NDE 4.0 - NDE for the 21st Century –

The internet of things and cyber physical systems will revolutionize NDE

N.G.H. Meyendorf†, L.J. Bond[1], J. Curtis-Beard[1], S. Heilmann, S. Pal[1], R. Schallert [2], H. Scholz[2], C. Wunderlich[2]

†*Center for Nondestructive Evaluation, Iowa State University, 1915 Scholl Road, Ames, Iowa, 50011-3041, USA*

†*E-mail: norbertm@iastate.edu*

[1]Center for Nondestructive Evaluation, Iowa State University, Ames, USA.

[2]Fraunhofer IKTS, Dresden, Germany

Abstract

Challenges and opportunities for NDE within the new ecosystem of cyber physical systems for production, the internet of things and management of Big Data will be discussed. New production techniques, for example 3D printing will allow efficient in-time production of low numbers of unique parts customized for the need of any purchaser. Aspects of NDE reliability and the effect of the human factor has to be reconsidered. New hand-held devices based on tablet computers will be applied to make NDE available and affordable for anybody. As a benefit, product inspection at home can become an additional component of monitoring the life cycle of a product. This might significantly increase the acceptance of NDE by solving new inspection problems for all day service. NDE will revolutionize to NDE 4.0 for Industry 4.0

Keywords: NDE 4.0, Industry 4.0, quantitative NDE, personnel training and certification, standardization, modeling and simulation, internet of things, 3D printing, remote NDT,

1 Introduction

The internet of things and the next generation of industrial production (Industry 4.0) encompasses the complete networking of all industrial areas. New production techniques as for example 3D printing will allow efficient in-time production for low numbers of unique parts. A significant aspect is also quality and maintainability of these sometimes unique structures and components. NDE has to follow these trends by not only adapting NDE techniques to the new technologies, but also introducing the capability of cyber systems into the inspection and maintenance processes. This can be named as NDE 4.0. Aspects of the new trends are: 3D volume data creation and management of large files, component live data files, management of big data, real time monitoring of structure integrity, reliable inspection of individual components, NDE planning and interpretation based on modelling, and remote NDE to include competence not available onside.

New hand-held devices based on tablet computers or cell phones make NDE available and affordable for anybody. This might significantly increase the acceptance of NDE by solving new inspection problems for all day service. Adapting NDE to this new industrial and technological environment will

require new concepts for standardization and personal training. NDE 4.0 means NDE networking with production faculties and products. However, it can also mean NDE for everybody.

2 Industry 4.0 requires NDE 4.0

Industry 4.0 stands for the fourth industrial revolution that is ongoing. Industry 4.0 is a terminology generally used in Europe to characterize the integration of production and communication technologies, the so-called "smart factory" [1, 2]. The first industrial revolution was the mechanization of work. The second was mass production and the assembly line. While the third revolution was the computer integrated manufacturing. Industry 4.0 encompasses the complete networking of all industrial areas. Lowering costs and efficient in-time production will be possible for low numbers of unique parts for example by additive manufacturing (3D printing).

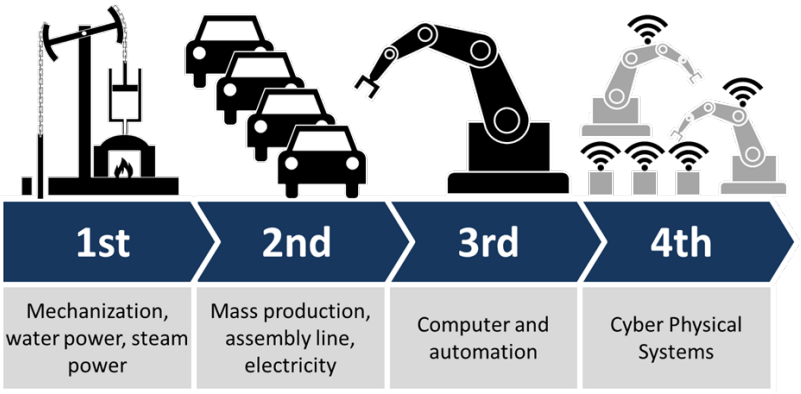

Figure 1: Industrial revolutions and future view [3]

A look into the history shows that every industrial revolution has been accompanied by the introduction of new NDE methods. However, it also results in new ways to apply these methods. The development of NDE can be categorized into four steps that are related to the industrial revolutions [4].

The first industrial revolution is characterized by mechanization, replacement of muscle power by steam power, and production of unique components. NDE has been performed randomly by using human senses (visual testing and sound testing).

The second Industrial revolution introduced assembly lines for mass production of identical components by using electricity. NDE applied techniques to enhance the detectability of human senses (**L**iquid **P**enetrant testing - LP, **M**agnetic **P**article testing - MP) for a 100% manual inspection of selected safety relevant parts.

The third industrial revolution made automation of production possible by electronic control and data processing using multifunctional microelectronic systems. NDE, as science, made significant progress

in applying physical effects to materials. Detection and quantification of defects and measurement of material properties by interplaying materials with radiation or electromagnetic fields is one such instance. Eventually this was termed as Quantitative NDE (QNDE) [5, 6]. **U**ltrasonic **T**esting (UT), X-ray Testing (RT) and **E**ddy Current **T**esting (ET) dominated among all other NDE methods. Until today, NDE in industry characterized by manual or automated 100% inspection of large quantities of parts using portable instruments or automated systems. Manual interpretation of results using basic rules and standards is still state of the art for in-service inspections.

Industry 4.0 stands for the fourth industrial revolution that is in progress. Industry 4.0 is a preferred terminology used in Europe to characterize the integration of production and communication technologies. It is the so-called "smart factory". AS described above this encompasses the complete networking of all industrial areas. NDE has to follow these trends, by introducing the capability of cyber systems into the inspection and maintenance processes. NDE 4.0 will require:

- the integration of NDE facilities into the industrial networks with automated inspection and interpretation of results,
- Introducing NDE modelling for development production and inspection processes,
- permanent monitoring of the production process as well as the components in service and
- handling large amount auf inspection date (Big Data).

New 3D imaging techniques are now introduced in the industry like x-ray CT, phased array ultrasonics, optical or thermographic methods and Terra Hertz imaging; techniques all capable of creating tremendous about of data in a very short time.

It can be concluded that an industrial revolutions will also trigger a revolution – in the technology of NDE available today. This will not only be a modification of NDE for the new world but also the new tools available on the marked today have the potential to revolutionize the way where, when, and how we apply NDE in the future. This is NDE 4.0.

3 NDE 4.0 for Additive Manufacturing and NDE modelling

Techniques known as Rapid Prototyping or Additive Manufacturing, for example 3D printing, are capable of producing unique parts tailored to the special needs of customs. The parts produced today with this technique are usually not safety relevant. However, this might change with progress of the technology. Theoretically, a complete turbine engines could be printed in the future. A significant aspect of this is also the quality and maintainability of these sometimes unique structures and components. New NDE methods have to be developed for monitoring of a laser melting process by acoustic backscattering or measurement of the emitted radiation, for example [7, 8]. Modeling will be a

significant tool for planning NDE experiments or interpreting NDE results. Such tools are now available. The CNDE had developed software tools for UT, RT and ET known as “CNDE SIM” [9].

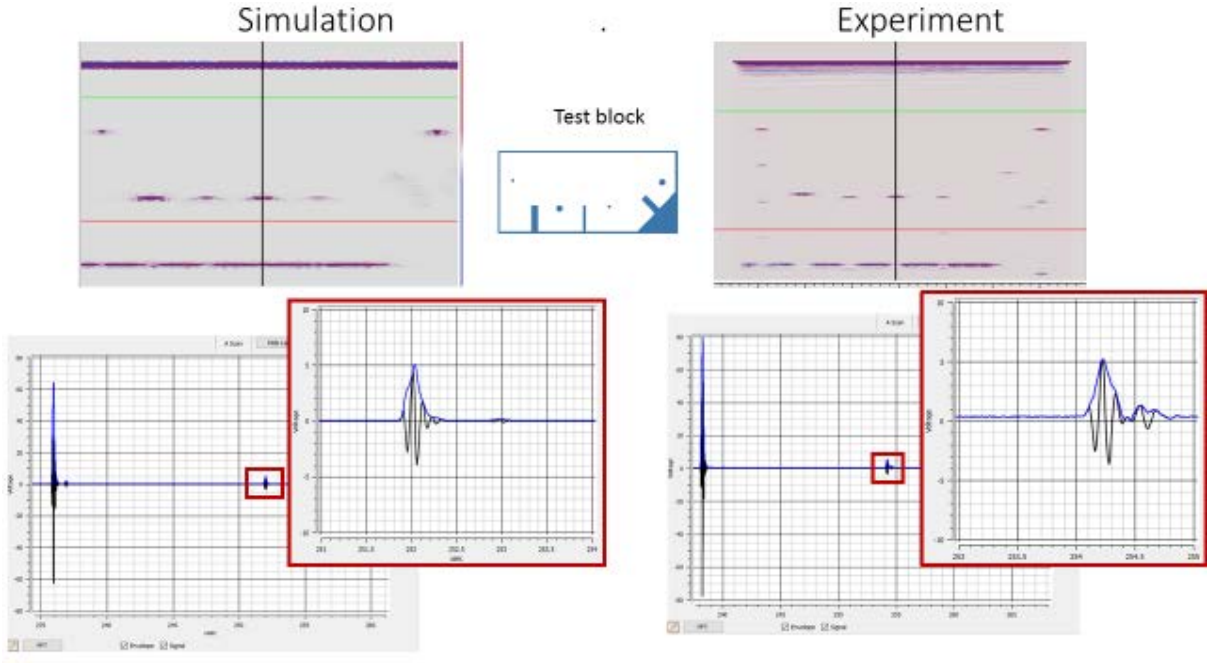

Figure 2: Comparison of simulated versus measured Ultrasonic results using UT SIM [10]

Techniques to quantify the microstructure of printed parts are under development [11]. For detecting micro porosity in complex shaped components, high resolution x-ray CT and laminography can become the golden standard for NDE of printed parts [12].

4 Reliability of NDE and the human factor in NDE 4.0

Production on demand will result in a paradigm shift in industrial quality management and NDE. Classical quality concepts are based on established optimized process chains, statistical process control and statistic quality planning (Six Sigma). This will not be applicable for unique individual tailored parts [13]. Process monitoring with integrated intelligence and self-teaching or including external experts in decision-making will be essential for components related to safety. Using new technologies to enable a “tele-presence” gives the potential to improve the inspection process. Today’s technology potentially allows one to control NDE inspections remotely, even form another continent. This has the added benefit of including the competence of the most experienced inspectors from around the world, in decision-making.

Conventional internet tools like Skype and Splashtop Remote Access can be used to communicate between inspectors and allow remote interaction via an external PC attached to the NDE hardware. For these applications, NDE hardware shall be used that uses a PC or laptop as the human interface.

An experimental remote interaction between two continents has been tried. The hardware used are the PCUS Ultrasonic system (manufactured by Fraunhofer IKTS), in combination with camera glasses (such as a google glasses or helmet cameras). The screen-sharing medium used in the process was Splashtop. The whole process requires a good WIFI/internet connection for both parties to be able to communicate.

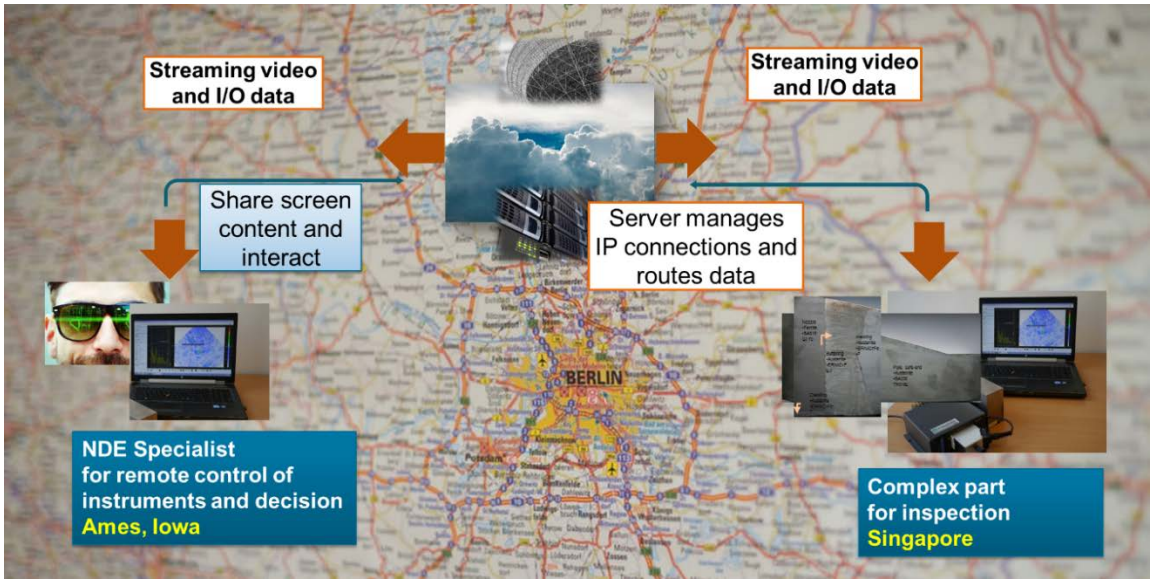

Figure 3: Concept for remote NDE [14]

New technology provides us with excellent measurement tools, affordable, simple to handle, and high performance that can be accessed from everywhere. However, we have to know what data we need and how to analyze. The Internet allows the involvement of specialists worldwide to discuss results and make decisions as shown in the remote NDE interaction above. The challenge is to identify the right persons.

In a world of composites, 3D printed components, smart structures and materials, data and information, we need is a “Machine Doctor” who is not only an expert in all the potential NDE techniques, but is also knowledgeable in the areas of materials structure and properties, design concepts and service conditions [15]. He must combine this knowledge to select the most efficient diagnostic (NDE) method for a case and make a final decision about the health of a structure. Indeed, this will raise the importance of the human factor. However, a specialist of such a stature might not be available for on-the-spot inspections all the time. Here lies the necessity of remote NDE interactions. For a complex task, like inspection of individual intricate components, there is a need for a specialist to be able to participate in an inspection remotely. It is also important to have this kind of specialists in the future. Therefore, NDE 4.0 should also take upon itself the task of nurturing, educating and training students and young scientists.

5 NDE 4.0 for everybody

The highly powerful but widely available electronic devices, such as tablet computers and cellphones, incorporate various sensors in the form of cameras, microphones, vibration sensors and accelerometers. Other smartphone attachable tools are available for purchase like IR cameras [16], terahertz arrays [17], eddy current transduces [18] that can be used for household NDE. The use of these tools is as simple as downloading an app from the App store and attaching the removable device to the phone. That is literally everything that is necessary to start taking measurements. This will make the whole world's accumulated knowledge (that is, a large amount of data) available to anyone at any time and any place. For the younger generation (a generation, unfortunately, not much involved in NDE jobs today) this technology is self-evident and they possess a natural flair for it. Merging the highly specialized knowledge of the NDE techniques with today's technology will open a new market for NDE 4.0 [19]. These new hand-held device will be applied to make NDE available and affordable to anybody. As a benefit, product inspection at home can become an additional component of monitoring the life cycle of a product. This might significantly increase the acceptance of NDE 4.0 by solving new inspection problems for all day service.

In [20] this author published some ideas that students in an introductory NDE class at Iowa Stata University generated in class projects. Examples are:

- Self-Inspection of used automobiles by acoustic signal analysis of, for example, engine noise, using a cellphone based eddy current measurement system,
- Portable viewing of x-ray films,
- Visual inspection of glass defects, for example at car wind shields,
- Unmanned Arial systems for pipeline leak detection and inspection,
- Detecting of heats loss, electrical overheating or fault ventilation at home.

6. Conclusion

Industry 4.0 and the ability to tailor individual components to the customer's needs will significantly impact the way we provide NDT inspections. NDE has to be integrated into the production process by networking with the machines and materials during the manufacturing. This will result in a paradigm shift in industrial quality management and NDE. Classical concepts based on comparison of multiple similar components and statistical analysis will not be applicable under this conditions. This will raise the impact of the human factor. Having specialist that are able to make the right decisions based on NDE results, the knowledge about the material and the components, loading conditions, and NDE modelling of NDE experiments, will be essential for the future. Instruments affordable for everybody

can significantly enhance the NDE market, and inspection at home can become an additional component of monitoring the life cycle of a product. Therefore, industry 4.0 will result in a transformation of NDE to NDE 4.0.

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