emerging technologies can be used to enhance NDE technologies and NDE data processing ("Industry 4.0 for NDE"). Second, a statistical analysis of NDE data provides insight into reliability, inspection performance, training status, consistency, and value of inspections ("Human Considerations"). Finally, NDE is the ideal data source for Industry 4.0 ("NDE for Industry 4.0") (Vrana and Singh 2020).

As with Industry 4.0, the aim is to create new information transparency through informatization and networking. This will turn NDE from a niche product into one of the industry's most valuable sources of information. Just like in the area of Industry 4.0, this will require a standardization of interfaces and the disclosure of data formats. Companies can now decide whether they want to follow the course of Blockbuster, Quelle, or Karstadt, or rather follow Netflix and Google.

Watch the video
The Four NDE Revolutions

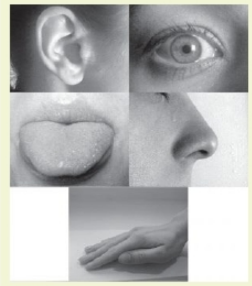
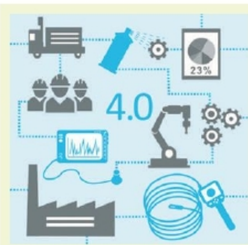
Challenges of NDE

To illustrate the benefits of NDE 4.0, a nonrepresentative survey on social media was conducted (Vrana GmbH 2019; Vrana 2019a). As the awareness of the benefits of Industry 4.0 and NDE 4.0 is not yet evident in practically any industry, the question was regarding criticism of NDE and inspectors. From this it can be determined how NDE 4.0 can help to master these challenges. A sampling of responses is listed below (to read all the responses, refer to Vrana GmbH 2019 and Vrana 2019a). They show a wide variety of challenges and identify some necessary improvements needed in the industry. Some of the answers might present stereotypes, but even stereotypes can contain a core truth. For a better understanding, the responses have been grouped and editorial comments within the answers are indicated by brackets. For a more detailed analysis of these comments, refer to the full study (Vrana and Singh 2020).

The following answers are related to criticism regarding education and morale in the NDE industry:

- "'NDE is not a skilled trade' is something I've heard over and over by some [people] in 'skilled trades.'"
- "Lack of process knowledge."
- "Lack of surface preparation."
- "Reference is not up to the mark."
- "Risk outcomes for miss-calls in NDE are higher, making it [a] more responsible and skill critical field whether it's aerospace, pipeline, or refinery work."

TABLE 2
The four revolutions of nondestructive testing*

NDT revolutions	Revolutionary innovations	Key enablers	Technological basis	
Perception	n/a	Simple tools	Human senses	 © Allan-Hermann Pool
NDE 1.0	Procedures	Optical elements, soot, oil, chalk, colors, stethoscopes	Procedures	 © BMB
NDE 2.0	"View" inside components	Chemical and physical findings, such as ultrasonic and electromagnetic waves (MT, ET, microwaves, terahertz, infrared, X-ray, gamma)	Electricity	 (Müller 1951)
NDE 3.0	Computers and automation	Digital technology, robots, drones, reconstruction	Microelectronics	 © VisiConsult
NDE 4.0	Networking, data markets	Informatization, digitalization, networks, interfaces, digital communication, artificial intelligence, machine learning, 5G, quantum technologies	Software, computer science	 © Franziska Vrana

*Developed in collaboration with Daniel Kanzler and Ripi Singh

- "Each NDE method's own limitations for defect characterization make it harder for techs to master all methods to find all anomalies. [A] UT expert may not confirm [their] finding by RT method since [they're] not [an] expert in RT, [making] it more specific to [an] individual with that skill. Which is hard for each tech to master all methods."
- "So many NDT inspectors who have not enough experience and little knowledge of welding making false calls."
- "I don't inspect chips [parts of components that will be removed in machining steps after NDT]."
- "Lack of ethics in certification/qualification/training of technicians."

The second group of responses is related to the external perception or criticism of the benefits of NDT, or comments addressed to examiners:

- "Many times, other engineers and project managers never include NDT engineering in planning because they believe they know everything there is to know about NDT. Many times, mindlessly prescribing methods that cannot detect the flaws or just throwing it in after planning with[out] even thinking. NDT Level IIIs and engineers should always be included in design and planning phases. This will save money [in] the long run."
- "Why don't you inspect at a different location?"
- "You mustn't look for indications in [the] area you expect defects."
- "You can use another method; then the findings are acceptable."
- "We don't need NDT—you only test [and introduce] flaws into the material."
- "NDT in civil engineering: 'We don't need NDT, the safety factors in design will cover any flaws (and probabilities will cover any uncertainties).'"
- "It's 'no value added.'"
- "Production brake."
- "Unnecessary cost factor."
- "NDT does not have any value at all. It only sorts out parts that in reality are good. I don't want it and I would never ever do it, but my customer insists on it."

As an NDE sector, these points must be accepted as a point of view, evaluated, and considered as opportunities for continual improvements in our field. The first group of answers is about training, morality, and reliability. These topics relate mainly to "Industry 4.0 for NDE" and "human considerations." "Industry 4.0 for NDE" could also be called emerging technologies for NDE and cover topics like the use of AI, machine learning, deep learning, big and smart data processing and visualization, cloud computing, augmented/virtual/mixed reality, blockchains, 5G, quantum computers, enhanced robotics and drones, and revision-safe data formats and storage for a safer, cheaper, faster, and more reliable inspection ecosystem. Human considerations include topics like management and leadership 4.0, digital transformation and organizational behavior, training and certification, standards and best practices, human factors, and human-computer interaction (Vrana and Singh 2020).

The second group of responses shows that NDE is seen by many as an unnecessary cost factor and relates mainly to "NDE for Industry 4.0." This paper focuses on NDE for Industry 4.0. Industry 4.0 for NDE and human considerations are not considered further in this paper.

NDE 4.0 is the chance for the NDE industry to free itself from this niche. Until now, NDE methods have "only" been used to search for indications in order to meet standards that many customers think are unnecessary. But NDE can do more. NDE offers a view into components and joints and is therefore an ideal database for use in digital engineering (Tuegel et al. 2017), better lifing calculations or fracture mechanical models (Vrana et al. 2018), the prediction of production problems, the improvement of production, and more. This must be used. For this purpose, however, the results of the inspection must be made available digitally so that customers can evaluate the results. It therefore requires standardized, semantic, manufacturer-independent interfaces and standardized open data formats.

This also requires a change of the thought processes for inspectors. Comments such as "I don't inspect chips" show that the concepts of Industry and NDE 4.0 need to be presented to inspectors. In the context of Industry 4.0, all information is important. Test results from areas that will later be machined also contain valuable information that can be used, for example, to improve lifing models (lifing analysis is the generic term for the lifetime calculation methods used in engineering, such as fracture mechanics or fatigue lifing).

Watch the video
What Is NDE 4.0?

Integration of NDE in Product Development, Production, and Operation

As indicated previously, NDE, as an integral part of the product development process, industrial production, and industrial operation, provides the quality assurance means needed by industry.

During the product development process (Figure 1), the specifications for production and inspection are created through the cooperation of experts from design, material sciences, production, and NDE. These are inspected to optimize design and inspections. The value of NDE can already be seen here, as NDE offers a look into the prototypes and can therefore make a significant contribution to improving design and production. This requires interfaces for the statistical evaluation of the data (together with the process data from the inspections).

The data that can be obtained during subsequent serial production and service provide an even better picture of the components produced and their joints. This allows further improvements in design and production. In addition, the data

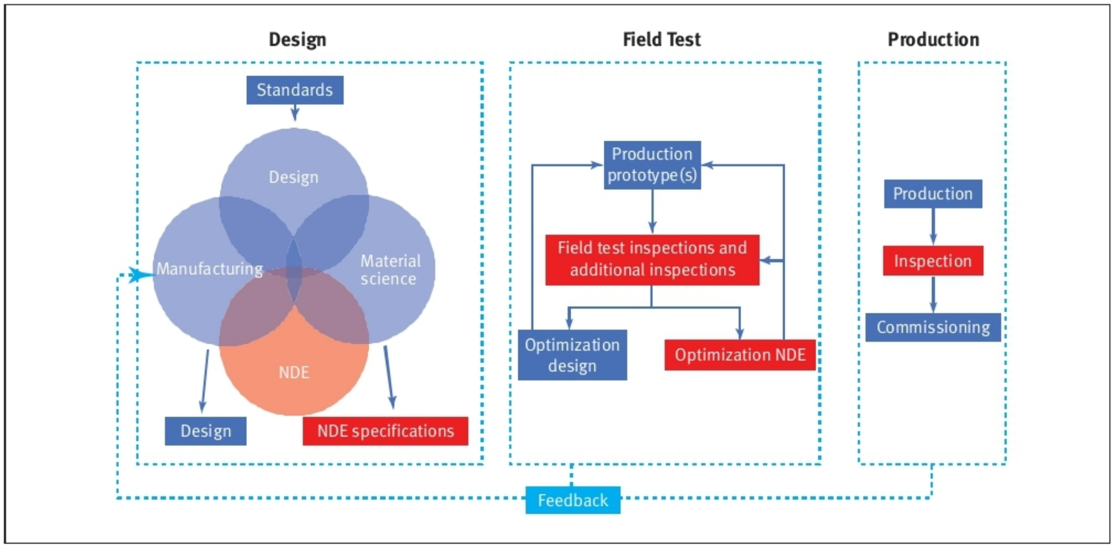


Figure 1. Typical product development process (© Vrana GmbH, used with permission).

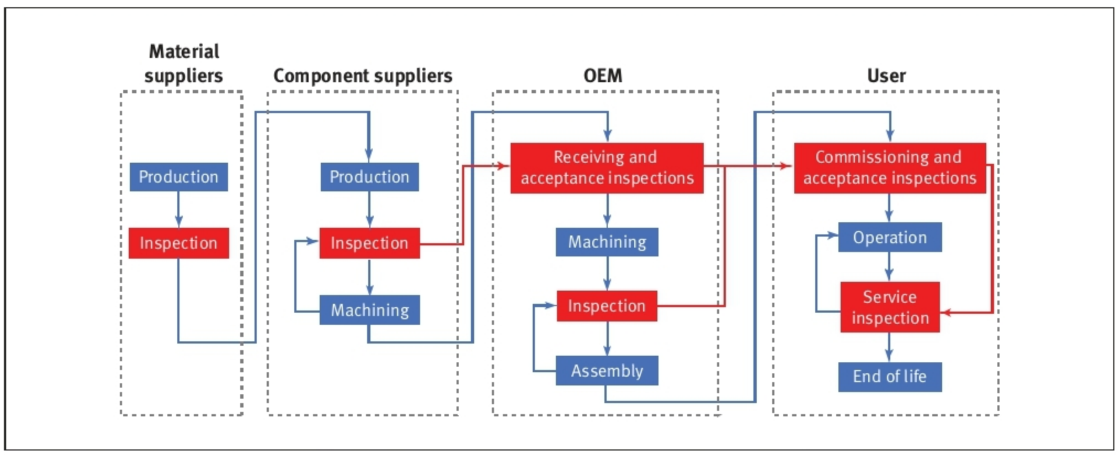


Figure 2. Typical supply chain with inspection steps in serial production. There could potentially be additional steps between component suppliers and OEM, like machining shops. (© Vrana GmbH, used with permission).

allow the next generation of products to be optimized in a "feedforward" fashion.

Figure 2 shows a closer look at serial production and inspection in the supply chain. It begins with material suppliers, who already carry out inspections on the raw material, continues through inspections at the component suppliers, and ends at the inspections conducted at the OEMs who assemble the final product and the in-service inspections during the use of the products. All of these inspections provide results that could be integrated into an Industry 4.0 world through appropriate interfaces and thus, as described previously, contribute to improving production and design.

Figure 3 shows the interfaces of each individual inspection step. The input interfaces marked in green (1) supply the order data; (2) provide the inspector with information on the component; (3) serve to correctly set the devices, the inspection, the mechanics, and the evaluation; and (4) document the results in accordance with the specifications.

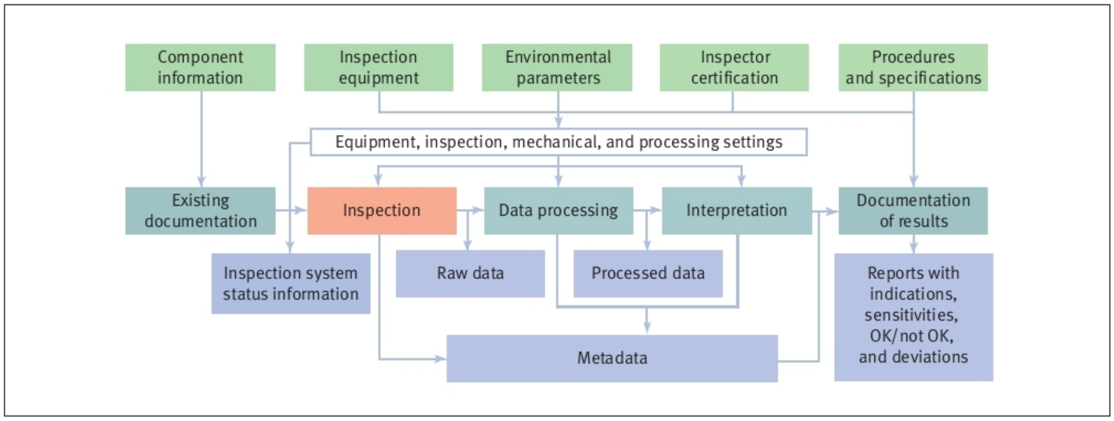


Figure 3. Typical sequence of an automated inspection in serial production (can also in principle be used for manual testing) (© Vrana GmbH, used with permission).

Digitalization of these input interfaces will help to support inspectors in their work by helping them avoid errors in inspection, optimize the inspection, and ensure a clear, revision-safe assignment of the results by means of digital machine identification of a component.

On the output side, the inspection system's status information and the inspection results are generated. The inspection system's status information could be used for maintenance and to improve the inspection system itself. The inspection results consist of the actual test data, the raw and processed data, the metadata (meaning the framework parameters of the inspection and evaluation), and, finally, the reported values. The reported values represent the key performance indicators (KPIs) of the inspection. For industry, interpreted data are the easiest to evaluate. Therefore, the reported values are usually the most relevant data obtained from the inspection. Consideration should be given to whether the currently reported values are sufficient for NDE 4.0 purposes or whether the results to be reported should be extended for statistical purposes and thus for greater benefit to the customer.

Automation Pyramid

In a digitized industrial production environment ("Industry 3.0"), the techniques and systems in process control are classified using the automation pyramid (Figure 4). The automation pyramid represents the different levels in industrial production. Each level has its own task in production, whereby there are fluid boundaries depending on the operational situation. This model helps to identify the potential systems/levels for Industry 4.0 and NDE 4.0 interaction (in particular regarding the beforementioned input and output parameters of an NDE inspection). However, validity of this model needs to be discussed in regard to Industry 4.0 and NDE 4.0.

The process level (bottom of pyramid) is the sensor and actuator level for simple and fast data collection. The field level is the interface to the production process using input and output signals. The control level uses systems like programmable logic controllers for controlling the equipment. Supervisory control and data acquisition of all the equipment in a shop happens at the shop floor level. Manufacturing execution systems (MESs) are usually used for collecting all production data and production planning at the plant level. Finally, enterprise resource planning (ERP) systems control operation planning and procurement for a company. Systems for product lifecycle management (PLM) are usually not included in the automation pyramid (as the automation pyramid visualizes the automation during production and not during the lifecycle of a product), but such PLMs are clearly connected to both the MES and ERP systems.

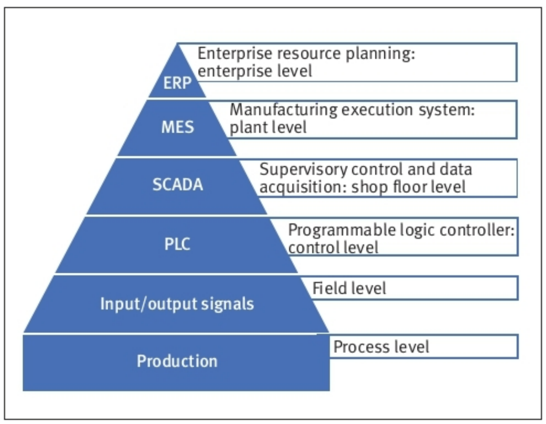


Figure 4. The automation pyramid (© Vrana GmbH, used with permission).

The information flow for the planning of production comes from the ERP system and is broken down to the field/process level (meaning the communication starts at the top level of the pyramid and is communicated down to the bottom level). Once production is running, the data are collected at the field/process level, then condensed into several steps (into the different levels), and finally the KPIs are stored in the ERP system (meaning the communication starts at the bottom levels of the pyramid and is communicated up to the top level). In order for this information to flow in both directions, interfaces need to be implemented between the levels. Depending on the number of systems or devices in a level, the number of interfaces needing to be implemented can be exhausting. This is why in a lot of production environments, analog (paper-based) or not-machine-readable digital (email or PDF) solutions are still used for certain interfaces between levels. However, such solutions require human action and are highly error prone (like errors that occur when entering the 10-digit serial number of a certain component). This already shows the need for standard, machine-readable interfaces.

In such an environment, the main interaction system for NDE is the MES system, as this is the point where all of the data from all of the equipment is combined.

However, the idea of Industry 4.0 is not only to collect and analyze the data from all devices and systems (including PLM), but also that every device and system (including all NDE equipment) is able to communicate with one another. All of this is independent from the levels shown in the automation pyramid (Figure 4). Therefore, not only do interfaces between two adjacent levels become necessary, but so do interfaces between all devices and systems throughout all of the levels. This would lead to an unmanageable number of necessary interfaces, and hence the implementation effort for all of these interfaces would prevent Industry 4.0. This is why standardized, open, and machine-readable interfaces become key for Industry 4.0 and why companies will have to shift from proprietary interfaces to standard interfaces if they want to survive the ongoing fourth industrial revolution. Looking at the member lists of the ongoing standardization efforts shows that most of the big players (for example, SAP, Microsoft, and Siemens) are beginning to understand this. Unfortunately, a lot of small- and medium-sized companies are still ignoring this development.

Digital Twins, Semantic Interoperability, and Data Security

Every asset (meaning every manufacturing device, sensor, product, software, operator, engineer, etc.), can be described in the virtual world with information like shape, type, functionality, material composition, operational data, financial data, interfaces, and more. All of this information combined creates a virtual representation—the digital twin.

Watch the video
The Idea of the Digital Twin

As discussed in the previous section, data for the digital twin comes from all levels of the automation pyramid including the MES for all manufacturing-related data, the ERP system for corporate data, and PLM for data from product development.

For creating digital twins and for all Industry 4.0 communication, it is important that the information is machine readable. It must be possible to interpret the meaning of the exchanged data unambiguously in the appropriate context. This is called semantic interoperability.

Watch the video
Semantic Interoperability using Ontologies and Information Models

With the semantic information stored in the digital twin, it will be possible to simulate the asset, predict its behavior, apply algorithms, and so on. A digital twin can also include services to interact with the asset.

User profiles and all user activities maintained by social media platforms or data stored about individuals by insurance companies, other businesses, or government can be seen as a part of a digital twin of a person. Already, the data stored by just one of those entities has quite some value. All the information combined in one digital twin would hold incredible value for certain entities but is a great threat for society, as it leads to transparent humans. This shows the need for data security and sovereignty.

Data security is a means for protecting data (for example, in files, emails, clouds, databases, or on servers) from unwanted actions of unauthorized users or from destructive forces. Therefore, data security is the basis for data-centric developments like the Industry 4.0 landscape discussed in this paper.

Data security is usually implemented by creating decentralized backups (to protect from destructive forces) and by using data encryption (to protect from unwanted actions). Data encryption is based on mathematical algorithms that encrypt and decrypt data using encryption keys. If the correct key is known, encryption and decryption can be accomplished in a short time, but if the key is not known, decryption becomes very challenging for current-day computers (requiring several months or years of calculation time). Therefore, the data is secured from unwanted access. However, with computers becoming increasingly more powerful over time, encryption keys and algorithms need to become more challenging. As well, data encrypted with old algorithms or keys that are too short need to be re-encrypted after some time to keep it safe. The only measure ensuring data encryption over time is to use keys that have the same length as the data to be encrypted and are purely random. One of the few methods to creating such keys is quantum cryptography, which is still quite expensive in installation.

Where data security is the necessary basis, data sovereignty goes one step further protecting data. Data sovereignty guarantees the sovereignty of data for its creator or its owner. Data itself, if not artistic, is legally not protected by any copyright. Therefore, currently if a dataset is submitted to somebody else, only individual contracts can hinder the receiver from forwarding or selling the data (even if it is submitted using data encryption). Therefore, two measures have to be implemented to guarantee data sovereignty: (1) legal documents need to be prepared; and (2) software and interfaces need to be implemented to restrict the use of the receiver in order to adhere to the rules of the submitter.

In the industrial world, data sovereignty is assured by measures like the ones discussed at the end of this paper. This enables the creation of reasonable digital twins, leads to added value, and creates new markets.

Industry 4.0 Asset Administrative Shell

Plattform Industrie 4.0 started the development of the Industry 4.0 asset administration shell (AAS) in 2015 (Plattform Industrie 4.0 2016, 2018). The AAS is the virtual representation of each asset—its digital twin. An asset can be a device, but also a component, a plant, an entire factory, a software, or even a person/operator/inspector.

Each AAS consists of a manifest and a component manager (Figure 5). The manifest is a table of contents that provides all of the information about the asset in the header. In the body, the manifest references all data stored by the asset and all functions that can be performed by the asset.

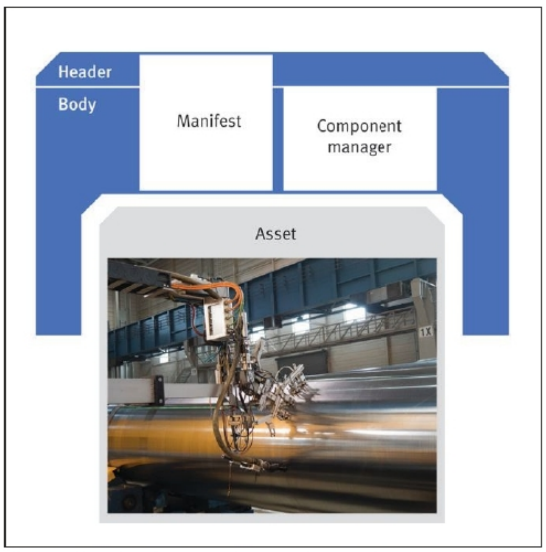


Figure 5. Industry 4.0 asset administration shell for an ultrasonic testing system (© Vrana GmbH, used with permission).

The manifest is defined in XML or JSON (Plattform Industrie 4.0 2018). The component manager contains the actual implementations and realizes the interaction, functionality, and high-performance data queries.

Each AAS and each individual asset must have a globally unique identifier (ID), which is stored in the header. The ID of the AAS is the ID of the type of component—for example, whether it is a drill or a conveyor belt. The ID of the asset is the ID of the instance—meaning whether it is drill 1, 2, or 25.

AASs may be nested within one another. The AAS for a production line can reference the AAS of the various processing machines, inspection machines, and so on. The AAS for an inspection system can, for example, contain the AAS for the mechanical drives, the sensors, and the actual test system.

People, such as operators or inspectors, are also represented by an AAS. For example, there may be an AAS for a Level III UT inspector specializing in the inspection of castings. This inspector receives the assigned task via a tablet or an augmented reality platform, and the results are stored digitally by the inspector. This shows that Industry 4.0 is not striving for a deserted factory. For Industry 4.0, networking is crucial, and results must be available digitally. It does not require automation. For some work steps, especially repetitive tasks, it makes more sense to use automated solutions. But for other work steps, a human being is more effective.

Interfaces

The introduction showed the need for standardized, vendor-independent interfaces, and the AAS provides a standardized virtual representation of each asset describing the functionality and interfaces offered by the asset. But what are the interfaces in this context? Is it the question regarding the physical interface? The question regarding USB, Wi-Fi, or 5G? The question regarding transmission control protocol/internet protocol (TCP/IP), hypertext transfer protocol (http), extensible markup language (XML), or OPC UA? Before further discussion, the term "interface" must be defined in more detail.

Open Systems Interconnection Model

The open systems interconnection (OSI) model (Figure 6) gives an overview of the different abstraction layers of digital interfaces and helps to select the interfaces that are decisive for NDE 4.0. The lowest level represents the physical connection, such as a cable or radio connection. The first OSI layer—the transmission of the individual bits—runs via this connection. The information to be transmitted is combined with transmitter and receiver addresses and other information in the data link layer to form frames. Information packets are "tied" in the network layer and combined into segments in the transport layer.

The layers above are the so-called host layers. The session layer is responsible for process communication. The presentation layer is responsible for converting the data from a system-independent to a system-dependent format and thus

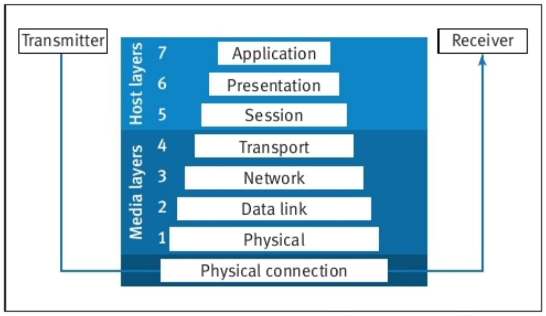


Figure 6. The OSI layers, a model for visualizing interfaces (© Vrana GmbH, used with permission).

enables syntactically correct data exchange between the different systems. Tasks such as encryption and compression also fall into this layer. Finally, the application layer provides functions for applications; for example, with application programming interfaces (API).

The application layer is the communication layer, which is decisive for Industry and NDE 4.0. However, semantic interoperability (not to be confused with syntactic) needs to be added on top for an appropriate Industry 4.0 communication. The physical connection (USB, WLAN, 5G, etc.) is irrelevant.

An example of an application layer protocol is health level 7 (HL7). HL7 is the protocol used in health care to ensure interoperability between different information systems. HL7 (besides DICOM, described later) should therefore be one of the interfaces for Medicine 4.0, and the communication can run over various physical connections. Other protocols such as OPC UA, data distribution service (DDS), or oneM2M are gaining ground in the industrial world.

Industrial Internet of Things

The Industrial Internet Consortium defines IIoT in its specifications. In Volume G5 (IIC 2018), Internet 4.0 interfaces are discussed. Those discussions are based on the Industrial Internet Connectivity Stack Model, which is similar to the OSI model. However, compared to the OSI model, it combines the three host layers into one framework layer. Based on this model, it compares the interface protocols OPC UA, DDS, and oneM2M with web services (Figure 7). Every interface protocol is considered a connectivity core standard, and the need for core gateways between the connectivity core standards is emphasized. This brings the benefit that every connectivity standard can be used, and the information can be combined using the gateways between the standards.

DDS is managed by the Object Management Group and focuses on low-latency, low-jitter, peer-to-peer communication with a high quality of service. It is data-centric and does not implement semantic interoperability. There are plans to integrate DDS into OPC UA in order to integrate OPC UA Publication-Subscribe (PubSub).

OneM2M is a connectivity standard used mainly for mobile applications with intermittent connections and low demands regarding latency and jitter. Semantic interoperability is planned.

Web services use http, known from the internet. It is primarily for human user interaction interfaces. Semantic interoperability can be reached using Web Ontology Language (OWL).

OPC UA, discussed in detail in the next section, is mainly used in the manufacturing industry. In contrast to DDS, it is object oriented and provides semantic interoperability.

For NDE applications, oneM2M could be of benefit for mobile devices. Web services are ideal for human-computer

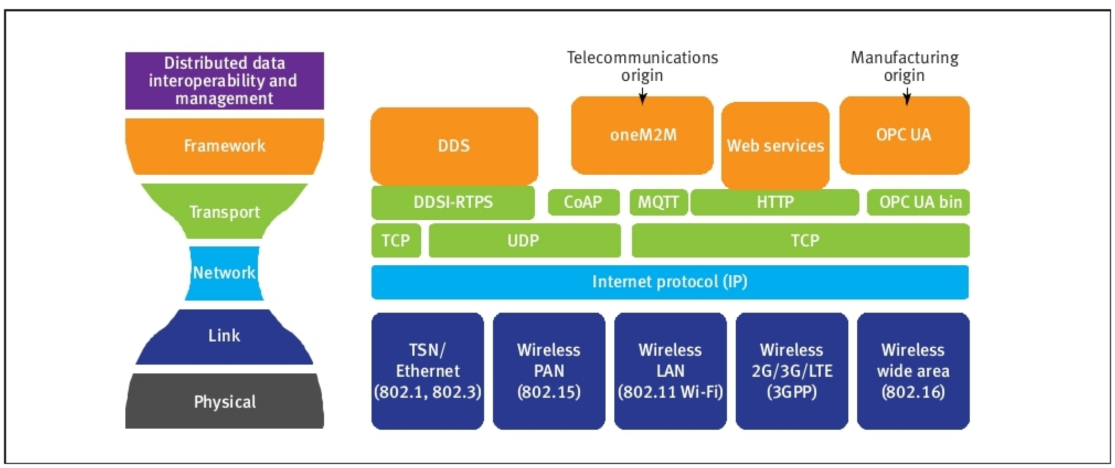


Figure 7. IIoT connectivity standards. OPC UA has a manufacturing origin and oneM2M a telecommunication origin, but both are now used for multiple industries, like DDS or WebServices. Transports that are specific to a connectivity standard are shown without any spacing between the framework and the transport layer boxes (IIC 2018, used with permission).

interaction and could be used for operator interfaces to store and read information regarding the component to be inspected. Low-latency and low-jitter communication is not necessary for typical NDE equipment; therefore, DDS will not be considered further. OPC UA, being the standard protocol for manufacturing and due to its included semantic interoperability, seems like the ideal interface for NDE 4.0.

OPC UA

The high-level communication protocol/framework currently established in the manufacturing Industry 4.0 world is OPC UA (OPC Foundation 2019a; IEC 2010–2019). OPC UA has its origin in the component object model (COM) and the object linking and embedding (OLE) protocol. OLE was developed by Microsoft to enable users to link or embed objects created with one program into another and is used extensively within Microsoft Office. COM is a technique developed by Microsoft for inter-process communication under Windows (introduced in 1992 with Windows 3.1). This standardized COM interface allows any program to communicate with another without having to define an interface separately. With the distributed component object model (DCOM), the possibility was created that COM can also communicate via computer networks.

Based on these interfaces, a standardized software interface, OLE for process control (OPC), was created in 1996, which enabled operating system independent data exchange (such as for systems without Windows) in automation technology between applications from different manufacturers.

Shortly after the publication of the first OPC specification, the OPC Foundation was founded, which is responsible for the further development of this standard. The first version of the OPC Unified Architecture (OPC UA) was released in 2006. OPC UA differs from OPC in its ability to not only transport machine data, but also to describe it semantically in a machine-readable way. At the same time, the abbreviation OPC was redefined as open platform communications.

OPC UA uses either TCP/IP for the binary protocol (OSI layer 4) or simple object access protocol (SOAP) for web services (OSI layer 7) (see Figures 6 and 7). Both client-server and PubSub architectures are supported by the OPC UA communication framework. Based on this, OPC UA implements a security layer with authentication and authorization, encryption, and data integrity through signing. APIs are offered to easily implement OPC UA in programs. In the .net framework, OPC UA is even an integrated component. This means that the users do not have to worry about how the information is transmitted. This is done completely in the OPC UA framework (referred to as "Infrastructure" in Figure 8). The only thing that matters is what information is transmitted.

As Figure 8 shows, the OPC information model already defines some basic core information models in which models are defined that are required in many applications. In addition, companion specifications exist for product classes

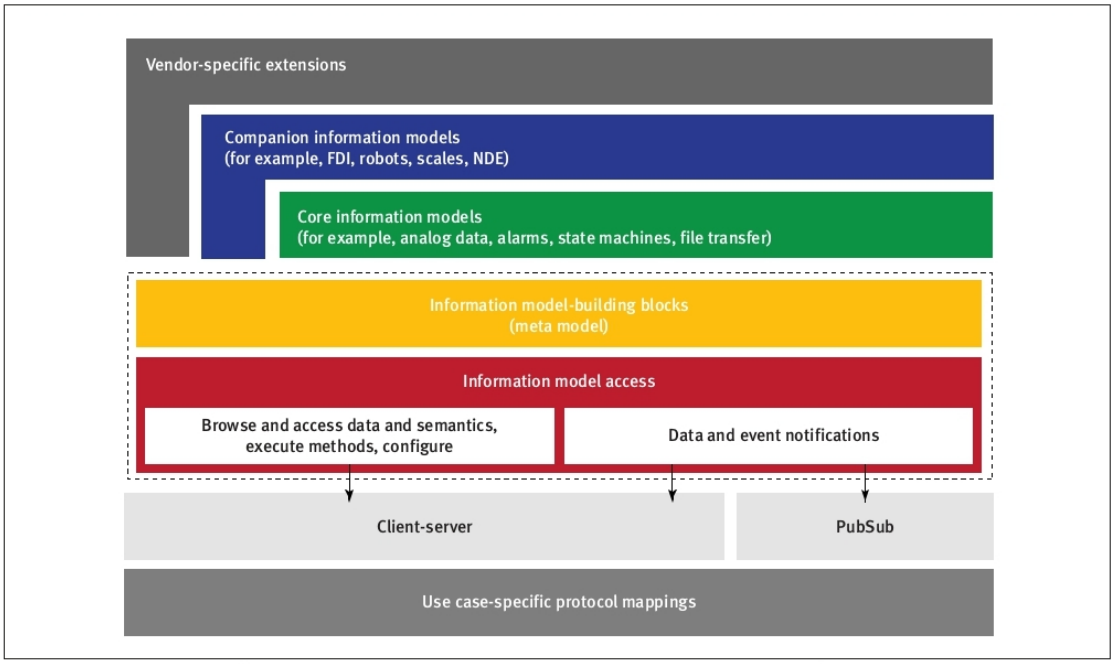


Figure 8. OPC UA architecture (© Vrana GmbH, based on OPC Foundation 2019b and used with permission).

such as field devices, robots, or scales. These companion specifications provide semantic interoperability and are therefore the basis for Industry 4.0, ensuring smooth Industry 4.0 interfaces and communication, and result in any OPC UA–enabled device being able to interpret data from others. In addition, there may also be manufacturer-specific specifications for the exchange of data between the devices of one manufacturer.

OPC UA PubSub integrates DDS into OPC UA to enable one-to-many and many-to-many communications. Moreover, the OPC UA time sensitive network will make it possible to transfer data in real time and to extend OPC UA to the field level. The OPC UA specifications are also currently being converted into national Chinese and Korean standards.

Moreover, it is planned to start the development of an NDE companion specification for OPC UA in a joint project between DGZfP, VDMA (Verband Deutscher Maschinen- und Anlagenbau, the German Mechanical Engineering Industry Association), and the OPC Foundation.

OPC UA is, like HL7 in health care, the standard for an interface to the manufacturing Industry 4.0 world. Similar to medical diagnostics, large amounts of data can be generated with NDE (in OPC UA, larger files are split into smaller packages—for example, the OPC UA C++ toolkit has a maximum size of 16 MB). Computed tomography, automated UT, and eddy current testing can easily result in several GB per day that need to be archived long-term. In the health care sector, large data files have resulted in the development of digital imaging and communications in medicine (DICOM) alongside HL7.

DICOM

DICOM is an open standard with semantic interoperability for the storage and communication of documents, images, video, signal data, and the associated metadata, as well as for order and status communication with the corresponding devices. This enables interoperability between systems from different vendors, which is what Industry 4.0 is striving for.

In health management, this leads to the necessity of interfaces between HL7 and DICOM (Figure 9). This interface is usually found in the picture archiving and communication system (PACS) server. In this process, patient and job data are translated from HL7 to DICOM for communication to the imaging devices. Information about the order status and provided services (such as "X-ray image of the lung"), as well as written findings and storage locations of the associated images, are communicated back. The returned data, texts, and references would usually be referred to in industry as KPIs.

The central system for the "process logic" in hospitals is the hospital information system (HIS) (comparable to an ERP system in industry), which communicates with all other systems via HL7. All image, video, and signal data are stored in DICOM format in PACS, which is designed to handle large amounts of data and serves as the central system for archiving and communicating the data.

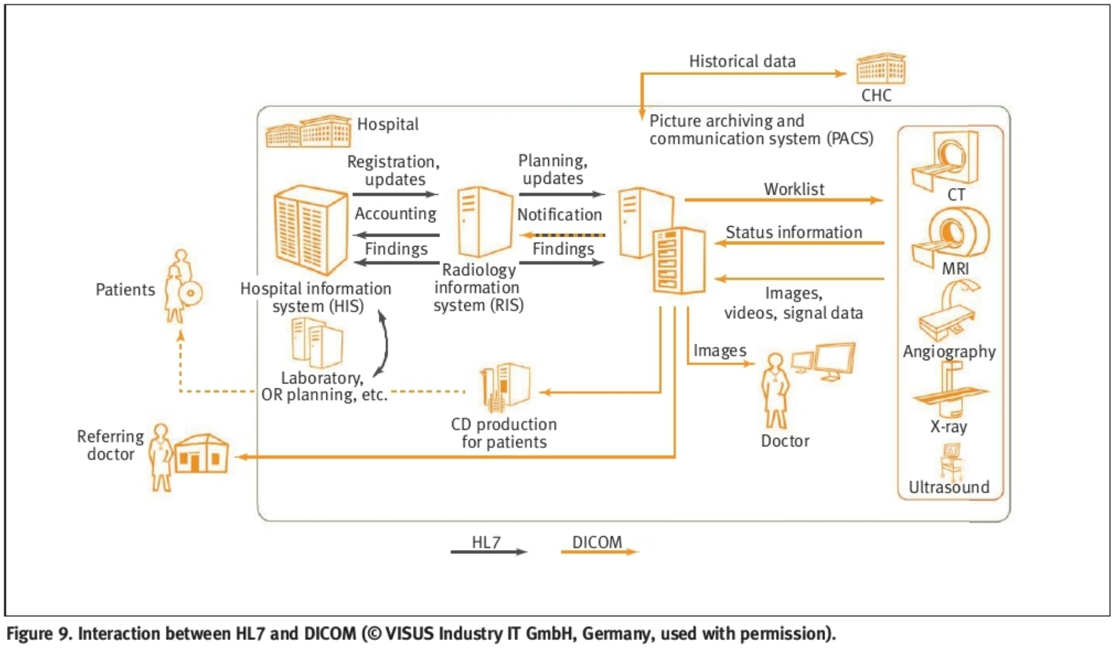


Figure 9. Interaction between HL7 and DICOM (© VISUS Industry IT GmbH, Germany, used with permission).

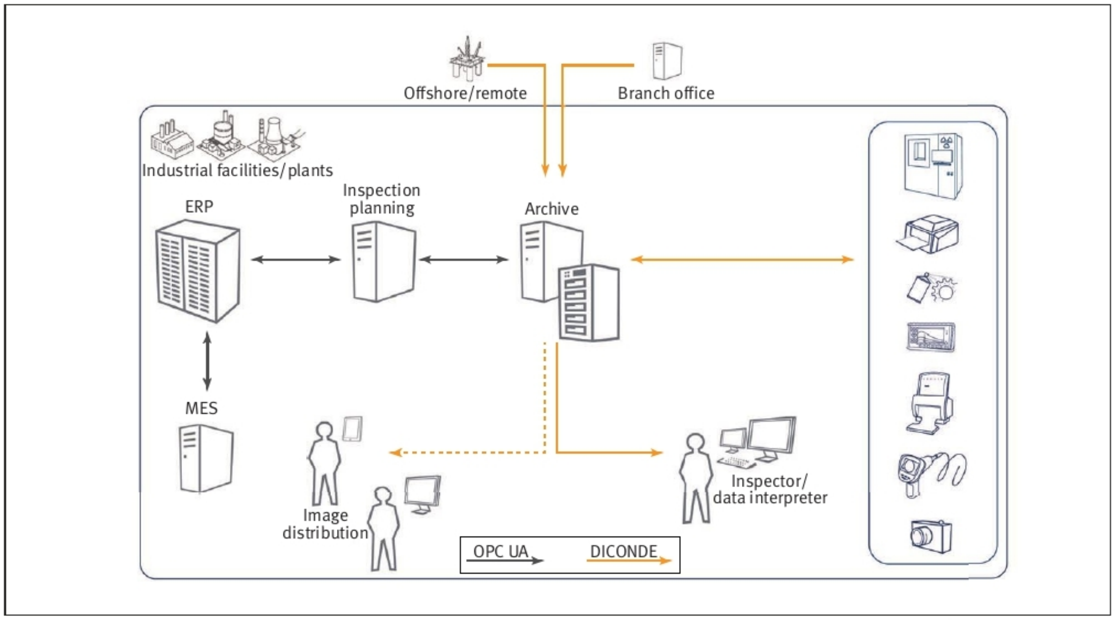


Figure 10. Possible interaction between OPC UA and DICONDE (© VISUS Industry IT GmbH, Germany, used with permission).

Digital Workflow in NDE with OPC UA and DICONDE

For the NDE world, this system can be transferred from HL7 and DICOM as follows (Figure 10): the Industry 4.0 world consists of ERP or MES servers for production planning or as a production control system, and assets supply data via OPC UA. A transmission of order data for inspections as well as a return transmission of notifications and inspection results (KPIs for storage in the MES) can be mapped via OPC UA. An integration of maintenance and calibration data from NDE equipment via OPC UA is also conceivable.

With a few exceptions, however, the raw data generated during tests are too large to be communicated via OPC UA. Like HIS in a hospital setting, ERP and MES are not designed for the administration, communication, and archiving of large amounts of images, video, or signal data, such as is generated via NDT techniques like radiographic testing (RT), computed tomography, UT, eddy current testing, and the total focusing method/synthetic aperture focusing technique. Therefore, it makes sense to store the raw data outside the OPC UA world in a revision-proof way. The DICONDE standard offers a protocol and data format offering semantic interoperability. DICONDE is based on DICOM and has been adapted by ASTM to the requirements of the various NDE inspection methods (ASTM 2015, 2018a, 2018b, 2018c, 2018d, 2018e). In RT, the DICONDE standard fits very well with the requirements of the users. There are already many manufacturers who store their data in the DICONDE format and have implemented the DICONDE communication interfaces; for example, for the digital query of inspection orders whose IDs are then automatically stored in the metadata of the DICONDE files. Thus, structural integrity between NDE raw data and ERP/MES is ensured. DICONDE is also currently established as the standard in the field of computed tomography. Similar to health care, an entity that "translates" order data and reported values between OPC UA and DICONDE makes sense.

For UT and eddy current testing, however, the medical requirements are further apart from the requirements of NDE. Although the DICONDE standard strives to define suitable data formats (ASTM 2015, 2018a, 2018b, 2018c, 2018d, 2018e), these are currently not supported by device manufacturers. It is necessary to clarify at which points the manufacturers see a need for action.

Contrariwise, DICONDE can be easily implemented for the connection of visual inspections, such as for photos in the field of liquid penetrant and magnetic particle testing, and videos of endo- and borescope tests.

Reference Architecture Model RAMI 4.0

IIoT, OPC UA, DICONDE, and the AAS are concepts for NDE 4.0. But how are they connected? What different tasks do they perform? And how can they be located?

The task of locating Industry 4.0 concepts is fulfilled by the Reference Architecture Model for Industrie 4.0

(RAMI 4.0) (DIN 2016), as illustrated in Figure 11. Unfortunately, RAMI 4.0 is quite abstract; however, it is one of the core models for Industry 4.0. Therefore, it is discussed briefly here.

RAMI 4.0 shows the Industry 4.0 world that it has to be completely covered by interfaces. With the help of RAMI 4.0, every Industry 4.0 standard, interface, protocol, administration shell, and asset can be described and located in a structured way. RAMI 4.0 also helps to clarify whether all necessary interfaces exist.

The "Life Cycle and Value Stream" axis shown in Figure 11 represents the value chain and life cycle of an asset, starting with the development and usage of a new type, through the production of the instance to the usage of the instance. The term "type" is used to identify a new asset type, such as a new X-ray inspection system. "Instance" refers to the test facilities that have actually been built.

The hierarchy levels correspond to the layers of the automation pyramid shown in Figure 4, except for the top level, "Connected World." The automation pyramid only covers communication within enterprises; however, for Internet 4.0 data exchange between companies, this layer needs to be included.

The architecture axis ("Layers") and the lowest layer ("Asset") in Figure 11 represents the physical object. The "Integration" layer is the transition layer between the physical and the information world. The "Communication," "Information," and "Functional" layers are abstraction layers to represent communication, and the "Business" layer describes the business perspective.

The Industrial Internet Reference Architecture, published by the Industrial Internet Consortium (2019), defines similar architecture layers compared to RAMI 4.0. However, it does not consider the other two axes.

Location of AAS, IIoT, OPC UA, and AutomationML to RAMI 4.0

Due to its three-axes design, RAMI 4.0 is the ideal tool to locate all Industry 4.0 concepts.

OPC UA, like most communication protocols, covers the information and communication layers for instances (not for types), such as the right half of the middle two layers in Figure 9. Moreover, the connected world and the enterprise level is not covered by OPC UA.

Due to its connection gateways between different connectivity standards, the IIoT Connectivity Framework covers the enterprise level, but not the connected world level.

AutomationML, an XML-based data format for storing and exchanging plant design data, covers the left half of the middle two layers in Figure 11. AutomationML therefore serves to describe the type of an asset.

The AAS sees itself as a virtual image—the digital twin—of each asset and thus as a link between all interfaces and protocols within the Industry 4.0 world. Projects for mapping between OPC UA, AutomationML, and AAS have begun and will be detailed in future publications.

Data Sovereignty, Data Markets, and Connected Internet 4.0 World

As shown in Table 1, the networking of industrial production through standardized interfaces and thus the storage and use of the resulting crosslinked data sets is elementary for the fourth industrial revolution. However, the linked data records also represent a value in themselves. Data itself becomes an

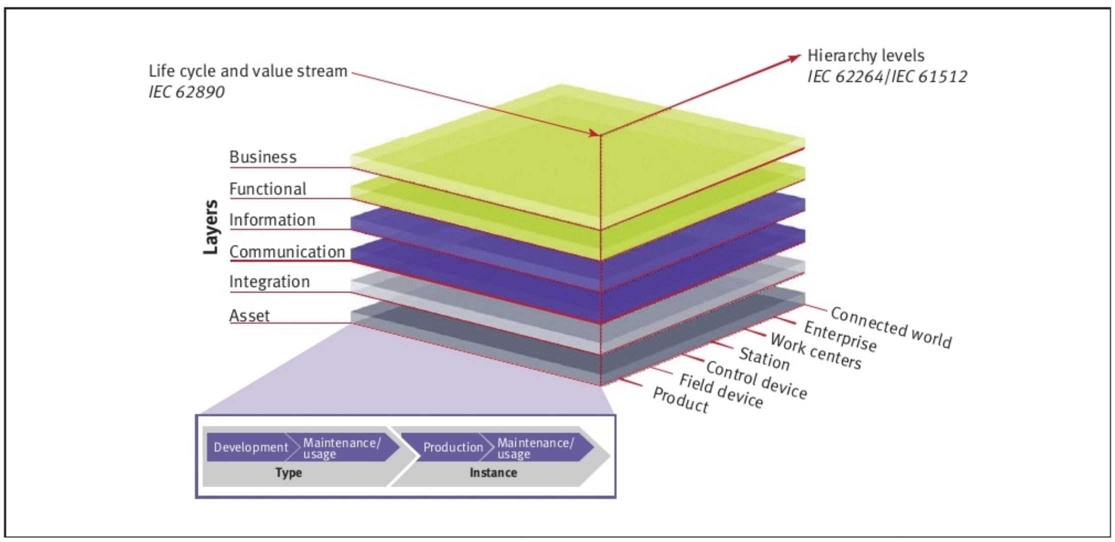


Figure 11. The Reference Architecture Model Industry 4.0 (RAMI 4.0) (© Platform Industrie 4.0, used with permission).

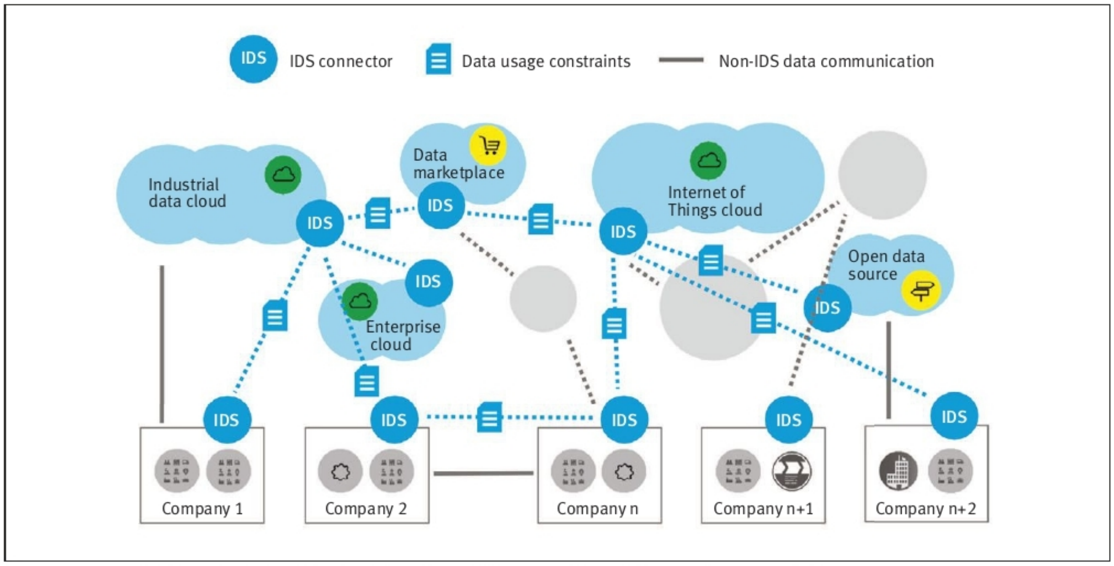


Figure 12. Connected Industry 4.0 world by the International Data Spaces Association (used with permission).

asset. There is a market for data, and it is important to use it. For NDE, the path to this market is through NDE 4.0 with the interfaces discussed in this paper. How to make this market safe and how to connect data between different companies is discussed in this section.

In the future, it will be possible to buy data, independent of suppliers. The aim is to prevent illegal data markets, to create data markets according to crucial values (like data privacy and security, equal opportunities through a federated design, and ensuring data sovereignty for the creator of the data and trust among participants), and to ensure that the companies who have generated the data also benefit from their value and not just a few large data platforms.

IDSA has set itself this goal. IDSA develops standards and de jure standards based on the requirements of IDSA members. IDSA also works on the standardization of semantics for data exchange protocols and provides sample code to ensure easy implementation.

One of the key elements that IDSA is implementing is the so-called IDS connectors (IDSA 2019), which guarantee data sovereignty (Figure 12). Both the data source and the data sink have certified connectors. The data provider defines data use restrictions. The data consumer connector guarantees that the restrictions are followed. For example, if the data provider defines that the data consumer is allowed to view the data once, the data will be deleted by the consumer connector after the data has been viewed. This also enables the producer of the data to decide which customer can use their data in which form. Due to these connectors, IDSA enables the connected world as required by RAMI 4.0.

For many, marketing the data will be a new business model. For NDE, it is an opportunity to move from the position of being perceived as an "unnecessary cost factor" to becoming a major data supplier. This will create a new, larger business case.

In order to help shape this development and equip NDE for the data market, DGZfP recently became a member of IDSA.

Summary and Outlook

With the AAS, IIoT, OPC UA, WebServices, AutomationML, and IDSA, protocols and interfaces have already been created in the industry to implement "NDE for Industry 4.0." In order to make NDE an integral part of the Industry 4.0 world, cooperation is required. Firstly, ontologies must be created for OPC UA (Companion Specifications), for web services (OWL), for AutomationML, and for the AAS to assure semantic interoperability. On the other hand, there is the task of guaranteeing the requirements of the NDE industry in IDSA.

With DICOM/DICONDE, there is an advanced interface and a well-developed open data format available. DICOM/DICONDE already offers semantic interoperability, and its standardized and open ontology can be used as a base for the NDE ontologies for the standard Industry 4.0 interfaces mentioned in the previous paragraph.

For NDE technologies with large data volumes, DICONDE is an ideal addition to the industrial interfaces (similar to the combination of HL7 and DICOM). This means that interfaces/mappings from DICONDE to the

Industry 4.0 world (OPC UA) are needed. For NDE technologies with small data volumes, it is necessary to decide, depending on the application, whether a direct interface is created using OPC UA or whether these are first stored in the DICONDE world and then transferred to the OPC UA world, in order to summarize all test results in one place. In addition, it is necessary to check which steps are required to be able to use DICONDE for UT and eddy current testing.

In general, a revision-safe and secure storage must always be ensured. The retrievability, integrity, and sovereignty of the data is key. Most of these requirements are already implemented in DICONDE and OPC UA.

Other open data formats for NDE data, like HDF5, can be viewed as alternatives to DICONDE. However, for most inspection situations, the standardized open information models of DICONDE, which enable machine-readable data using semantic interoperability, surpass the information models of the other data formats. Also, revision-safe and secure data storage needs to be implemented.

In order to ensure the interests of NDE in the Industry 4.0 world and for the development of the necessary ontologies, cooperation with Industry 4.0 must be strengthened.

NDE 4.0 represents a chance for NDE to move from the niche of the "unnecessary cost factor" to one of the most valuable data providers for Industry 4.0. However, this requires the opening of data formats and interfaces. The protectionism that companies previously adhered to will now have a damaging effect on business in the foreseeable future. For companies that recognize the signs of the times, NDE 4.0 presents a completely new business model for the industry via the data market.

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NDT 4.0: Opportunity or Threat?

by Lennart Schulenburg*

ABSTRACT

There is no doubt that the world currently is in the midst of a technology-driven transformation that is evidenced in our everyday lives via technical advances like self-driving cars and artificial intelligence. The world around us is changing at a rapid pace, and this also affects the way we produce nearly everything. Entire industries are transformed, resulting in major implications for professionals in many fields. This transition is so compelling that it has been named "Industry 4.0," the fourth industrial revolution. A variety of disruptive factors are compounding one another and have a massive impact on the status quo. These include robotics, big data, additive manufacturing, integrated systems, augmented reality, cloud computing, the Internet of Things, and much more. The NDT industry cannot escape these fundamental changes. Nearly all methods are impacted—some more, others less. Therefore, the question arises: Is this an opportunity or a threat? This paper will explore these fundamental shifts using some specific examples from the field of radiography, as this is the field of expertise of the author. Also, the radiographic testing method is among those that will see the biggest changes caused by the new technology, as we have already seen in the medical realm.

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KEYWORDS: NDT 4.0, connected computer systems, cloud utilization, Internet of Things, IoT, smart factories, big data, artificial intelligence, AI, autonomous robots, predictive maintenance, additive manufacturing

Introduction: What Is Industry 4.0?

The concept of NDT 4.0 (Vaidya et al. 2018) is simply a subset of change sectors that are driven by the far bigger movement of Industry 4.0. It is important to understand where the term comes from (Epicor 2020). Figure 1 shows the different phases. The first industrial revolution happened between the late 1700s and early 1800s. During this period, manufacturing evolved from focusing on manual labor performed by people to a more optimized form of labor by using water and steam-powered engines in addition to other types of machine tools. In radiographic testing (RT), this phase is represented by the status of using analog film and isotopes.

In the early part of the 20th century, the world entered the second industrial revolution with the use of electricity in factories. The introduction of electricity enabled manufacturers to increase efficiency and helped make factory machinery more productive. It was during this phase that mass production concepts, such as the assembly line, were introduced to boost productivity. The legacy of the Ford Motor Co. is a great example of that period. In RT, the noteworthy changes in this phase would be the incorporation of electric components in order to improve the process and workflow. Particularly, this goes along with the usage of X-ray tubes that replaced the use of isotopes, simple manipulators, and automated film developers.

Starting in the late 1950s, a third industrial revolution slowly began to emerge as manufacturers began incorporating more electronic—and eventually computer-based—technology into their factories. During this period, manufacturers began experiencing a shift that put less emphasis on analog and mechanical technology and more on digital technology and automation software. Within the RT world, this phase is characterized by the transition to digital detectors, numerical

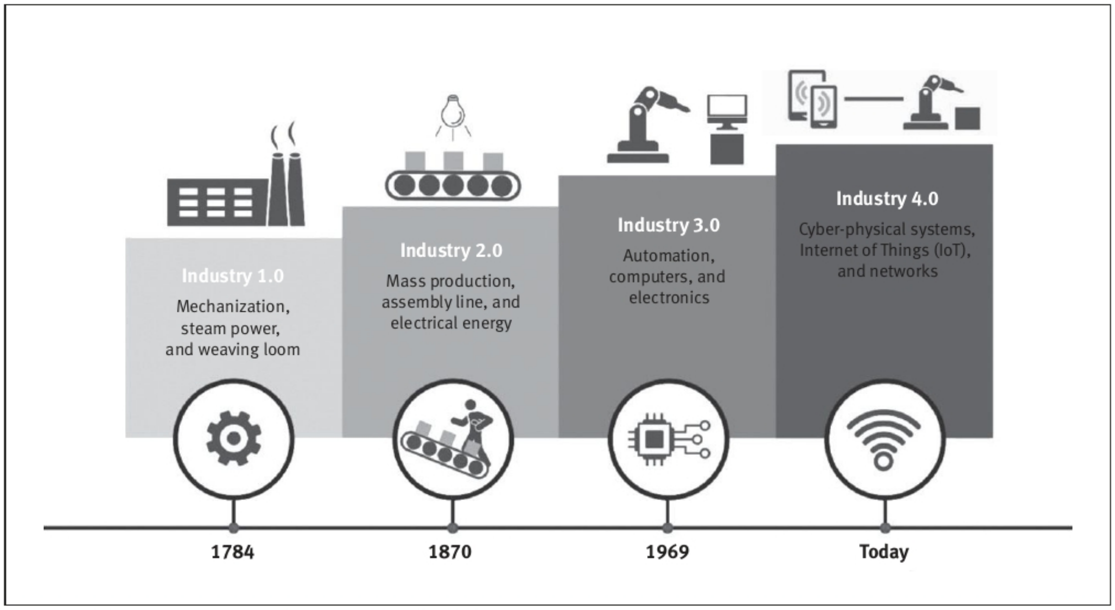

Figure 1. Defining innovations of Industry 1.0 through Industry 4.0.

control (NC) programmable manipulators, digital archiving systems, and robotics. This phase is often confused with the fourth phase. It is very important to note that a robot and an ERP connection alone are not enough to qualify as an NDT 4.0 system. Figure 2 shows such a system.

Figure 2. Typical example of an X-ray cabinet of the third industrial revolution, equipped with computer numerical control (CNC) drives.

The fourth industrial revolution is characterized by connected computer systems, cloud utilization, the Internet of Things (IoT), smart factories, big data, artificial intelligence (AI), autonomous robots, predictive maintenance, and additive manufacturing (AM). The adoption of these technologies is leading to substantial improvements in productivity and efficiency. As this implementation is not merely an "evolution" but rather a "revolution" of the traditional manufacturing paradigm, it is widely considered as disruptive. Within the nondestructive testing (NDT) world, this results in fully integrated in-line systems, cloud connectivity, usage of AI for interpretation, and advanced analytics. High performance gains have been realized by the integration of NDT directly into the manufacturing line. Self-adapting systems allow automation to be used even on very small batch sizes. Discontinuities and defects are automatically detected and compared against inspection criteria using automated defect recognition (ADR) systems, and computed tomography (CT) is used to three-dimensionally reconstruct objects and to perform complex analysis (VisiConsult 2020a).

This means that NDT professionals on the shop floor face fundamental challenges and may have a steep learning curve ahead, as these new tools often require a different approach and perhaps even a completely different skill set (IFR 2018). Digital skills and know-how become more important than ever. Managing this change is the key for future success and competitiveness.

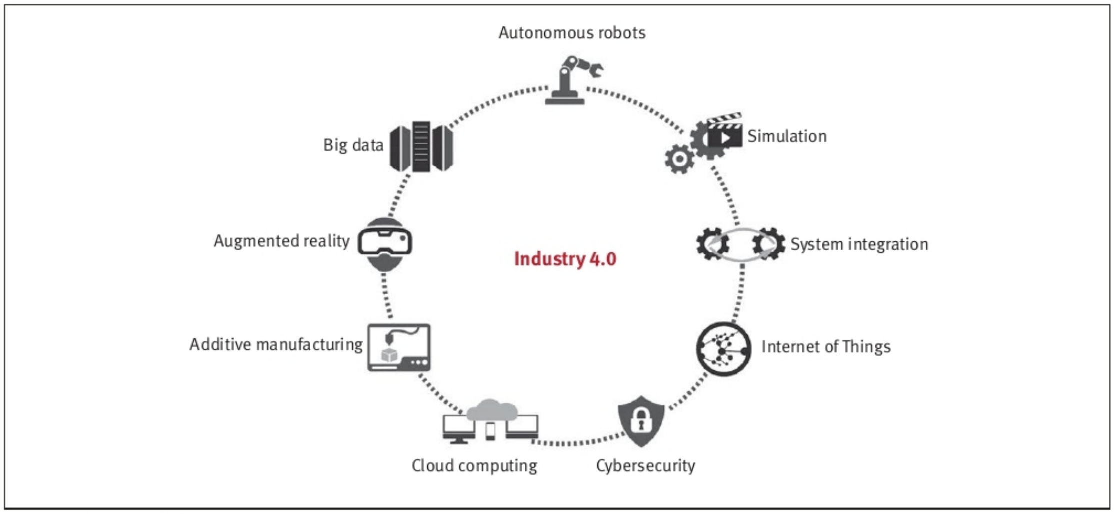

Figure 3. Different fields of Industry 4.0.

NDT + Industry 4.0 = NDT 4.0?

Figure 3 shows the different fields of Industry 4.0, which also apply to the NDT sector (Singh 2019). This section will assess some of them and will provide real examples of how they already impact NDT today. Due to space constraints, this assessment cannot be holistic, but it should provide a good overview.

Robotics

First, we will investigate robotics and simulations that allow repetitive handling tasks to be automated. This enables higher throughput, lower inspection costs, and higher process safety. Figure 4 shows an example solution where three robots work jointly to inspect airducts and pipes used in the aerospace industry. This team of robots collaborate together, sharing the tasks of part handling and inspection. This way, cycle time is effectively reduced from several hours to several minutes. When an operator wants to inspect a part, a barcode is scanned and the system automatically loads the applicable parameters and part holders. This results in a healthier work environment for operators, where heavy and potentially dangerous tasks are performed by machines.

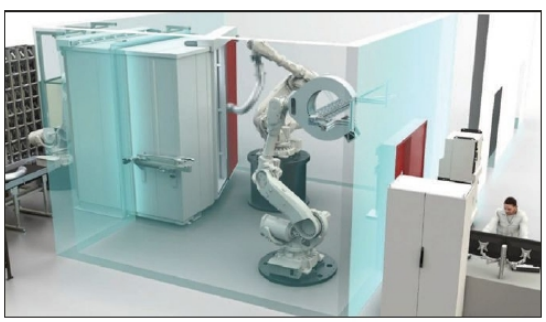

Figure 4. Inspection by inline robots.

All images are archived under a serial number and full traceability is given. Image quality is always supervised as the system performs automatic long-term performance evaluations according to *ASTM E2737* (ASTM 2018). New programs can be programmed offline, including the option to use a CAD/CAM simulation tool, so that the system can be utilized 100% for production and does not need to be shut down for engineering purposes, thereby significantly increasing system utilization and throughput. To further optimize the process, X-ray technicians can simulate the X-ray images digitally before even loading the part into the system. This allows operators to easily check the inspectability of the part and establish the right X-ray parameters very early in the process. Figure 5 shows a real X-ray and a simulated image. It is clear to see that the results are very closely correlated.

The usage of robotics is enabled through the introduction of digital detectors that replace traditional X-ray film. This shows clearly how the single steps of the industrial revolution are building on one another. Without digitizing the image acquisition process, the improvements represented by robotics alone would be marginal. This is a great reminder of the incremental nature of implementation. For companies that want to enter the age of NDT 4.0, it is important to analyze the status quo and then create a clear roadmap where innovations are introduced in a meaningful sequential order.

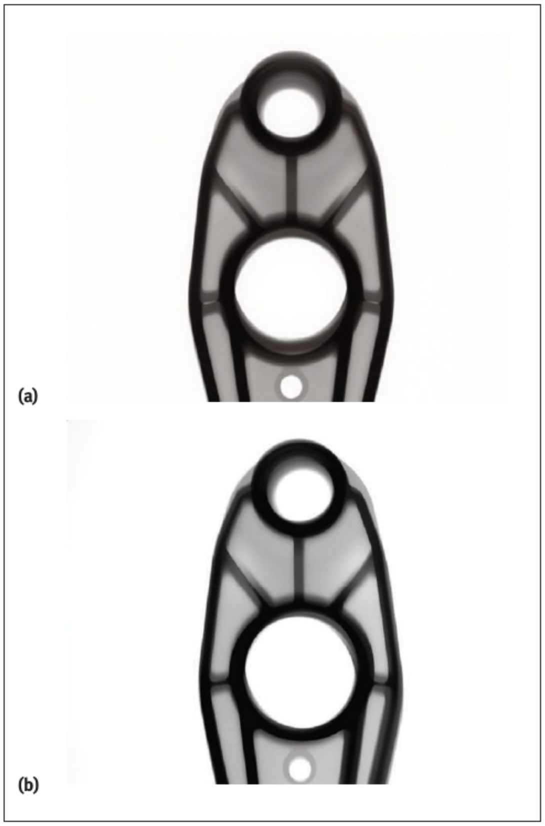

Figure 5. X-ray image of a part: (a) simulated; (b) real.

AI and Big Data

Another significant focus of Industry 4.0 includes AI and big data. These concepts are realized, for example, as ADR in radiography (VisiConsult 2020b). Indications like porosities, cracks, and inclusions are automatically detected, measured, and evaluated against the inspection criteria. Already widely adopted by the automotive industry, the author absolutely foresees other industries like aerospace following in these automation footsteps. During this revolution, it often makes sense to adopt an assisted defect recognition strategy, where an AI implementation supports the human operator by cross checking or aiding in the decision-making process (Perner et al. 2001).

This approach is also called supervised learning in data processing, and it allows rapid training of the underlying AI system. As soon as sufficient data is collected that can be correlated to decisions by the operator, the AI software can build the required proof for qualification of the ADR system by using probability of detection (POD) methods (Kurz et al. 2013). With increasing computational power, AI reveals its power. Figure 6a shows an example where ADR was used to evaluate a digital radiograph of an automotive casting.

In order to implement automated evaluation algorithms based on AI, one needs to have a huge amount of data that can be used to train the neural networks and to perform machine learning. Therefore, it is highly recommended that companies start to collect and archive as much data as possible. In our case, this would be X-ray images along with the decision and discontinuity classifications. Before starting this process, it is important to consult with a subject matter expert in the field of image processing about establishing suitable data formats to make sure the data is machine readable. Typical neural networks require thousands of images to be trained and verified.

Additive Manufacturing and CT

Additive manufacturing (AM) means that parts are manufactured layer by layer rather than by subtractive means. One example would be parts that in the past have been carved out of blocks through computer numerical control (CNC) milling machines (subtractive manufacturing) and can now be built in an additive way using 3D printers. Typical materials include different metals and plastic. AM also allows users to build futuristic shapes through generative design. The downside of these capabilities is that AM parts have a huge need for inspection. Due to the novelty of the manufacturing process, the industry is still lacking proven NDT standards, which are currently under development by ASTM and other committees.

When looking into the inspection of AM parts, RT plays a large role. Industry experts have stated that CT is one of the leading technologies that can sufficiently inspect complex AM parts and qualify them for safety-critical environments (du Plessis et al. 2020). Figure 6b shows a scan of a tensile probe; the upper part shows the horizontal cross-sectional view, and the lower part shows the vertical cross-sectional view. By acquiring substantial amounts of digital radiographs and computing them into a 3D model, we can gain information about parts like we have never been able to before. It is also possible to conduct advanced analyses like actual-nominal comparison, porosity analysis, and metrology. With increasing computational power, we currently see CT moving from a lab environment to the shop floor. This allows the implementation of in-line CT systems that perform a 100% inspection of parts while at the same time checking the geometric tolerances.

AM also plays an additional role in NDT. For many inspection methods, there is a need for precise fixtures and part holders. These objects can be easily manufactured through plastic AM printers. For many years, foam blocks and other crude tools have been used to position parts in the X-ray beam. By using 3D-printed fixtures, the setup time can be reduced significantly. This technology has been widely adopted, as entry-level plastic 3D printers are affordable and easy to use these days.

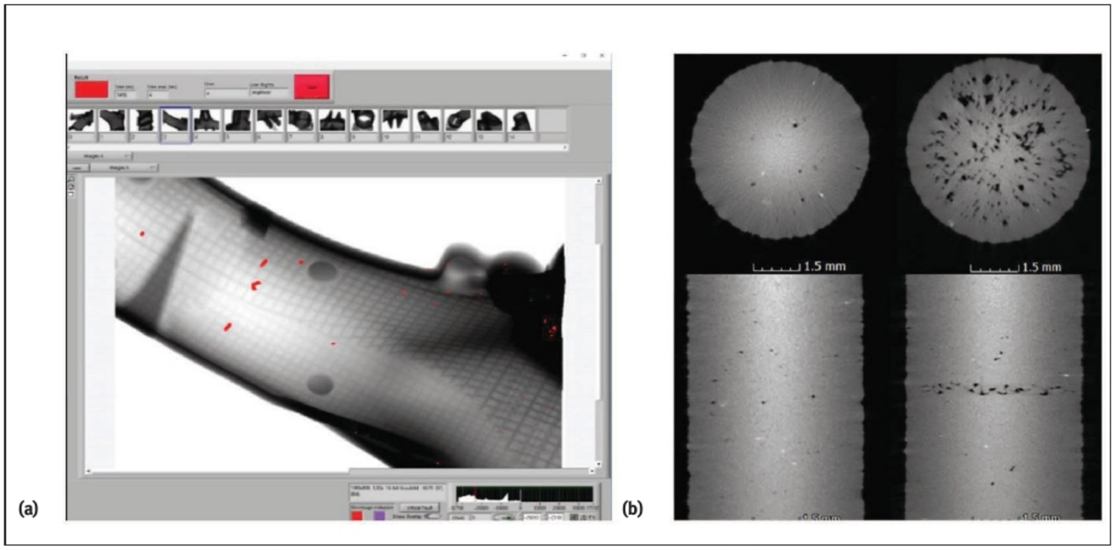

Figure 6. Examples of automated defect recognition (ADR) on an additive manufactured part: (a) digital radiography; (b) computed tomography.

Digitalization: Cloud and Connectivity

With today's technology, it becomes possible to connect nearly everything: system to remote viewer; systems to other connected systems; systems in different factories; and, if desired, even complete connected factories around the globe. Today it is possible to have image acquisition done locally (computer scientists call it "the edge") and interpretation centralized in an excellence center. This could be a solution to compensate for the lack of qualified personnel that many companies face or for temporary imbalances of workloads. Standardized interfaces on machine communication like OPC UA (OPC 2020) allow systems to interact, while standardized data formats like DICONDE (Voelker 2003) allow interoperability between devices from different manufacturers. Currently, NDT is often seen only as a means for ensuring quality, but it can provide so much more information.

As an example, consider a casting company where every 20 s one aluminum casting is manufactured. Sometimes process parameters get out of bounds, and parts with discontinuities (porosities, for example) are produced. The company performs digital RT to prevent these parts from being delivered. In the past, the X-ray inspection has been done by an operator at the end of the line with a substantial delay of hours and even sometimes days between casting and inspection. By implementing an in-line X-ray system with ADR directly into the manufacturing line and thereby bringing the stations much closer together, the manufacturer gains many improvements. It ensures that fewer value-added steps are being performed on parts with defects, and more importantly, the X-ray system can communicate with the casting system to "warn" of increasing scrap rates or, even better yet, communicate directly with the appropriate process to enable automatic correction. This way, the casting process can be corrected in order to get back to the desired quality. Now NDT has just saved the company a lot of money, while at the same time fulfilling its main purpose of preventing the delivery of parts with defects.

All the different fields of Industry 4.0 promise significant gains in efficiency, but the effect is compounded even more if they are combined. Let's assume that a supplier of aerospace castings has digital X-ray systems in factories A and B, and let's say that there is a lack of qualified inspection personnel in that region. As currently ADR is not approved by the customer, the manufacturer decides to transfer all images to factory C, which is its NDT excellence center. Image interpretations are performed centrally for all other locations. At the same time, it is ensured that there is a baseline for inspection quality. All data is archived in a local data center, and an AI system is constantly being trained in the background. The smarter the system gets, the more help the interpreters/inspectors get, which further improves the image evaluation quality, while the goal is to statistically prove that the POD of the AI algorithms is good enough to be implemented. This simple scenario shows the powerful impact that robotics, cloud connection, system integration, and AI can have on our industry.

Figure 7 shows an example of a fully integrated workflow, which forms a so-called cyber-physical loop. The physical is represented by the X-ray system and robotic automation, while the digital is represented by the database backend and

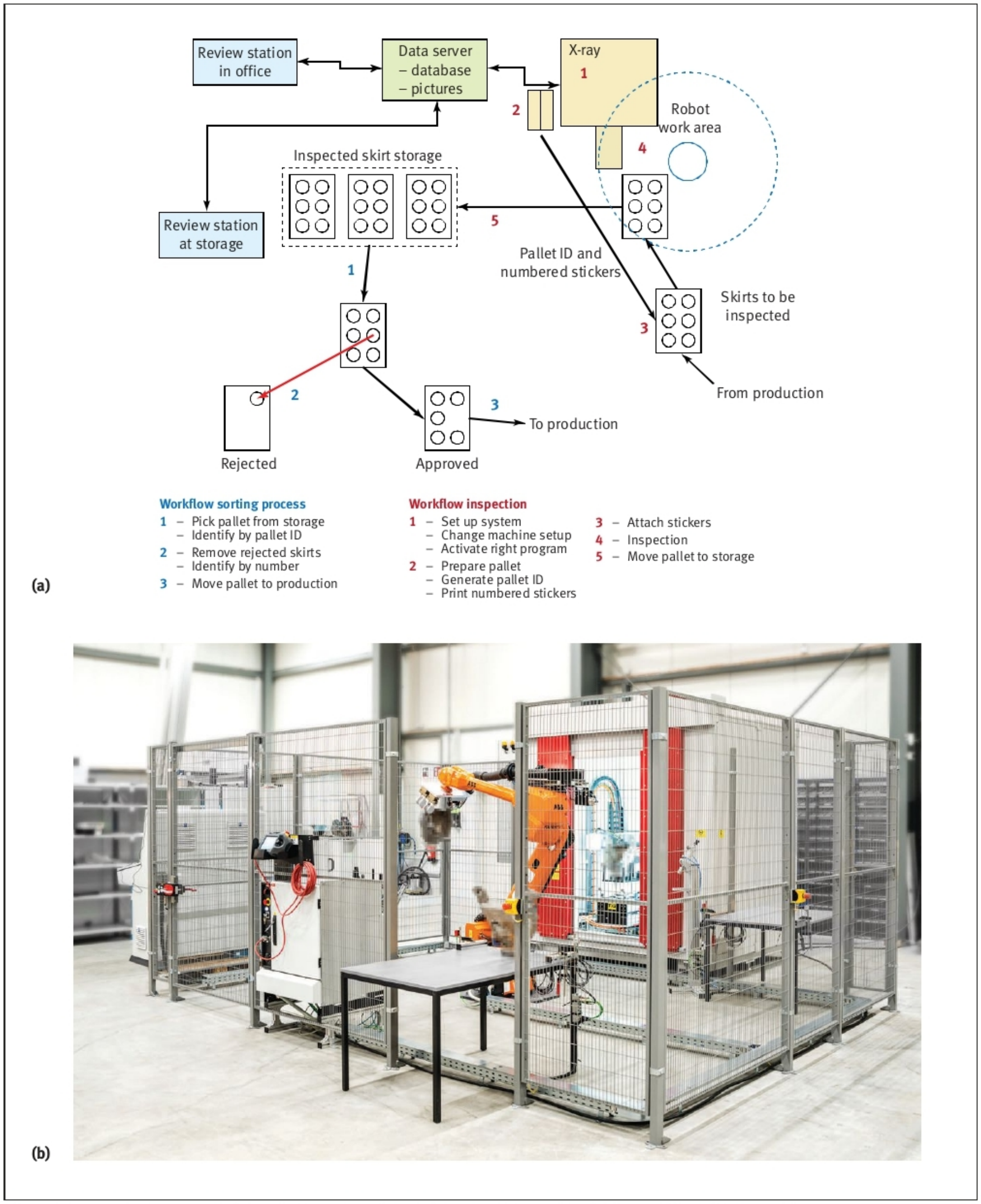

Figure 7. Example setup of a fully integrated workflow: (a) workflow chart; (b) physical implementation of the concept.

Figure 8. Example of a globally connected NDT operation. Each site has a number of X-ray systems that are linked to a central server. The servers are connected to the company-wide "NDT cloud," which is also used as the central image archive. It is also possible to connect portable devices that can be used outside of specific sites. The interpretation can be done from anywhere in the world using a review software that is connected to the cloud.

offline evaluation. This allows users to decouple inspection from evaluation and thereby parallelize it. This yields huge productivity gains. By introducing a single part flow and traceability based on serial numbers, the overall process safety is fully given at any time. By using the cloud, it is even possible to connect systems and sites into a world-spanning NDT network. This ensures that interpretation results and archived data are available to all employees of a global company everywhere at any time. End customers can be easily integrated into the cloud and given access to the data from their parts. Figure 8 shows an example of such a setup.

How Does This Affect Me?

The world has never been more complex. As supply chains are expanding to cover every corner of the world, we see the rise of large-scale automation on the shop floor and beyond. Especially Western economies face a growing competition from lower-wage countries that are quickly catching up in terms of technology. Many internal company departments have already been transformed by the digital disruption, and robots have become valued contributors in many areas. In every sector, from automotive to aerospace, the impact of automation is undeniable. Companies understand that they are in a global competition these days, and that just continuing to do things the way they've always done them will most likely have severe consequences.

NDT has traditionally been cautious when regarding change, and there are good reasons for it. In the end, all of us are responsible for the quality of the product that is delivered by our companies. Our work is far too important for thoughtless experiments with technology. As the guardians of quality, the NDT industry has created a strong network of rigid standards and regulations. The upside is an unprecedented quality system that protects our products, but on the downside these rigidities can often slow us down significantly. As a recent example, a supplier in the aerospace industry discovered substantial cost savings (roughly by a factor of 10) if they would switch from X-ray film to digital radiography, robotics, and computer numerical controls. The return of interest was amazing, and it would help the company to stay in business against its new competitors from Far East. Unfortunately, the project had to be abandoned as it was discovered that the parts were governed under a standard established in the 1970s, which could not be altered. Such situations are quite frequent in our industry and effectively destroy a huge amount of value that could be captured for our companies and countries.

Even though such stories are common, our industry is already witnessing a fundamental transformation. New technologies and approaches have been embraced in several industries like the automotive industry, which has less-rigid quality requirements than, for example, aerospace. To give a recent example, one of Germany's leading automotive manufacturers has just adopted an in-line CT system to inspect rotors for electric motors (VisiConsult 2019). The system uses an industrial robot for part handling and AI for the interpretation of the images. At the same time, the system is fully hooked up to the company's cloud system and processes all the data in real time. The skill sets required for the operators of this system are completely different than what was required for the manual process of the past. It is important to realize the ongoing transformation and to invest in the new skills early.

Figure 9 shows the economies of scale of an automated system based on an exemplary implementation in the automotive industry. It can be clearly seen that with film (second industrial revolution) and even with digital radiography (third industrial revolution), the cost increases linearly with the volume. By using automation, robotics, and automatic evaluation, the unit cost decreases with increasing production volume. This allows companies to manufacture in higher-wage countries and still be competitive, while putting all human effort into quality control and innovation.

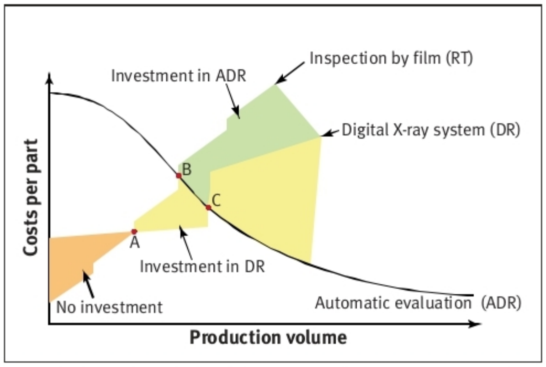

Figure 9. Economies of scale of an automated system: A, B, and C represent the "break even" points of the investment. From A it makes sense to invest in DR and from B/C to invest in automation.

NDT as a Sensor

The data-driven trends of Industry 4.0 and NDT 4.0 are fueled by information provided by sensors. These sensors are omnipresent and range from discrete data points (such as temperature, time, position, etc.) to the most complex sensors that provide a much greater depth of information. An example found in NDT is CT systems, which have the potential to delivery large amounts of data and insight about inspected parts. In manufacturing, a current trend of interest is the digital twin, which is considered a virtual copy of the part (Madni et al. 2019). What people sometimes do not realize is that NDT can supply a lot of information that can be used to build this digital twin. Imagine the possibilities when you have all the as-built data for every component in a given system combined with the ever-advancing simulation capabilities. This is a paradigm shift for the industry, transforming NDT from a pure quality step to a full industrial sensor in the manufacturing process.

Once we stop thinking of X-ray images as only NDT quality inputs, we start to see the next level of value in this data. This is true of both 2D and 3D images, so we must ask ourselves, what else can we learn from the hundreds and thousands of images that we are generating? Imagine what else a production process can learn from subtle changes in these images that mostly go unnoticed during quality inspections. Then, compound this effect by correlating these small variances with the data gleaned from other process parameters used to make that same part. The possibilities are vast, and the NDT world can be proud to provide that information—not just with respect to quality, but to process improvement and control as well.

This development will raise the importance of NDT even more. It is important to evaluate quality and provide the information if a part is acceptable or scrap. More valuable would be to also provide information on how to prevent scrap from happening in the future. This is the added value that puts NDT on the map of the most important processes of any company.

How to Be Prepared for the Future

The initial question posed in this paper was related to opportunity versus threat. There is no singular answer to this, as it is highly dependent on context, but this movement will, one way or the other, change our industry fundamentally. There will be a need for this change to be adopted. This process will stretch over the next several years, and pressure will be increasing during that time. Nevertheless, this is no reason to panic or to blindly grasp at technology offerings—everyone must remember that each NDT professional's job, first and foremost, is to ensure part integrity and to prevent faulty parts from being delivered. This should never be jeopardized by efficiency improvements or new technology; therefore, there is a requirement to develop a strategic change roadmap with realistic milestones and contingency measures. A careful process analysis will reveal low-hanging fruits that can be easily approached. Beyond the scope of this paper, there are other fields of Industry 4.0 that pose even more potential for efficiency increases. A great example would be the use of big data for predictive maintenance (Vrana 2019).

It is also very important to not take too many steps at one time. For example, making the leap from film (2.0) to a fully automated ADR robot system (4.0) may be too difficult for some organizations to achieve in a single effort. A better way could be to first switch from film to digital RT (3.0), then establish new processes and techniques, then qualify all operators before moving further. After the people have been acclimated with the new processes and techniques, the next step could be to then carefully automate and digitize further process steps with automatic/assisted defect recognition, and so on. It is recommended to reach out to established solution providers early in the process to get valuable input.

Final Thoughts

There is a big fear that robots, AI, and automation will take away jobs. This fear is mainly driven by misleading media articles and futuristic movies. Even though the new technology can do amazing things, it does not even come close to the capabilities of the human brain. We will not see these systems replacing professionals in NDT anytime soon—the medical industry is perfect proof of this. The reality is that despite the fact that the medical industry is now using AI to help interpret images, they still cannot keep up with the tsunami of data that is being generated by the new technologies. There needs to be a paradigm shift in the perception of these helping technologies. Robots help us to move parts and reduce the amount of physical labor and the cloud makes archiving and processing results much easier, while AI helps us to improve our evaluation capabilities. No doubt, our jobs will change and the activities we perform will be more computer oriented. This requires requalification and learning/adopting of new skills, but in the end, every machine needs a human to supervise it (Meyendorf et al. 2019). Consider the other industrial revolutions like electrification: it happened, and we have more jobs than ever before. It is more important to approach this new technology with openness and to embrace the opportunities it has for us. The biggest threat would be to wait for the things to come and get disrupted by others who adopted them earlier. Industry experts even state that companies not investing in the emerging technologies face a significant risk of being put out of business by more efficient local competition or the emerging global competition (BDI 2015).

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Deployment of Digital NDT Solutions in the Oil and Gas Industry

by Casper Wassink*†, Marc Grenier*, Olivier Roy*, and Neil Pearson*

ABSTRACT

Case studies of Industry 4.0 usually focus on manufacturing or logistics. While these are also important disciplines in the oil and gas industry, manufacturing and logistics are not the first things that come to mind when addressing the challenges related to safety and asset integrity. However, the technologies that are commonly associated with Industry 4.0, such as supply chain management solutions, robotics, additive manufacturing, and big data, play a major role in nondestructive testing (NDT). The owner/operators of installations in the oil and gas industry certainly support these trends and routinely request these technologies to be applied to NDT. This paper will explore how the discourse on Industry 4.0 applies to NDT 4.0 and how the trending technologies mentioned previously play a role in innovations. This will be done by showing where the technologies have been applied in research and development efforts currently underway. The first case study focuses on tube testing. The second focuses on the inspection of large structures such as storage tanks, pipelines, and vessels. These case studies will highlight how applying NDT 4.0 concepts contributes to increased quality of testing, and ultimately to safety and asset integrity in the oil and gas industry.

KEYWORDS: NDT 4.0, tube testing, storage tank inspection, eddy current testing, MFL, oil and gas industry, nonintrusive inspection

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Introduction

The signs of a new industrial revolution are all around us. Established industrial giants are stumbling, and new ones are emerging in every aspect of our lives. Although we may not yet know exactly where this will go for us, it is obvious that things are changing. The term "Industry 4.0" originated in 2011 from a working group within the German federal government. Klaus Schwab, chairman of the World Economic Forum, coined the term "fourth industrial revolution" and brought Industry 4.0 to the world's attention. These concepts have been adopted by several nondestructive testing (NDT) societies, first in Germany by the German Society for Non-Destructive Testing (DGZfP), and more recently by the American Society for Nondestructive Testing (ASNT) and the British Institute for Non-Destructive Testing (BINDT), to establish a platform for guiding the NDT community during this global transformation. Industry 4.0 refers to industry that makes productive use of digital connections between all parts of society. Technologies like autonomous vehicles, robotics, artificial intelligence (AI), and personalized manufacturing including additive manufacturing (AM) all fall under the umbrella of Industry 4.0.

It is important to realize that NDT is already associated with many of the component technologies involved in Industry 4.0. To collect big data, sensors and measurements are needed. NDT is one of the fields associated with data collection, sensors, and measurements. Robotics have been used for a long time in NDT, and NDT has important practical experience to contribute, such as experience in the spatial positioning of data and accuracy of measurement. Products made with AM will require testing before they can be used for critical applications, and NDT has a role to play here as well.

Industrial Revolutions

Industry 4.0 is not the only theory on industrial revolutions. Such theories go back to early economists like Schumpeter (1939) and Kuznets (1930). After the dot-com crisis of 2000 and financial crisis of 2008, these theories have been revived. Perez (2002) offers some useful concepts on the process of successive industrial revolutions. She describes that each technological revolution has an installation period, in which the technology gets developed and installed, but does not yet create societal value; then, there is a deployment period in which the real value is realized and society changes. In the installation period, the technologies get invented and the infrastructure installed (for example, the internet). In the deployment period, the technology gets used to its full extent. Along this line, Industry 4.0 can be considered the deployment period of digital technologies, and the period between 1970 and 2000 was the installation period. One of the findings of this type of analysis is that most technology implemented in the deployment period already existed before that period. The authors believe the same to be true for Industry 4.0, and especially for NDT 4.0, given the record of innovation in NDT (Wassink 2012), where technologies often get implemented decades after other sectors use them.

In the literature on Industry 4.0, several key attributes are listed. These include integration of value and supply chains, interconnectedness of processes, decentralized decision making, and customization of product offerings. Many of these have a relationship with the supply chain. Therefore, the authors will start the discussion of the case studies with a look at the inspection and maintenance supply chain.

Introduction to Case Studies

In the next section, a number of cases will be discussed that will show how features of NDT 4.0 are being realized in new products. The first case study will discuss heat exchanger tube testing and will highlight developments in automated interpretation software using AI. It will also touch on issues related to cloud storage of data. The second case study will discuss the inspection of storage tanks and will highlight developments in software for maintaining a digital twin. The final case study will discuss the inspection of pressure vessels and will highlight the development of software for adaptive inspection of complex geometries.

Case Study 1: Heat Exchanger Tube Testing

Tube testing is performed during the in-service life cycle stage of heat exchangers and is typically delivered by a specialist service provider or internal department to the owner/operator of the equipment. Over the last decade, equipment for tube testing has become more widely available, and more service providers have started to offer the service. This has led to an increased concern about the quality of testing and an increased demand for standardization, evident from projects in industry bodies such as the Electric Power Research Institute (EPRI), American Petroleum Institute (API), and HOIS (a joint industry project with more than 40 participating partners).

The actual test needs to be performed after the equipment has been taken out of service. Getting the equipment back in service on time is important. The work involves testing hundreds of individual tubes, and testing a single heat exchanger may take many hours. In addition, the results of a heat exchanger test may give important clues about the cause of failure and may prompt additional maintenance activities before the heat exchanger is put back into service. In this context of high productivity, NDT 4.0 technologies and concepts can play an important role in improving efficiency, reliability, and the confidence level in the overall heat exchanger inspection process. Smart sensors, accessories, and software can support service companies and asset owners by:

- providing better traceability of the data throughout the inspection process
- assisting the operator in crucial steps that could affect the data integrity
- improving the analyst efficiency in data interpretation, including the automatic detection and classification of indications
- providing realistic 3D heat exchanger representations to facilitate interpretation (Figure 1)
- promoting the sharing of data, analysis, and reports based on secure cloud services

Current equipment enables full traceability of instruments, probes, configurations, and metadata related to the test condition, including building a testing history of a specific heat exchanger. This again enables the smart use of data for auditing and risk-based inspection (RBI) to maximize the in-service period of the asset.

In addition, projects are ongoing for creating a tool to automate the interpretation of heat exchanger results. At first, this will be implemented through assisted analysis to the technician. A huge effort is currently made to integrate an AI processing technique to perform data quality validation during acquisition as well as automatic data screening. The conventional eddy current bobbin probe inspection is already well accommodated by those automated processes, and the automation of other tube inspection techniques (such as remote field testing, near field testing, and eddy current array) is under active development. The goal is to drastically reduce the number of tubes to review so that the analyst can concentrate on the most challenging tubes. On top of decreasing the influence of the human factor in analysis, this will create feedback that helps train the technician.

Currently, the AI classifiers, created using open source tools, have been running in beta trials with some service providers. The performance of these algorithms shows increased performance over previous rule-based algorithms; for example, bringing the position error of tube features from 9.4% down to 2.3%. Figure 1 shows a 3D representation of a heat exchanger with defects graphically marked and the result of feature detection software.

Although every test starts with a good sensor that provides high-quality data, digitization may help in several other ways. The testing results can be made available online, in the cloud, or connected in real time. Some service companies are already doing this by using commercial cloud-based solutions such as OneDrive, Google Drive, or Dropbox, but those solutions are not optimized for NDE. An optimized solution would offer different types of access depending on the ownership relationship with the asset and the data. Such cloud services will be useful for the service companies to perform data analysis with remote Level III experts to provide immediate feedback to the acquisition crew for any area of concern that may need to be rescanned. The cloud also plays a role in sending automated messages to the company level when the equipment starts

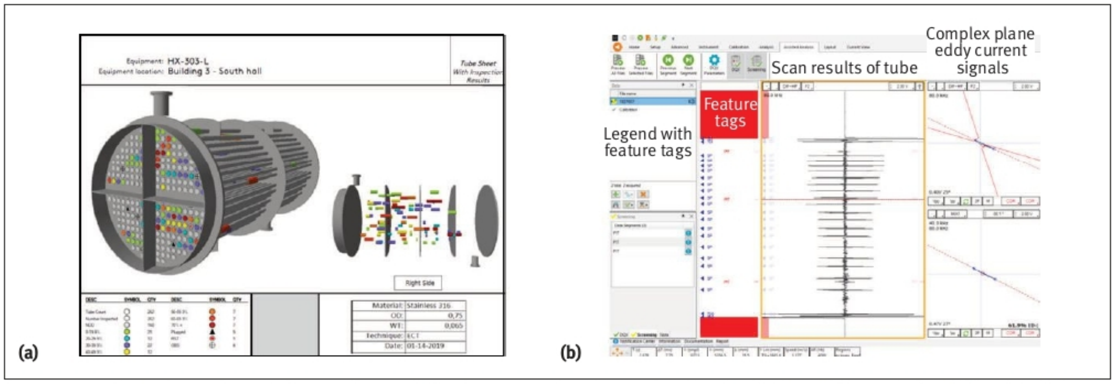


Figure 1. Nondestructive testing of a heat exchanger: (a) 3D representation after testing showing defects and flawed tubes; (b) results of feature detection software.

running outside the boundaries set at instrument validation, in order to share instrument configuration, historical data, and reports. For the owner/operator, it could mean receiving real-time feedback of testing results, monitoring inspection progression, and consulting realistic 3D tube sheets and bundle maps, which enable spotting of patterns in the occurrence of defects and helps determine the underlying problems to degradation. This could definitively help to smooth turn-around planning.

The processing of data using cloud processing has been achieved and trialed as well, but issues concerning data ownership and data security have, so far, limited the application of cloud storage and processing as a commercial model.

Case Study 2: Storage Tank Testing

Storage tanks may operate for many years without interruption. Maintenance windows are small, and, depending on the stored product, the tank may be emptied for inspection and repair only once every 20 years. The inspection of a storage tank tends to use a range of technologies for its components such as the floor, wall, roof, and ancillaries. This may involve one service provider, or several, and results may be delivered directly to the owner, or to an intermediary such as a maintenance contractor. As supply relationships are very diverse, there is an obligation to use open data formats if digital integration is to be achieved. One of the most common is simple comma-separated values (CSV) files.

With large amounts of data available, oil companies have started to harness the idea of digital twins in order to gain a better holistic insight into the behavior and life expectancy of their equipment. This can begin by first creating a virtual representation of the structure in computer-aided design (CAD) software. Data gathered from recent inspections can then be used to adjust the digital twin to create a current-case model of the asset. This could be done by deforming the 3D model itself or with a color-coded textured overlay of recorded maps from corrosion-mapping tools. This would result in a benchmark representation of the asset. Further information, such as historic inspections and previous repairs, could be added to the digital twin to complete its virtual representation. This baseline model is considered the "initialization" stage of the digital twin and is represented by the first stage in the life of a digital twin, as illustrated in Figure 2.

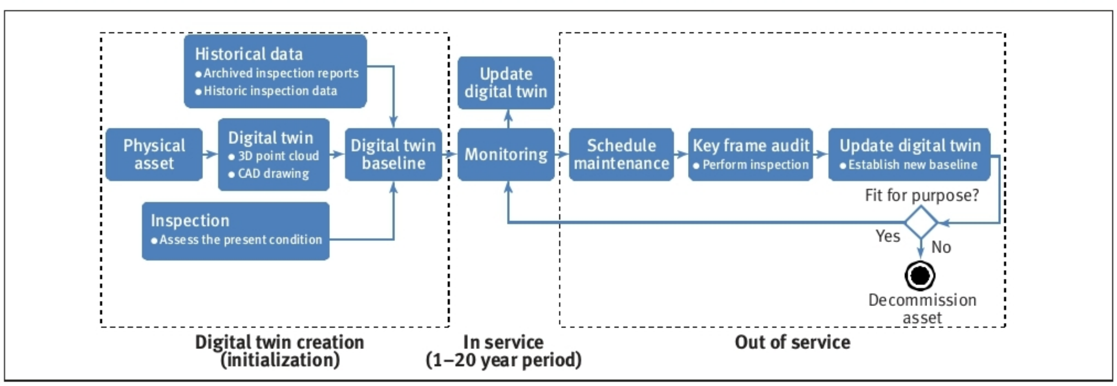
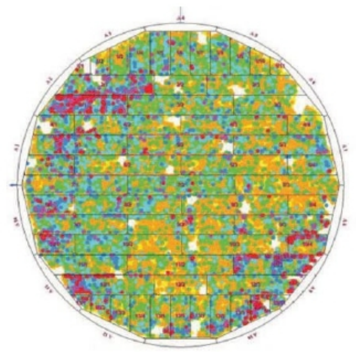


Figure 2. Simple illustration of the creation of a digital twin and its upkeep throughout the life of an asset.


(a)

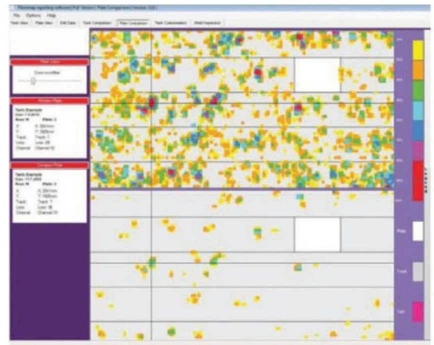

(b)

Figure 3. Tank floor inspection: (a) digital twinning software; (b) screenshot of software showing a comparison of new (top) and old (bottom) data from the same floor plate.

Magnetic flux leakage (MFL) scanners have been collecting and digitizing information relating to the condition of tank floors for 20 years. Early adopters of MFL scanners from as early as 1999 can use their data as historic records to feed into the creation (or updating) of the digital twin (Figure 3). This data provides some history of the asset's condition and can be used in conjunction with other inspection modalities or subsequent MFL inspections to identify any common trends, which is ideal for scheduling the next out-of-service interval. This then feeds into the third stage in Figure 2, which represents an out-of-service interval where a detailed internal inspection can be performed. One component of this stage is that the detailed inspection can be used to fully update the baseline condition of the digital twin because during the in-service stage, there will be a limited amount of information available to update. Data is the center of Industry 4.0, and although semi- or automated procedures can provide a huge benefit with large-scale data sets, even simple visual inspections with checklists can be used to bolster the information to the digital twin, continually improving its representation. This is considered a "keyframe" audit, which can be used to reset the baseline of the existing model to be used for the next in-service cycle.

It is also important to note that advancements in inspection systems can be considerable between out-of-service intervals. This can add complications as the data may no longer have the same format, and newer inspection systems may present the same defect differently. However, the increased quality and new information available from contemporary inspection systems (for example, top-side/bottom-side automated discontinuity recognition with improved sensors [Pearson and Boat 2012]) can also enhance the keyframe audit and add further value when used to readjust the baseline periodically.

In current digital twinning software for the tank bottom, through signal processing algorithms, discontinuities can now be automatically segmented and fed into RBI analysis tools to predict the time until the next maintenance activity is needed and the overall remaining tank life. Development work includes features that will enable automatic fitting of the scan data on the digital image of the tank. From this data, repair plans for the tank floor can be generated to enable faster maintenance activities. Over time, through subsequent scanning or periodic monitoring, sensor information can be used to update the representation of the tank floor and bring it up to its present condition.

As gaining access to the tank floor when the tank is in service is challenging, updating the digital twin during the monitoring stage can be limited. To advance the in-service aspect of inspection, developments are ongoing for incorporating equipment into robots that can inspect the storage tank while filled. Tanks that contain product may have substantial contaminations on the tank bottom, which need to be tested through. A pulsed eddy current system has been tested in this environment and phased array ultrasonic testing (PAUT) will be soon evaluated. The complementarity of these two techniques should allow, in the coming months, a reliable way of monitoring tank floors between major shutdowns.

Alternatively (or in tandem), fixed Internet of Things (IoT) sensors permanently placed on the tank floor may be used to perform remote and perhaps wireless transmissions of data. At present, this remains a challenge, but if made available, such sensors could monitor areas of localized corrosion discovered during the tank's last MFL inspection. This brings us to one important note for NDT 4.0, which is the security of the readily available and popular IoT range of devices. One must consider that these devices are aimed to be always connected and potentially vulnerable to attack. For example, smart sensor spoofing could be one area where security needs to be considered. In spoofing, an attacker may mimic the smart sensor and send fraudulent readings to the digital twin

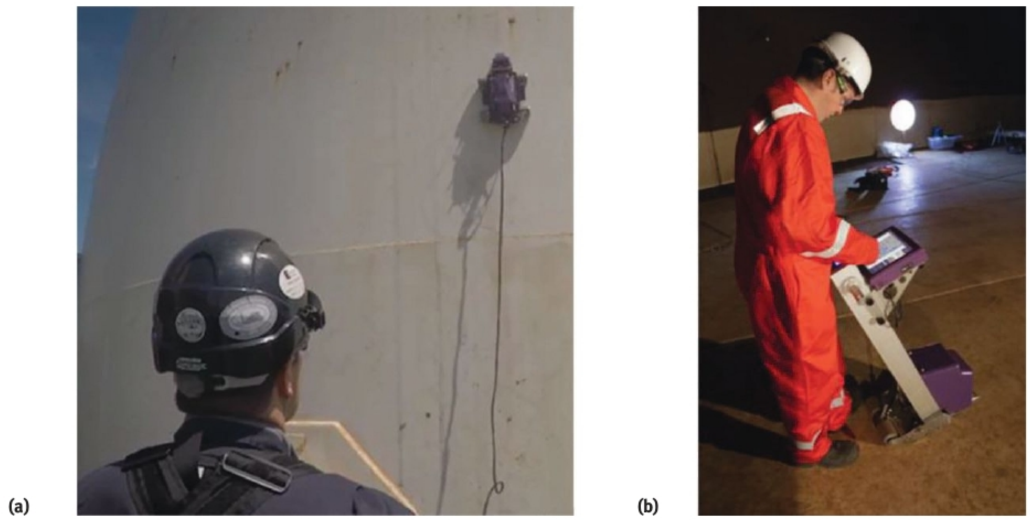


Figure 4. Nonintrusive tank inspection: (a) remote crawler utilizing dry-coupled UT; (b) MFL floor scanning for out-of-service tank.

monitoring station, resulting in false alarms and disrupting productivity. Suitable security for these connected devices needs to be addressed, particularly as condition monitoring with smart sensors becomes more common.

Monitoring the accessible surfaces of the storage tank can be carried out through nonintrusive inspection. Components of the digital twin, such as the roof and tank shell, can be updated more frequently. Among standard manual techniques, there are many benefits to utilizing robotics; for example, a robotic crawler can scale the tank wall to record a thickness profile without the need for expensive scaffolding (Figure 4). Several vertical profiles can be taken around the tank, with their frequency usually depending on the tank's diameter. A remote crawler offers enhanced safety through remote inspection and culminates in a graphical digital record. When using a dry-coupled ultrasonic wheel probe (which adds portability), the thickness profile helps to identify any ring corrosion generated at a maintained product level. Such corrosion can be correlated with the number of scans taken around the periphery of the tank, but also note that this will provide a greater probability of detection than traditional manual thickness measurements on a sparse grid separation. The data itself serves as a record and input to the asset's digital twin.

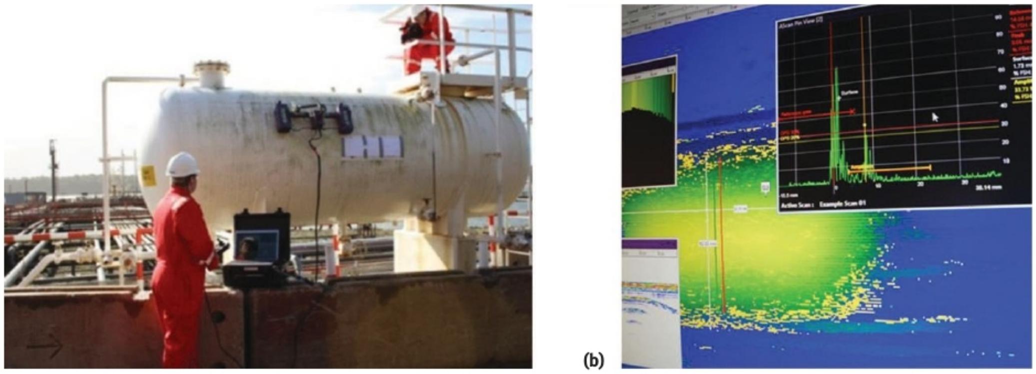
Capturing the inspection results of the various technologies in a digital twin of the tank will, in the future, also enable more advanced forecasting of degradation through prediction modeling in order to determine future capabilities of the storage tank.

Case Study 3: Nonintrusive Vessel Testing

In addition to the technologies discussed in the section on storage tanks, a virtual representation needs to mimic the condition of an asset to provide a picture of its current state or enough information to perform risk analysis and schedule maintenance. Having as much "good" data as possible about the condition of the asset is paramount in order to facilitate decision making. For example, fit-for-purpose decisions would greatly benefit from knowing the most accurate condition of a vessel wall through mapping, as similarly described for tank shell walls.

One of the most discussed trends in the oil industry is the requirement to no longer enter confined spaces. Where until now vessels were often inspected visually by a person entering them, several oil companies have expressed that they will no longer allow this. This means two possibilities: inspect from the exterior or utilize a remote robotic system on the inside. Automated NDT is essential for many industries where maintaining and evaluating the safety of components is crucial. Applying automation can increase not only safety but the overall longevity of an asset with an increase in measurement and positional accuracy, as well as cost benefits through efficiency. One key component of Industry 4.0 is the reduction in human errors.

One example of applying automation to improve productivity is automated ultrasonic inspection and its impact on inspection quality and consistency on large assets such as pipelines, vessels, and storage tanks (Figure 5). The inspection

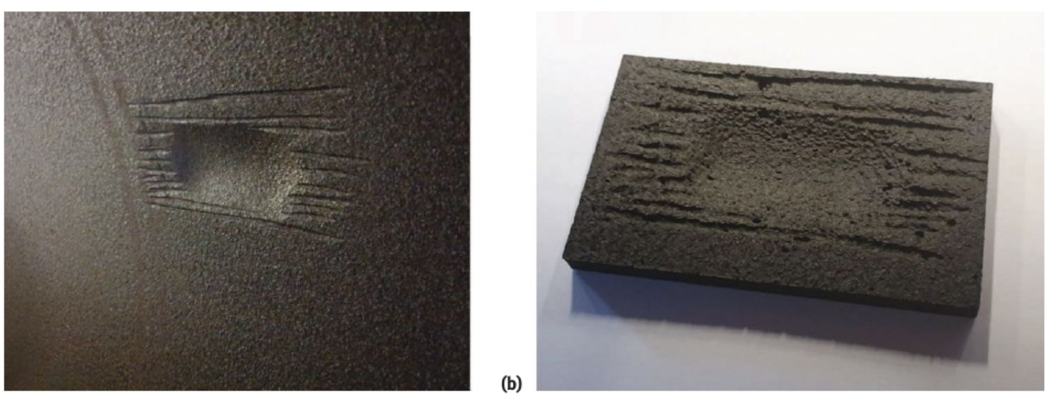


(a) (b)

Figure 5. Nonintrusive inspection of vessel: (a) ultrasonic inspection with magnetic crawler; (b) results of a defect recorded with the crawler in the reporting software.

company can greatly benefit from the automated process, increased probability of detection, and gains in efficiency and inspection speed. The asset owner benefits from a full digital record of the asset's condition. Automated inspection systems have been around for many years. More recently, systems have evolved to include PAUT, which can significantly decrease the inspection time and improve the quality of reported thicknesses. Through the single crystal process, a scanner would need nearly 10 min to complete an inspection of a 500 mm × 450 mm area at a resolution of 1 mm × 2 mm. By replacing the probe with PAUT, not only is the scan time reduced to less than 2 min, but because of the array, the system can increase the scan width from 450 mm to 510 mm. Overall, the efficiency is increased by a factor of nearly 6, but with the added benefit of enhanced defect representation through PAUT.

On the development side, more accurate ultrasonic techniques based on the full matrix capture/total focusing method (FMC/TFM) are being developed, which create a more realistic image of corrosion. Not only can the true corrosion shape be captured, but it can also be exported into a 3D point cloud, which can be used in other applications. Results of these kind of scans have already been used as input for 3D printing (Figure 6). This will enable better characterization of



(a) (b)

Figure 6. Defect data used for 3D printing: (a) physical defect; and (b) corresponding 3D-printed defect from the map created via ultrasonic inspection.

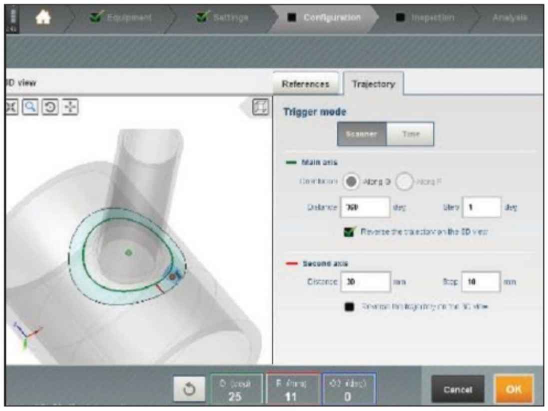


Figure 7. Screen display showing nozzle design and calculation of the probe trajectory.

Figure 8. Nozzle inspection with a PAUT unit and specific scanners to hold the probe on the main pipe.

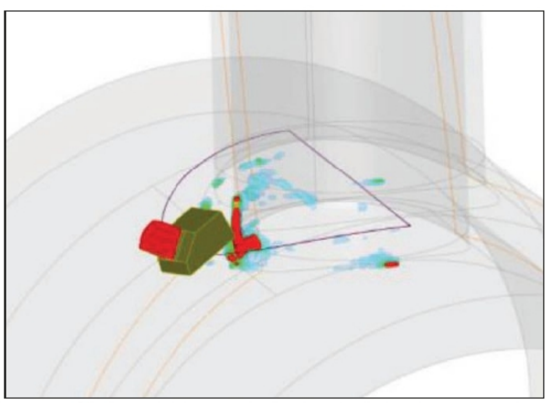


Figure 9. A 3D view of the nozzle and detected indications related to probe position.

discontinuities. In addition, these results have been used as input for fracture mechanics analysis (Adriano et al. 2019).

Nozzles are an important class of joints used in pressure containing equipment. Because of their complex shape, nozzles are very difficult to inspect using ultrasonic techniques. Typical defects such as cracks and lack of fusion are highly sensitive to the beam orientation. Defects located close to the front surface often require the sound beams to be reflected off the backwall, making it very complicated when dealing with nozzles where the inside surfaces of the vessel are curved.

Currently, the inspector has to estimate the local cross section of the complex 3D-shaped component in order to understand the location of received signals and interpret the position of the indications. CAD software already allows for the designing of complex nozzles; thus, the operator can determine where to place its sensor, but there is no immediate combination of the ultrasound image and the actual geometry of the nozzle. Therefore, the inspection must be performed in a blind way and combined later with the geometrical design of the nozzle, which introduces delays and potential mistakes.

A solution has been developed using augmented imaging, which uses the capabilities of simulated UT modeling and 3D CAD to produce understandable real-time images of the inspection. Using these models, the user can build a digital twin of the nozzle to be inspected and define the trajectory of the transducer to cover the region of interest (Figure 7).

This solution was implemented on a portable PAUT unit (Figure 8). Its capability to read three-axis encoded nozzle scanners allows computing cross-section overlays as the operator moves the probe, which are superimposed with the ultrasonic data to produce real-time augmented imaging during the inspection.

As all ultrasonic data are saved in the same file with synchronized probe positions and the digital nozzle, full analysis can then be achieved, as illustrated by Figure 9, which shows a 3D representation of the nozzle with detected indications and related probe positions.

The complete solution, including a nozzle scanner and selected transducer, has been successfully assessed by an independent research institute, who proposed a procedure for field inspection (Nageswaran 2016). This application matches well with the advent of the NDT 4.0 era by using combined digital models embedded in a portable system to provide understandable images to field operators.

Conclusion

The benefits of digitization are starting to show in NDT. In this paper, several case studies were presented with examples of digital integration. Each of the main features of Industry 4.0 is present in these cases: robotics, AI, AM, IoT, cloud computing, and integration into the inspection supply chain. Ultimately, it is the digital interconnection of these systems with one another, constantly collecting and sharing information, that will truly unleash the power of NDT 4.0.

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Intelligence Augmentation and Human-Machine Interface Best Practices for NDT 4.0 Reliability

by John C. Aldrin*

ABSTRACT

NDT 4.0 is a vision for the next generation of nondestructive inspection systems following the expected fourth industrial revolution based on connected cyber-physical systems. While an increasing use of automation and algorithms in nondestructive testing (NDT) is expected over time, NDT inspectors will still play a critical role in ensuring NDT 4.0 reliability. As a counterpoint to recent advances in artificial intelligence algorithms, intelligence augmentation (IA) refers to the effective use of information technology to enhance human intelligence. While attempting to replicate the human mind has encountered many obstacles, IA has a much longer history of practical success. This paper introduces a series of best practices for NDT IA to support NDT 4.0 initiatives. Algorithms clearly have a great potential to help alleviate the burden of "big data" in NDT; however, it is important that inspectors are involved in necessary secondary indication review and the detection of rare event indications not addressed well by typical algorithms. Examples of transitioning algorithms for NDT applications will be presented, emphasizing the successful interfacing of inspector and software for optimal data review and decision making.

KEYWORDS: Industry 4.0, artificial intelligence, intelligence augmentation, human-machine interface, reliability

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Introduction

Industry 4.0 is a term developed by German industry leaders and researchers to describe how the Internet of Things (IoT), an emerging network of linked cyber-physical devices, will improve engineering, manufacturing, logistics, and life-cycle management processes (Jahanzaib and Jasperneite 2013). The number 4.0 refers to a fourth industrial revolution. Beginning in the 1700s, three major waves of technological changes transformed the industrial landscape and increased productivity: (1) mechanization and water/steam power; (2) mass production (for example, assembly lines) and electricity; and (3) computers and automation. The fourth industrial revolution is expected to be based on connected cyber-physical systems. There is a parallel vision for the next generation of NDT capability referred to as NDT 4.0 (Meyendorf et al. 2017a, 2017b; Link and Riess 2018; Vrana et al. 2018; Singh 2019). A key aspect of NDT 4.0 is leveraging automation in the evaluation of the workpiece and providing characterization of the state of the part for improved life-cycle management (Lindgren 2017; Forsyth et al. 2018).

A diagram of an integrated vision for NDT 4.0 is presented in Figure 1. One key innovation of NDT 4.0 is the integration of advanced control systems and NDT algorithms to support complex inspections, NDT sensor data acquisition, and data analysis tasks. In recent years, major advances have been made in the field of machine learning and artificial intelligence (AI) to perform complex data classification tasks, leveraging training on "big data" sets (LeCun et al. 2015). While this technology is promising, challenges do exist with transitioning machine learning/AI algorithms to NDT applications. Training AI requires very large, well-understood data sets, frequently not available in NDT, and there are major concerns about the reliability and adaptability of such algorithms to completely perform complex NDT data review tasks. One of the primary objectives of this paper is to survey the potential benefits and challenges of emerging algorithms for NDT 4.0 systems. Experience and perspective on the transition of algorithms for NDT applications will also be discussed.

The Inspector and NDT 4.0

A critical component of any NDT tool is the interface with the human that uses it. Figure 1 shows the human-machine interface as a critical link between the NDT inspector/engineer and

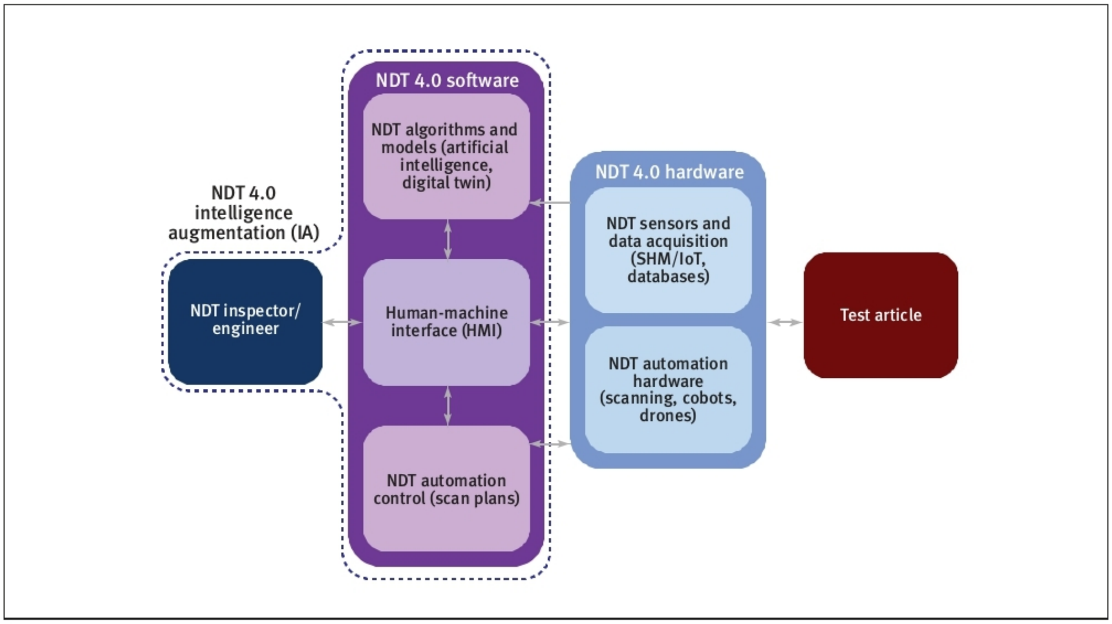

Figure 1. Vision for NDT 4.0: intelligence augmentation (IA) for NDT inspectors and engineers is achieved through a human-machine interface to NDT automation hardware, sensors, and data acquisition algorithms and models.

NDT 4.0 software and hardware. Care must be taken with the implementation of automation to ensure that operators have the necessary awareness and control as needed. In addition, as a counterpoint to recent advances in AI algorithms, intelligence augmentation (IA) is introduced as the effective use of information technology to enhance human intelligence. From this perspective, the inspector is an integrated part of NDT 4.0 systems and performs necessary tasks in collaboration with automated NDT systems and data analysis algorithms. This paper will present a series of best practices for the interface between NDT hardware, software, and algorithms and human inspectors and engineers to ensure NDT 4.0 reliability.

Algorithms and AI in NDT

NDT algorithms that perform indication detection and characterization can be organized into three classes: (1) algorithms based on NDT expert knowledge and procedures (heuristic algorithms); (2) model-based inversion; and (3) algorithms incorporating statistical classifiers and/or machine learning. The most basic algorithm is one based on human experience. The term *heuristic algorithm* is useful to describe a class of algorithms based on learning through discovery and incorporating rules of thumb, common sense, and practical knowledge. This first class of algorithms essentially encodes all key evaluation steps and criteria used by operators as part of a procedure into the algorithm. The second class of algorithms is a model-based inversion that uses a "first principles" physics-based model with an iterative scheme to solve characterization problems. This approach requires accurate forward models and iteratively compares the simulated and measurement data, adjusting the model parameters until agreement is reached. The third class of algorithms covers statistical classifiers and machine learning, which are built through the fitting of a model function using measurement "training" data with known states. Statistical representation of data classes can be accomplished using either frequentist procedures or Bayesian classification. Machine learning and AI are general terms for the process by which computer programs can learn. Early work on machine learning built upon emulating neurons through functions as artificial neural networks using layered algorithms and a training process that mimics a network of neurons (Fukushima and Miyake 1982). In recent years, impressive advances have been made in the field of machine learning, primarily through significant developments in deep learning neural network (DLNN) algorithms (Hinton et al. 2006; LeCun et al. 2015; Lewis-Kraus 2016). Large sets of high-quality, well-characterized data have been critical for the successful training of DLNNs. As well, software tools have been developed for training neural networks that better leverage advances in high-performance computing. A recent overview on algorithms for NDT classification is summarized in a previous paper (Aldrin and Lindgren 2018).

Benefits of Algorithms/AI in NDT

There are a number of advantages associated with incorporating algorithms as part of an NDT technique. First, algorithms are typically very good at performing laborious and repetitive tasks. For most parts under test, either in manufacturing or in service, the presence of critical NDT indications is a fairly rare event. Therefore, the data review process can often be a tedious task for most operators, who can expect mostly good parts. Second, given the amount and complexity of some data review tasks performed for some inspections, such tasks can be a challenge, especially for inexperienced inspectors or inspections that are rarely performed. This trend appears to be growing with the increasing quantity of data acquired with automated scanning and array sensing systems. Third, in many instances, algorithms can perform the data review task faster than manual review, providing potential savings in maintenance time and costs. Fourth, algorithms are typically not biased by expectation, such as the frequency of indications in past inspections. With a reduction in errors, the overall risk of maintaining a component can be improved. Fifth, algorithms can be designed in such a way to support the operator as a "digital assistant." Algorithms could potentially help alleviate the burden of "mostly good data" and allow operators to focus on key data review tasks. As well, algorithms can be used to reduce the size and dimensionality of NDT data and present the operator with a reduced feature set for manual classification. Lastly, there are challenges with the aging workforce and transitioning expert knowledge to the next generation. Algorithms, if designed properly, can be repositories for expert knowledge in an NDT organization.

Challenges of Algorithms/AI in NDT

While the application of NDT algorithms shows great promise, there are a number of potential disadvantages with applying algorithm-based solutions to NDT inspection problems. First, the development and validation of reliable algorithms for NDT can be expensive. Training DLNNs requires very large, well-understood data sets, which are frequently not readily available for NDT applications. While the NDT community often possesses a large amount of data, the material state behind the data is often not perfectly known. Acquiring data from parts with well-characterized damage states, such as cracks, corrosion, or impact damage, requires either high-resolution NDT techniques for fingerprinting, or destructive characterization for full verification. The design, training, and validation of algorithms also require unique software development skills and many hours of engineering labor to successfully implement.

Second, algorithms also can perform poorly for scenarios that they are not trained to interpret. There have been concerns for decades about the reliability and adaptability of machine learning algorithms to completely perform complex NDT data review tasks. In NDT, many promising demonstrations have been performed by the NDT research community, but frequent issues concerning overtraining and robustness to variability for practical NDT measurements outside of the laboratory have been noted (Aldrin and Lindgren 2018). Prior successful NDT applications of neural networks have been dependent on taking great care to reduce the dimensionality of the data and provide reliable features as inputs for classification. As well, designing algorithms to address truly rare events—so-called black swans—is extremely difficult (Taleb 2007).

Third, while human factors are frequently cited as being sources for error in NDT applications, humans are inherently more flexible in handling unexpected scenarios and can be better at making such judgement calls. Human inspectors also have certain characteristics like common sense and moral values, which can be beneficial in choosing the most reasonable and safest option. In many cases, humans can detect when an algorithm is making an extremely poor classification due to inadequate training and correct those errors.

Fourth, for many machine learning algorithms like DLNNs, it can be difficult to ascertain exactly why certain poor calls are made. These algorithms are often referred to as "black boxes," because the complex web of mathematical operations optimized for complex data interpretation problems does not generally lend itself to reverse engineering. Approaches are being developed to sample the parameters space to ascertain the likely source for decisions (Olden and Jackson 2002), but the field of "explainable AI" (XAI) is still in its infancy (Stapleton 2017).

Lastly, with the greater reliance on algorithms, there is a concern about the degradation of inspector skills over time. As well, there is a potential for certain organizations to view automated systems and algorithms as a means of reducing the number of inspectors. However, many of these disadvantages can be mitigated through the proper design of human-machine interfaces.

NDT Intelligence Augmentation

With recent progress and hype on the coming wave of AI, some perspective is needed to understand how exactly these algorithms will be used by humans. While the original vision for AI was to mimic human intelligence, in practice AI has been successful only for very focused tasks. While today certain algorithms can perform better than humans for certain predefined and optimized tasks, we have not achieved the early goal of independent AI. Humans not only have the capability to perform millions of different tasks, many in parallel run by the unconscious mind, but they also have the wherewithal to determine when it is appropriate to switch between tasks and allow the conscious mind to have awareness as needed. The real value of AI today is using it as a specific tool (Aldrin et al. 2019).

As a counterpoint to AI, IA refers to the effective use of information technology to enhance human intelligence (Skagestad 1993; Rastogi 2017). This idea was proposed in the 1950s and 1960s by early cybernetics and computer pioneers. IA uses technology to essentially "support" a human in performing specific tasks. Relative to AI, IA has a long history of success. For example, consider the history of information technology, from the birth of writing and slide rules to smartphones and the internet. All of these forms of technology have essentially been developed to extend the information storage and processing capabilities of the human mind. Fundamentally, progress on AI algorithms should be viewed as an evolution of tools to better support human performance.

While most of the attention in recent years has been on the performance of AI over humans in games such as chess and Go (Lewis-Kraus 2016), there are a number of applications that have been cited where humans plus algorithms can exceed the performance of computer algorithms alone. "Centaurs" (Scharre 2016; Case 2018) and "cyborgs" (Tharp 2017) are terms used to refer to such human-plus-machine collaborations. One example that is frequently cited is chess. A team of amateur chess players paired with three chess programs convincingly defeated a series of teams made up of chess grandmasters and some of the world's best chess programs (Cowen 2013; Tharp 2017). While this case study is slightly dated and may not hold up to the success of AlphZero (Gerbert 2018), fundamentally, all of these algorithms at some stage in their design for operational tasks have incorporated human input. This collaboration between humans and algorithms leveraging high-performance computing has the potential to solve an array of greater problems than mere games of strategy. For example, for many decades the practice of engineering has consisted of humans leveraging their intellect with the support of computational tools to solve technical problems. Humans are still critical in asking the right questions and providing the appropriate focus, complementing the brute force computational power with creativity in selecting the most promising problem space to investigate (Wilson and Daugherty 2018). Humans also have a natural flexibility, versatility, and intuition that AI systems have yet to achieve. These uniquely human qualities are still quite impressive, especially considering the relatively low power consumption of the human mind.

From the perspective of NDT applications incorporating algorithms, IA has the potential to address most of the disadvantages of the AI-based algorithms cited previously. For example, many of the most promising DLNN applications today—from speech recognition to text translation and image classification—are still far from perfect. However, that does not mean that these tools are not useful. In practice, humans can frequently detect errors made by AI and can quickly work around poor results. Humans often develop an understanding where such algorithms can be most appropriately applied and where they should be avoided. By leveraging the algorithms where they are most useful, it becomes less critical for the algorithm to be able to handle all scenarios, especially very rare events. Lastly, by operators working in conjunction with algorithms, there is no need to pursue eliminating the human entirely. In general, the most cost-effective and reliable solution will mostly likely be some hybrid, human-plus-machine based approach.

Human-Machine Interfaces

Typical human interfaces with computer systems in NDT have included monitors, keyboards, mouses, and possibly joystick interactions. While these classic PC interfaces are still efficient for many tasks, there are also a number of emerging devices and tools that connect humans with automation. For example, industrial touchscreen tablets, augmented reality glasses, wearable devices (such as smartwatches), voice-recognition systems, and position tracking devices (such as Microsoft Kinect) all have the potential to provide more natural human-machine interfaces to support emerging NDT 4.0 systems. Several promising applications of augmented reality for aircraft maintenance applications have demonstrated feasibility in recent years (Avatar Partners 2017; Jordon 2018). Unique visualization support tools have also been developed for automatically aligning and visualizing data to 3D models, which enables detailed analysis to detect trends at specific locations on the model, indicating potential process problems (Sharp et al. 2009).

Challenges for Implementation

While this is an exciting time for new human-machine interface tools, there is a critical need to carefully optimize the fine interactions between humans and computer algorithms in NDT. Some work has studied the human-machine problem for different NDT applications (Dudenhoeffer et al. 2007; Bertović 2016a, 2016b). For example, Bertović performed a detailed survey of prior work on human factors when interfacing with automation in NDT (Bertović 2016a). While extensive human-automation interaction has clear benefits, research suggests that increased automation has a number of challenges, costs (a paradox frequently dubbed as "automation ironies" [Bainbridge 1987]), or "automation surprises" (Sarter et al. 1997). In this work, a failure modes and effects analysis (FMEA) was conducted to identify potential risks, and a number of preventive measures were proposed. Subsequent studies were used to verify the benefit of the preventive measures, highlighting mixed levels of success (Bertović 2016a).

Additional guidance on the challenge of human-machine interfaces can be gained from the experiences of other communities that also require very high levels of reliability. For example, in aviation, the use of autopilot systems and the handoff between human control and autopilot is a pertinent case study for NDT. In recent years, the accident rate for major aircraft has been reduced to one major accident per

2.56 million flights (Oliver et al. 2017). While overall air safety has been improving, incidents of the loss of control have not. Loss of control occurs when pilots fail to recognize and correct a potentially dangerous situation, causing an aircraft to enter an unstable condition. One example of the possible catastrophic consequences of automation is the tragic crash of flight AF447 (Oliver et al. 2017). Another very recent example concerns the Lion Air and Ethiopian Airlines crashes of Boeing 737 Max aircraft (Rice and Winter 2019). Such incidents are typically triggered by unexpected, unusual events, often comprising multiple conditions that rarely occur together, that fall outside of the normal repertoire of the pilot's experience. In the case of the Boeing 737 Max, the handoff between the human and autopilot systems appears to have not been designed well, and many pilots were not instructed on its operation (Rice and Winter 2019). This paradox of almost totally safe systems, where the same technology that allows the systems to be efficient and largely error-free, can also create systemic vulnerabilities that result in occasional catastrophes. Lessons learned from these cases include: (1) avoiding the cycle of implementing more automation to correct for poor human performance with existing autopilot systems; (2) encouraging more hand-flying to prevent the erosion of basic piloting skills; (3) improving the management of handovers from machines to humans; (4) increasing pilot training for rare events; and (5) supplementing training using simulation of various rare event scenarios. It is critical to avoid the natural tendency to blame the human in these situations when the human-machine interface and/or algorithm design is poor (Hao 2019). Alternatively, it is important to find ways to make such systems robust and ideally "anti-fragile" to randomness and disorder in the environment (Taleb 2012). The human operator must have some level of "skin in the game" (Taleb 2012) and not become reliant on automation over time. Designing human-machine interfaces and providing the necessary training to achieve this balance is far from trivial.

Best Practices for Design of IA and Human-Machine Interfaces

Building on this prior work and experience, a series of best practices for IA in NDT 4.0 is proposed, highlighting how the operator should best interface with NDT data and algorithms. Algorithms clearly have a great potential to help alleviate the burden of big data in NDT; however, it is important that operators are appropriately involved in secondary indication review and the detection of rare event conditions. The following best practices are proposed:

- Provide inspectors with a natural user interface for NDT workflow management. Usability of human-machine interfaces is a critical aspect of workflow management for NDT techniques, from setup, standardization, data acquisition, and indication review. Ideally, inspectors need a way to report results and efficiently provide feedback on indications. Frequently, there are means in NDT software systems to annotate indication results; however, making this metadata readily available to external systems is one of the challenges for NDT 4.0 going forward. Such information will be very useful for refining NDT algorithms and improving life-cycle management.
- Implement data analysis algorithms to address frequent NDT calls and complex data interpretation. It is important to address the low-hanging fruit on implementing algorithms for NDT applications and to help alleviate the burden for inspectors of reviewing "mostly good" data. As well, some complex interpretation problems (especially in ultrasonic NDT) can benefit from algorithms and data guides. The design of these algorithms requires a focus on the base capability for making NDT indication calls to provide value and help ensure reliability. The algorithm design process should consider the necessary engineering development time, cost for acquiring necessary data, and the approach with the highest likelihood of success. There will be a payoff for some applications, but not all applications may benefit from automation. However, as NDT 4.0 systems mature, development costs for each new application should be reduced.
- Ensure inspectors provide a secondary review of indications and review data for rare events. While there is often an initial desire to have NDT algorithms make all indication calls and present simple (good or bad) calls, based on prior experience, additional information is always requested by engineering and management to understand the details on why an indication call was made. Inspectors need a natural user interface to review each call with supporting data and provide feedback on the call details in light of the technical requirements. As well, because no algorithm will be perfect, inspectors need to have a straightforward means to review NDT data quickly. This entails identifying rare indications and determining when the acquisition of the NDT data is out of specification.
- Develop an integrated NDT "simulator" to provide operator training and support complex indication review. There is a potential to leverage the same software interface for training purposes, by having the operators periodically train and test their skills with various conditions in NDT data. Specific rare events can be stored and introduced periodically as part of the regular re-training process. Thus, the interface could be used similar to how flight simulators are used for pilots to verify their performance under standard conditions and rare events. As well, integrated models within the user interface can also provide a means for the verification of indications and support sizing by the inspectors.
- Implement open architecture for NDT data and reporting. Promising software tools exist to support NDT practitioners with data archiving, visualization, and special queries (Sharp et al. 2009), and continued improvements with usability and functionality are expected in the future. Ideally, to share data between NDT 4.0 components, leveraging open data

standards (such as DICONDE and HDF5) and incorporating flexible software architectures, will greatly accelerate the evolution of these systems (Meier et al. 2017; Vrana et al. 2018).

- Reliability must be demonstrated for NDT 4.0 systems. The capability of inspection procedures incorporating NDT 4.0 systems that depend on the performance of both algorithms and the NDT inspector must be evaluated jointly. Probability of detection (POD) evaluation procedures, such as *MIL-HDBK-1823A* (US DOD 2009), are designed to validate the reliability of NDT techniques, regardless of how the indication call is made.
- Software and algorithms can also support NDT reliability as process controls. Simply demonstrating POD capability does not ensure reliability of the technique (Rummel 2010). FMEA should be performed for all NDT techniques incorporating automation to understand the potential sources for poor reliability (Bertović 2016a). In practice, NDT reliability depends on a reproduceable calibration procedure and a repeatable inspection process (Rummel 2010). Process controls and algorithms can thus be used to ensure all calibration indications are verified and to track key metrics that show the NDT process is repeatable over time and under control. As an example, recent work on model-based inverse algorithms with eddy current inspections has shown the potential to reduce error due to variability in probes through calibration process controls (Aldrin et al. 2017). NDT 4.0 systems are also expected to improve the safety of inspections in dangerous environments. By collecting environmental conditions (using environmental sensors and/or weather monitoring) and test system state data from the site, one can ensure the reliability of the inspection task and reduce the level of risk for all involved.
- Build trust over time and consider the cost-benefit for future algorithms and user interface enhancements. Managing costs and mitigating risk drive most decisions for NDT today. For organizations that depend on NDT, there are likely certain applications that will provide the greatest payoff in terms of cost and quality for their customers, transitioning from conventional NDT

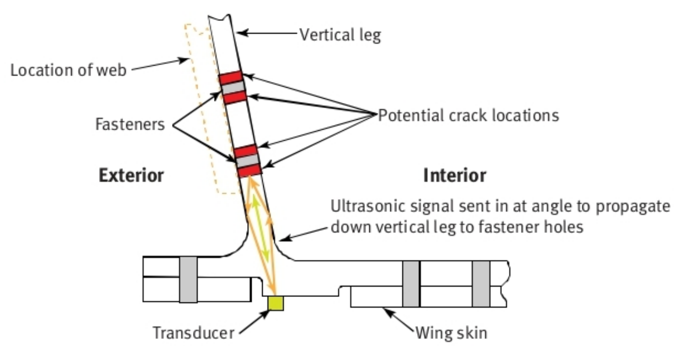

Figure 2. Inspection of beam cap holes in C-130 aircraft: (a) photo of area being inspected (looking forward); and (b) diagram of inspection problem (from Lindgren et al. 2005).

to NDT 4.0. The transition of algorithms should initially be a phased approach, to both validate the algorithm's performance and build an understanding of where algorithms are reliable and where limitations exist. By tracking called indications over time, it becomes feasible to refine algorithms as necessary. Building that experience internally and achieving an initial payoff will lead to a broader transition of these best practices across an organization and greater shareholder value. Organizational change management must ease this transition through the proper training of inspectors and also management of expectations.

Applications

Several case studies are presented in the following sections that highlight these best practices of leveraging algorithms in NDT applications and addressing human-machine interfaces. These early examples can be considered in the context of a minimal viable product, providing a product with just enough features to satisfy early requirements and provide feedback for future product development. These examples provide key insight on both the promise for NDT 4.0 applications as well as opportunities for future improvement.

Early Example Where AI Vision Becomes IA in Practice

Following the success of the C-141 weep hole inspection program (Aldrin et al. 2001), the development of automated data analysis algorithms was investigated for the inspection of beam cap holes in US Air Force (USAF) C-130 aircraft (Figure 2a) (Lindgren et al. 2005). Here, the fastener sites of interest were in locations of limited accessibility from the external surface and contain fasteners with sealant (Figure 2b). Due to limitations with the NDT capability at the time, there was a need to develop improved ultrasonic techniques to detect fatigue cracks at these locations. A key challenge was the ability to discern multiple signals originating from a possible crack and a geometric feature in a part that was either closely spaced or superimposed in time. The C-130 beam cap holes provided a special challenge given the skewed riser, installed fasteners, and limited transducer accessibility of the B-scan inspection (Figure 2b). This inspection problem frequently produced reflections from the fastener hole (referred to as reradiated insert signals) occurring at similar times of flight (TOF) as near and far crack signals. To address this challenge, a novel feature extraction methodology was developed to detect the relative shift of signals in time for adjacent transducer locations due to differing echo dynamics from cracks and part geometries (Aldrin et al. 2006). This technique was the first ultrasonic NDT method using assisted data analysis methods, validated through a POD study, to inspect for fatigue cracks on USAF structures (Lindgren et al. 2005).

A view of the operator's user interface, dating back to 16 years now, is presented in Figure 3. The original vision for the approach was to have the automated data analysis (ADA) algorithms make all of the indication calls. The team referred

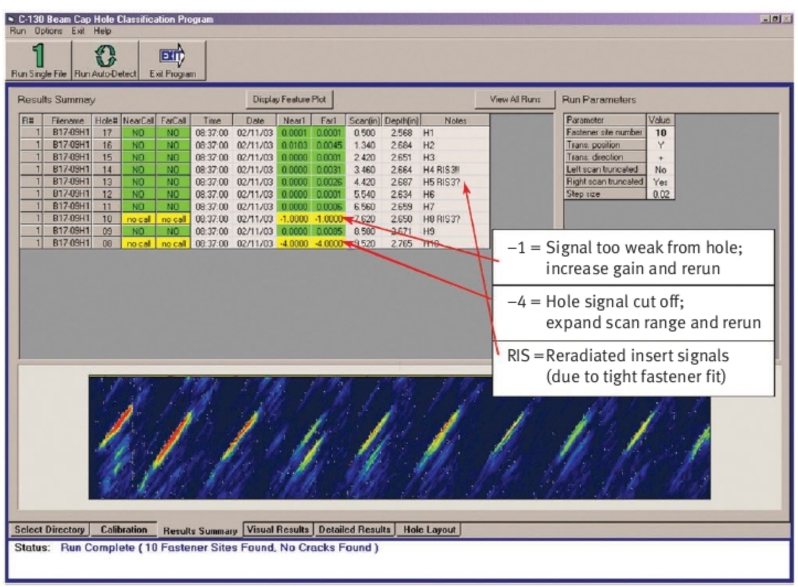

Figure 3. Graphical user interface for automated data analysis (ADA) software incorporating neural network classifiers.

to this early interface as simply "red light/green light." However, during transition, when a call was made by the algorithm, the question of "Why was the call made?" would immediately follow. Enhancements were made to the software to provide more specific feedback on called indications and highlight when data was not adequate for making indication calls. A couple examples of hole indications being too weak or cut off to make proper calls are shown in Figure 3. As well, certain severe structure-plus-fastener conditions were found to produce false calls on rare occasions. To manage these false calls by the algorithm, the results and raw data required a secondary review by inspectors. Inspectors were trained on what to look for in the B-scan to manage this limitation with the algorithm. Although this technique was the first AI/neural network–based approach used to inspect a portion of the USAF C-130 fleet, this case study is actually a very good example of IA in practice.

Lessons Learned on Improving the Human-Machine Interface

Ultrasonic testing is one of the most effective methods to detect critical defect types and ensure the reliability of aerospace polymer matrix composite structures. Most inspection applications of composites are based on pulse-echo ultrasonic testing and manual C-scan data interpretation. Using amplitude and TOF C-scan data, delaminations, disbonds, porosity, and foreign materials can be detected and located in depth. However, the ultrasonic inspection of large composite structures requires a significant work force and production time. To address this inspection burden, ADA software tools were developed and implemented (Aldrin et al. 2016a). The ADA minimizes the inspector's burden on performing mundane tasks and allocates their time to analyze data of primary interest. When the algorithm either detects a feature in the data that is unexpected or that is found to be representative of a defect, then the indication is flagged for further analysis by the inspector.

A software interface for the ADA toolkit is shown in Figure 4. The main view provides a summary of the found indications in the analyzed data, a visual presentation of an indication map, and quantitative metrics assisting the operator in understanding why each call was made. An example of ADA processing results is reported in the interface display shown in Figure 4. Options are provided to enter feedback into the "review" column to indicate if certain calls are incorrect. This example specimen contains artificial defects that have been added at varying locations and ply depth, including above and below the adhesive layer. Indications are listed in the spreadsheet display in the upper left, and corresponding numbers are presented identifying the indications in the C-scan image display on the right. For these ADA evaluations of the two different scan orientations, the three triangular inserts in the bond region were all correctly called. The left-most triangle is in front of the bond and the right two triangles are behind the bond. Indications for the six inserted

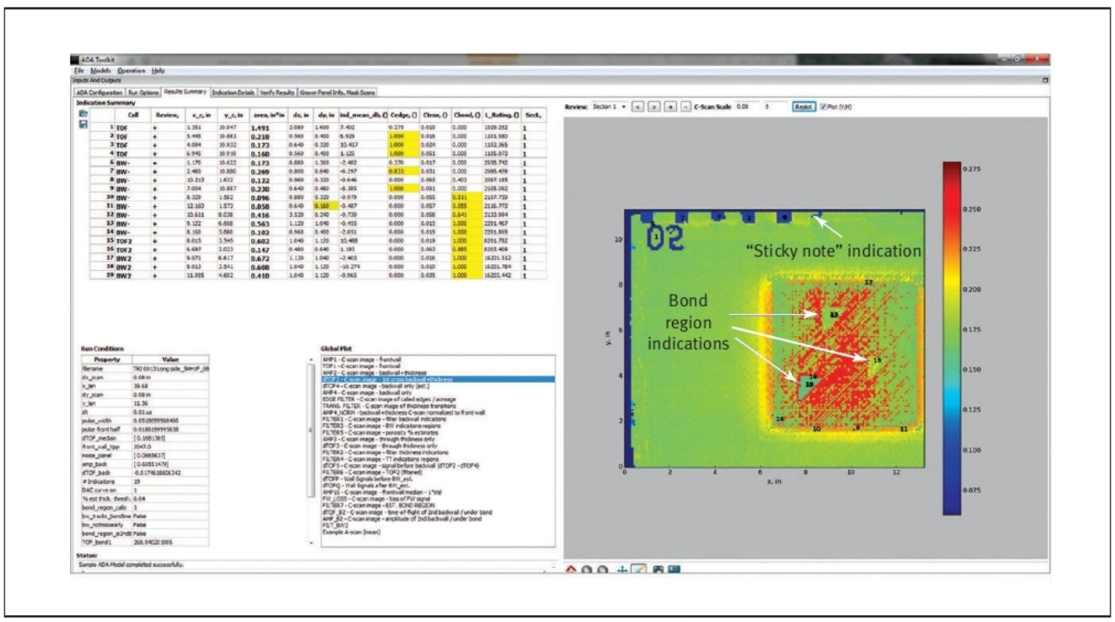

Figure 4. Example ADA toolkit interface with results for a test panel with embedded artificial defects, scanned from tool side, with time of flight C-scan view (adapted from Aldrin et al. 2016a).

materials at the radii are also observed in the TOF map in Figure 4. As well, there are options to add uncalled indications as missed calls into the ADA report with comments. Lastly, features are also provided to support verification of calibration scans, detecting the file and matching the indication calls with expected calibration results. During this development program, feedback from the team and end users was critical in delivering the necessary capability.

Ensuring NDT 4.0 Reliability

A helpful model to represent the reliability of an inspection system has been introduced by Müller and others (Müller et al. 2000, 2014). Total reliability of an NDT system is defined by the intrinsic capability of the system, providing an upper bound for the technique under ideal conditions, with contributions from application parameters, the effect of human factors, and organization context that can degrade the performance. While NDT 4.0 systems are expected to enhance POD performance through improved human factors (supporting ease of use) and repeatability in making complex calls with varying application parameters, NDT 4.0 capability must be evaluated. NDT techniques, whether incorporating AI algorithms, manual inspector data review, or a mixed IA-based approach, require validation through a POD evaluation. Comprehensive POD evaluation procedures (US DOD 2009; ASTM 2015) have been developed to validate the reliability of NDT techniques, regardless of how the indication call is made. In prior work, a POD study was conducted to evaluate the capability of an ADA algorithm to detect cracks around holes in vertical riser aircraft structures (Aldrin et al. 2001). In the study, an ADA approach incorporating neural networks was compared with manual data review by inspectors. Results demonstrated that the automated neural network approach was significantly improved in both detectability, false call rate, and inspection time relative to manual data interpretation (Aldrin et al. 2001). Other recent studies have also addressed the role of POD evaluation when human factors are involved (Bato et al. 2017).

The greatest challenge with validation of NDT algorithms is ensuring that the algorithm is not overtrained but can handle the variability of practical NDT measurements outside of the laboratory. Testing algorithms with independent samples with respect to training data is critical. Model-assisted approaches for training (Fuchs et al. 2019) and validation (Aldrin et al. 2016b) will help provide a diversity of conditions beyond what is practical and cost-effective with experimental data only. Because of these challenges, properly validating NDT techniques using IA is expected to be far easier than a purely AI-based technique. For the example of validating self-driving car technology, simply augmenting the driver experience with collaborative safety systems is much more straightforward to validate than fully validating an AI only–based self-driving car technology. Recent accidents during the testing of self-driving cars indicate the care that is needed to properly and safely validate such fully automated systems when lives are at stake.

Lastly, at this early stage in the application of AI and IA, there are currently no certification requirements for people who design and/or train such algorithms. However, as the field matures, such best practices should be shared throughout the community and included in accredited training programs. Over time, the potential value of implementing certification programs should be considered, possibly under the umbrella of NDT engineering.

Conclusions and Recommendations

While an increasing use of automation and algorithms in NDT is expected over time, NDT inspectors will play a critical role in ensuring NDT 4.0 reliability. As a counterpoint to AI, IA was presented as an effective use of information technology to enhance human intelligence. Based on prior experience, this paper introduces a series of best practices for IA in NDT, highlighting how the operator should ideally interface with NDT data and algorithms. Algorithms clearly have a great potential to help alleviate the burden of big data in NDT; however, it is important that operators are involved in both secondary indication review and the detection of rare event indications not addressed well by typical algorithms. In addition, IA provides more flexibility with the application of AI. When applications are not a perfect fit for existing AI algorithms, a human user can adapt and leverage the benefits of AI appropriately.

Future work should continue to address the validation of NDT techniques that leverage both humans and algorithms for data review and investigate appropriate process controls and software design to ensure optimal performance. Currently, AI algorithms are being developed primarily by engineers to perform very specific tasks, but there may come a time soon when AI tools are more adaptive and offer collaborative training. It is important for adaptive AI algorithms to maintain a core competency while also providing flexibility and learning capability. Care must be taken to avoid having an algorithm "evolve" to a poorer level of practice, due to bad data, inadequate guidance, or deliberate sabotage. Like computer viruses today, proper design practices and FMEA are needed to ensure such algorithms are robust to varying conditions. It is important to design these systems to periodically do self-checks on standard data sets, similar to how inspectors must verify NDT systems/transducers using standardization procedures or having inspectors perform NDT examinations periodically.

Lastly, NDT 4.0–connected initiatives such as digital threads and digital twins are examples of how material systems can be better managed in the future (Kobryn et al. 2017; Lindgren 2017). The digital thread provides a means to track all digital information regarding the manufacturing and sustainment of a component and system, including the material state and any variance from original design parameters. The digital twin concept provides a digital equivalent of a system and exercises the digital twin model through various use scenarios to evaluate individual performance and forecast possible emerging maintenance issues. NDT 4.0 systems are critical to achieving these digital thread and digital twin concepts, enabling an evolution in knowledge management for end users.

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