Using Remote NDE, including External Experts in the Inspection Process, to Enhance Reliability and address Todays NDE Challenges

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Abstract. The paper discusses the challenges for NDE operating in the environment of advanced manufacturing techniques characterized by networking of systems. The information environment is impacting all industrial areas (Industry 4.0) and production of individual components tailored to meet the needs of individual customers. The emerging approach of using remote NDE is seen as a potential technique to increase reliability of NDE inspections by integrating additional specialist in to the decision process by "tele-presence." This can also help to leverage the scarce resource of senior inspectors and have them engaged with industrial inspections at multiple sites. This distance engagement has the potential to enhance performance of inspections, starting from inspection design through to enhanced data analysis and hence enabling reliability of NDE to be improved.

1. Introduction

Lowering costs and improving efficient in-time production will be possible for small numbers of unique parts fabricated using new technology such as additive manufacturing (3D printing). These manufacturing changes are being accompanied by networking of systems in all industrial areas, and with the "internet if things," and paradigm shifts such as Industry 4.0 which bring together cyber-physical systems and cloud computing.

Industry 4.0 stands for the fourth industrial revolution that is ongoing at present. The terminology Industry 4.0 is preferred in Europe and used to characterize the integration of production and communication technologies into 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 and the third revolution was the integration of computers into manufacturing. Industry 4.0 moves connectivity to a new level and encompasses the complete networking of all industrial areas. Such changes can result in lowering of costs and enable efficient in-time production for small numbers of unique parts, for example those built using additive manufacturing (3D printing). A significant aspect of additive manufacturing is the need to also ensure initial quality and maintainability, particularly for what can be unique structures and components. To meet such quality challenges NDE has to be adapted to address needs throughout the process, from feed stock characterization, through in-process measurements and then inspection of finished parts, which can be near impossible to inspect using conventional NDE. Such needs can only be met by adapting NDE techniques to meet the needs of the new manufacturing technologies, but also by introducing the capability of cyber systems into the inspection and maintenance processes.

Looking into the history of manufacturing it is seen that each industrial revolution has been accompanied by the introduction of new test, measurement and NDE methods However; it also results in new ways to implement and deploy established methods. The development of NDE can be understood and in four steps that are related to the changes that occur in an industrial revolution. With changes in manufacturing and processes it has been seen that an industrial revolution will also trigger an evolution if not a revolution of NDE technology needed to address the resulting new needs (Table 1).

Table 1. Stages of industrial development and related NDT applications

Industrial Revolution	**1st**	**2nd**	**3rd**	**4th**
	Mechanization Replacement of muscle power Unique components	Mass Production Assembly lines Electrical Energy Identical components	Automating Electronic control and data processing Multifunctional micro-electronic systems	Cyber-physical systems Learning and decision making machines Individual customer tailored components
NDT/NDE	**1st**	**2nd**	**3rd**	**4th**
	Using human senses (Sight and hearing) Random inspection	Enhancing detectability for instance for surface breaking cracks by human senses (LP, MP) 100% manual inspection of selected safety relevant parts	Using physical effects, radiation or energy fields to detect defects, measure material properties (RT, UT, ET) Manual or automated inspection 100% inspection of large quantities of parts	Use cyber-physical systems (Internet of things, Cloud computing, Modelling) (CT, PA, IR, THz) Continuous monitoring of manufacturing processes or components in service, Large volume data files (3D images), Modelling NDE for everybody

2. Classic NDE Strategies and Reliability

The science and technology that is now employed in NDE, and an increasing range of related endeavor’s, has been developed over a period of much more than the 45 years of existence of the QNDE community [3]. Its roots go back to the activities that spawned NDT; the measurement components, which employ radiography, followed from the discovery of X-rays in 1895 by Wilhelm Roentgen. Ultrasonics had its roots in physical acoustics and SONAR from about 1912, and many millennia earlier in “tap” testing for pottery condition assessment and in electromagnetic methods for NDT. These can be traced back to work in the 1880’s.

The needs for applications of NDT received a real boost during World War II, and its use grew further in the post-war period, but it remained a workmanship standard and a tool for use in periodic testing. In the 1960’s and into the early 1970s, there was a growing fundamental understanding of the significance of flaws in metal structures and their subsequent impact on performance. This was, in part, driven by the desire for safety with the emergence and utilization of high-cost, high-risk technologies in defense systems and in the civilian aerospace and energy communities, including nuclear power.

It was also becoming clear that there was a need to better understand the significance of defects, in terms of component life, the potential which they had to cause failure and the statistical performance capabilities of both inspectors and inspection methods. A science base for the theory and measurement of materials characterization, including the use of accelerated aging programs, began to be developed. It was increasingly seen that the capabilities of then available nondestructive testing (NDT) were limited, and that there was a *lack of an adequate science base for NDT to become a quantitative science*. It was also seen to be necessary to improve the understanding of the science for interrogating energy-material interactions on which reliability of inspection is based. There followed the desire to better relate types and size of defects to their structural significance, under structural integrity, and to quantify NDT performance with probability of detection (POD) and ultimately implement risk-based reliability assessments [4, 5].

Several major research programs were initiated to provide the required science base, including one that considered the development of what was named *quantitative nondestructive evaluation (QNDE),* which sought to meet the needs of the aerospace community. Examples of developments included, in Germany, the establishment of the Fraunhofer Institut für Zerstörungsfreie Prüfverfahren [Nondestructive Testing] (IZFP) in Saarbrucken, in the United Kingdom (UK) it was the U.K. Atomic Energy Authority (UKAEA), Harwell NDT Center, which initially looked at nuclear needs and the British Gas programs for pipeline inspection. These activities all largely followed the growth of high technology energy (principally nuclear, and then off shore oil and gas), aero-space and defense systems [3, 4, 5].

NDE has tended to be driven by failures in systems, such as the early de Havilland DH 106 (Comet) crashes, the Aloha airline crash (1988) and the United, Sioux City, Iowa, crash (1989), together with corresponding events in other industries, but it is more than just a tool to improve safety. It is an enabler for understanding and characterizing materials on the engineering scale, it is a bridge that connects the insights of “slice and dice” for materials examination in the laboratory to inspection at manufacture, during fabrication/integration, installation and during service. It can be an integral part of the design and optimization of the life cycle, which can guide materials selection, contribute to setting performance boundaries and impact energy utilization [3, 4, 5].

NDE science continues to seek to understand the physical mechanism of nondestructive inspection methods, mostly implemented using isolated systems usually not capable of communicating and exchanging data with other production devices and units in the facility. Opportunities now exist for a next step forward that can be truly transformational.

Everybody is familiar with cellphones and tablet computers making the world’s knowledge and a large amount of data available to anybody at any time and place. These systems can operate with diverse arrays of sensors. Additional components can be purchased with the potential to perform NDE tasks. Most of this capability has been created or even re-invented without the community being aware that this is a field of activity known as NDE. How can this new technology impact NDE?

Classical NDE strategies are based on experience gained through making repeated measurements on similar objects and understanding defects types and the responses they produce using sensors and instruments. Determination of a probability of detection (PoD) is most useful for assessing inspection of larger numbers of similar objects. The need to address quality assurance and maintainability for unique structures and components, such as those increasingly produced by additive manufacturing, is an increasingly important challenge.

There seems to be an opportunity for a *Paradigm Shift in Industrial Quality Management and NDE*. A change as significant or even more significant as the move from NDT to the more science based NDE. Classic quality concepts are based on established

optimized process chains, statistical process control and statistic quality planning (Six Sigma) and validation through destructive testing of random samples.
Advanced manufacturing is seeking to enable production “on demand” – customer configured additive and classical fabrication technologies in combination with a new paradigm of quality assurance and integrated intelligence [6]. In a recent Frost and Sullivan [7] report the author makes various 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.

NDE needs to look at how best to enable inspection of complex and unique components and make the ability and experience of the senior inspector (Level 3) locally available. This might be able to happen in conjunction with modelling capabilities when for example performing ultrasonic inspection and interpretation of results.

3. Market Available Communication Tool to be Used for Inspections

Using new technologies to enable a “tele-presence” gives the potential to transform and improve the inspection process. Today’s IT has the potential to allows remotely controlling of an inspection, even form another continent, and including the competence of the most experienced inspectors in decision-making. This can be supported by modelling of the inspection process and new approaches to data recording such as CT with X-ray and full matrix capture for ultrasonics. These data can then be analysed and results, such as defect locations and characteristics added to analysis and life estimation tools.

For the young generation (unfortunately a generation that is not much involved in NDE jobs today) this new approach to IT and data is self-evident and they perform tasks using multi-media devices, communication and connectivity with virtuosity. Merging the highly specialized knowledge of the NDE techniques with today’s IT technology, such as:

- Internet of Things,
- Cellphones and tablets,
- Data Clouds,
- Low cost miniaturized sensor systems and cameras,
- Effective modelling of NDE techniques

has the potential to prepare NDE for the challenges of Industry 4.0 and make NDE attractive as an area of endeavour for the young generation.

As a benefit the ability to utilize NDE techniques will become affordable for everybody and product inspection at home can become an additional component of monitoring the life cycle of a product.

Conventional internet tools like Skype and Splashtop Remote access can be used to communicate between inspectors and allow remote connection and interaction form an external PC combined with NDE hardware, such as that shown in Figure 1. This NDE hardware it can be used with a PC or laptop as human interface. An example is the PCUS system form Fraunhofer IKTS in combination with a helmet camera or camera glasses.

In demonstrations of remote NDE between continents Splashtop was used for the remote access to the UT device and a parallel Skype channel was available simultaneously at the some devices for communication. Figure 2 depicts the concept.

Figure 1. Hardware for Remote NDE

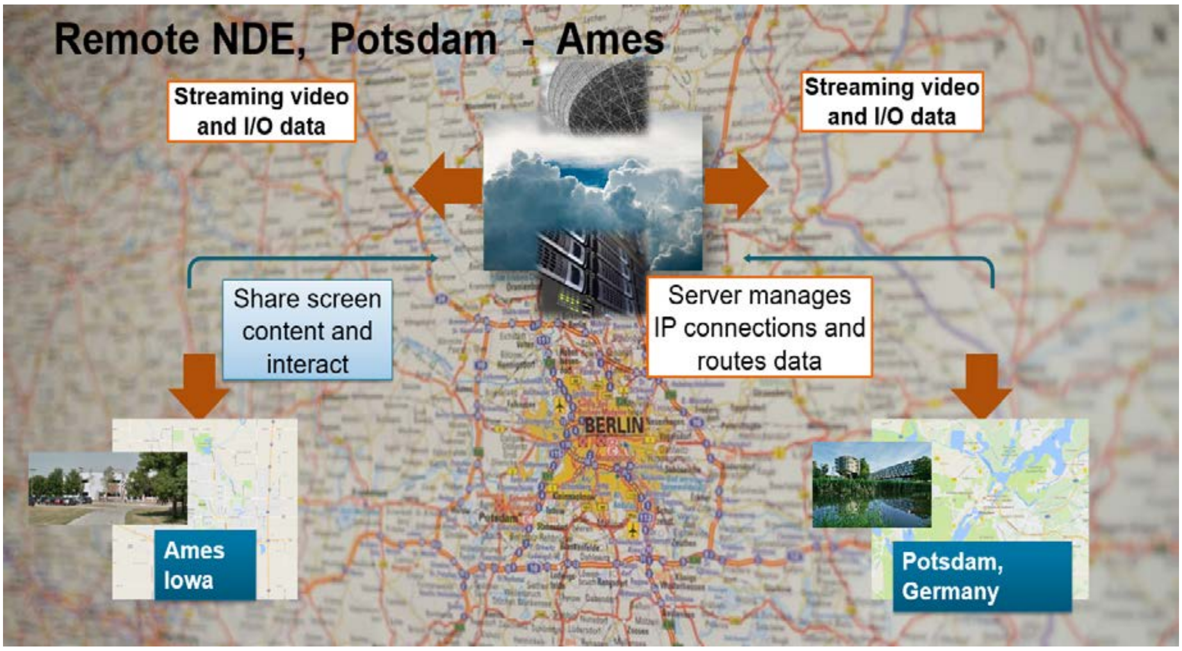

Figure 2. Concept for Remote NDE

4. A new Way of Performing NDE Inspections

NDE can provide a lot of useful (or useless) data regarding a structure, loading conditions, and health of a material or component. However, it is very unlikely that only by processing of NDE data and combining this with modelling reliable life predictions for aging components will be successful. This is due to the complexity of design, material structure, and real world loading conditions (combines mechanical, thermal, chemical…). After decades of research worldwide we don't have widely and reliable applicable solutions for many complex metallic components. For composites the situation is even more complex and challenging. A more demanding case will be for items created using additive manufacturing, where uncertainties in the printing process and the resulting microstructure arise. We need a new way of thinking in NDE.

The traditional NDE philosophy is:

- One component,
- One inspector,
- One instrument,
- Decisions based on rules and standards.

This will not satisfy future challenges where we theoretically can print complete aircraft engines and every part can be unique. We should learn from medicine where doctors are always challenged by the complexity of the health, and sickness, condition of humans. One possible way where NDE could learn from medicine is set out in Figure 3, and it appears that such an approach could help NDE to be successful in the future.

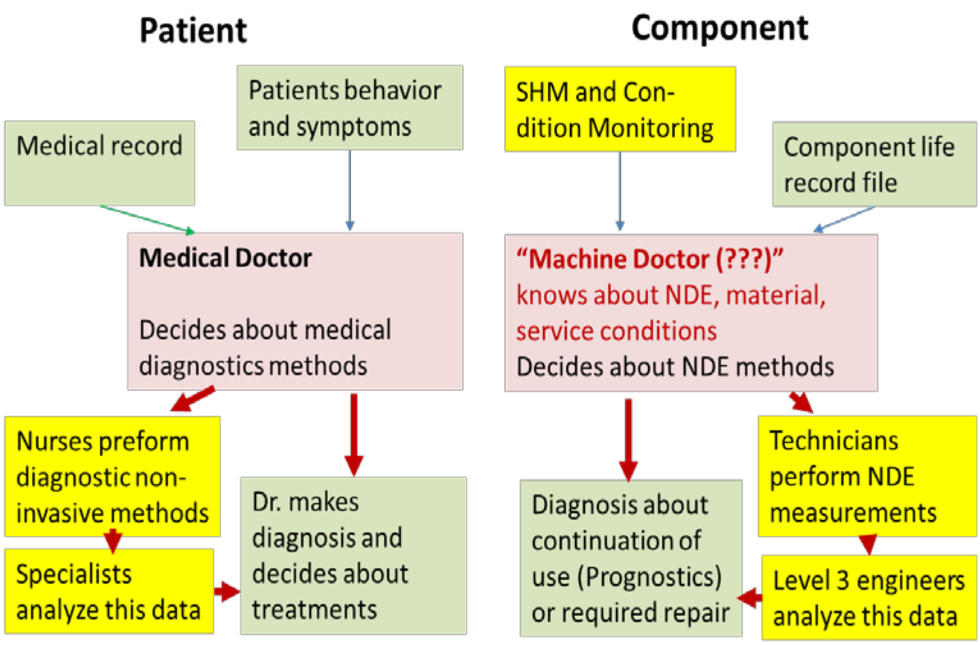

Figure 3. Learning from Medicine [5]

Today's IT technology provides us with excellent measurement tools, affordable, simple to handle, and high performance that can be accessed from everywhere, but there is a need to know what data are needed and how they should be analysed. The Internet gives the opportunity to enable engaging specialists in a worldwide NDE network to discuss results and contribute to decisions as shown above. The challenge is most likely to be how to identify and access the right person. Powerful modelling tools make us believe that we can understand everything, but todays modelling is always based on simplifications and assumptions which are needed to create algorithms.

What we need to face future challenges in a world of composites, 3D printed components, smart structures and materials, and infinite data and information is a "Machine Doctor" who is an NDE expert and also understands materials structure and properties, design concepts and service conditions. This person is a NDE Engineer who has the combination of knowledge needed to select the most efficient diagnostic (NDE) method for a part or system and who can make a final decision about the structures health. Indeed this will raise the significance of the human factor in the analysis process. However, for such complex tasks as inspection of individual complex components adding the specialist that might be able to participate from a distance may become critical, particularly given aging issues in the NDE and wider engineering workforce. This remote connection may be the only way to provide access to the specialist in the future.

5. Conclusion

Industry 4.0 and the ability to tailor individual comports to the customers needs will significantly impact on part design and on the way we will provide NDT inspections. Concepts based on comparison of multiple similar components and statistical analysis will not be applicable under these conditions. This will raise the impact of the human factor. Having specialist that are able to make the right decisions based on NDE results, have the necessary knowledge regarding materials and the components operational conditions can be important for the future. The specialist can participate in inspections remotely form a distance. The challenge will be having these specialists. Such changes will require a revolution in the education and training process, and in the way NDE is implemented, data reviewed and managed.

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