The future of NDT with wireless sensors, A.I. and IoT

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Abstract

Wireless connectivity to test probes and sensors is entering the Non-Destructive Testing (NDT) sector. Processing of data in many industries already relies on Artificial Intelligence (A.I.). And, at the same time, cloud-based data storage has been surrounding the NDT field, as virtually every NDT user also employs cloud storage for production data, processing tools, and reporting. Despite hurdles such as oil & gas regulations and restrictive guidelines and habits with respect to workflows and data storage, the Industry 4.0 revolution is omnipresent. The opportunities of the Internet of Things (IoT) and Big Data are understood and adopted by virtually all industries and more and more companies today. In this paper, we identify major inefficiencies in NDT workflows today. On examples from various industries, we illustrate how productivity levels can be increased, money saved and overall inspection speed multiplied. Capabilities of A.I. in test data interpretation, combination of data, immediate reporting, and real-time sharing are demonstrated. With this paper, we propose to initiate a task group of experts to foster usage of the new Industry 4.0 instruments in NDT and to support users in adapting the internal workflows and processes to increase the competitiveness of NDT overall.

Keywords: Non-Destructive Testing (NDT), Instrument, Wireless, Internet of Things (IoT), Big Data, Industry 4.0

1 Non-Destructive Testing (NDT) in the era of Industry 4.0

In recent years, much is being written about the growing degree of manufacturing automation thanks to the implementation of increasingly sophisticated, interconnected, and data-exchanging industrial systems, also known as “Industry 4.0”. The drivers behind this trend are the increasing affordability of miniaturized, wireless sensors; the ubiquity of their interconnectivity over the Internet; the cratering costs of cloud-based data storage/processing; and the rapidly improving analysis and recommendation capabilities based on said data, by using increasingly accessible and performant use-cases for Artificial Intelligence (A.I.).

Far less attention has been paid to the Non-Destructive Testing (NDT) industry’s role in supporting the goals of Industry 4.0, beyond just in manufacturing operations, and in fact along the entire lifecycle of products and productive assets, the integrity and safety of which must be assured periodically. Contributing factors are the typical lifecycles of products of an average of seven up to ten years, business models that rely on one-time hardware purchase schemes, standardization hurdles, and the high degree of expertise that has traditionally been required from inspectors.
To the contrary, the authors have been observing and shaping a decisive and growing overlap between the goals of Industry 4.0 and NDT. NDT stands for increased quality, productivity, safety, and — ultimately — sustainability. Hence, the future of NDT is tightly linked to processes featuring higher accuracy, fewer errors and hence an increased probability of detection, as well as granular data and valuable insights that are accessible anytime from anywhere around the world. Testing will be carried out by groups of people rather than individuals, with a higher variance of skill. Productivity and speed will play an increasing role. We thus foresee that future-proof NDT will enable cost savings while improving outcomes, to a large part by helping users to massively reduce or even entirely avoid rework.

2 NDT as a poster child for Industry 4.0

By taking a value-stream-focused, customer-oriented view of operations and processes, we have observed that contemporary NDT technology is already gradually enabling two of Industry 4.0’s four design principles: 1) interoperability and 2) technical assistance. This is achieved by utilizing more and more NDT data collected by wireless sensors, exchanged over the Internet of Things (IoT), and analyzed by A.I. to generate insights around the object at hand, be it an artifact traced along a production line, or an entire building monitored and recorded along its entire lifecycle, respectively.

In the near future, we also expect NDT technology to gradually enable also the other two principles of Industry 4.0: 3) information transparency and, ultimately, 4) decentralized decisions. This could be achieved by enabling users to shift the burden of deriving actionable insights from fused heterogeneous data onto automated A.I. algorithms, thus making it possible to increase the level of object’s predictive and reactive self-monitoring and self-management.

As any technology and product, also NDT is subject to increasing regulatory pressures. For example, in the oil & gas sector and automotive industry, usage of recording devices, data storage and sharing over the IoT, as well as a legacy of restrictive guidelines and habits of established workflows increase the barrier to the actual user to adopt new technologies that can significantly advance testing in terms of productivity and certainty of the results. Nevertheless, the transformation and shifts of large blue-chip supply companies to become IT companies, the introduction of Industry 4.0 sensor concepts in the production lines as well as the adoption and pressure from new market entries and start-ups drives the trend to adopt these new technologies. Early adopters not only see their immediate benefits, but also understand the advantages of adopting associated new business models.

3 A value-stream view of NDT applications

On the following pages, we present the results of adopting a value-stream view to create and observe in action the future of NDT thanks to the key technologies of wireless sensors, A.I., and the IoT. We have
done so using examples from NDT applications in the post-construction inspection of reinforced concrete structures, and in the hardness testing of metal parts, respectively.

The value-stream focus led us to take an end-to-end view of operations and processes involving NDT. We have thus evaluated the potential for increased productivity across applications and industries by looking at the total lead-time of a high-level, generalized NDT inspection process. This consists of three phases: a main “Measurement” phase buffered between a “Preparation” and a “Reporting” phase. In the prior “Preparation” phase all user activities are included that are necessary to ensure an accurate measurement according to a given standard. In the latter “Reporting” phase all user activities are included that are necessary to generate an error-free, high-quality report of the measured data and any derived insights according to a given standard.

Most surprisingly, our finding has been that, despite the prevailing perception of users that the “Measurement” phase stands for NDT by itself, across applications it frequently accounts for less than 50% of the total lead time of an end-to-end NDT inspection. Moreover, the flip side of this finding is that the “Reporting” phase frequently accounts for more than 50% of the total lead time. And, given the large degree of manual and repetitive work involved, it is often the source of preventable errors, e.g. regarding the quality of data transcription and interpretation. In contrast to these findings, the “Preparation” phase typically represents a small part of an end-to-end NDT inspection workflow, even though diligent execution of its sub-tasks (e.g., calibration) can decidedly impact the quality and effort required for the next phase. Or, in the inverse case of a botched Preparation, can render moot the large effort for the “Reporting” activities of flawed collected data.

Correspondingly, we have identified and addressed five major pain points associated with end-to-end NDT inspection processes as described above. We have done so through the practice of Design Thinking in the field next to NDT equipment users in manufacturing and post-construction inspection processes. For example, in optimizing workflows we accompanied NDT professionals in the field, observed their working procedure, broke it down into separate steps, and analyzed each step as well as the entire procedure for improvement potential. We have also taken inspiration from contemporary achievements in the growing fields of A.I. acting to augment the human user’s “intelligence”, as well as by questioning the status quo of expensive activities, such as those in the “Reporting” phase.

4 Major pain points in the NDT industry

Complex user interfaces: Most of the NDT equipment looks complex and is also complex in use, as it has typically been designed by technicians for experts. Not only the measuring process itself but also the presets intended to ensure the correct setup prior to the measurement exceed, in some cases, the understanding of the user.
**Inefficient workflows:** As an example, creating and marking a test grid on the object to be investigated is time-consuming and cumbersome. Current solutions require a fixed grid that is usually plotted with a chalk line, measuring tape and a marker. The accuracy of the result depends on the exact positioning of the probe on the predefined grid. Another example relates to a popular method to assess the compressive strength of a concrete structure according to the EN 13791 standard. The procedure requires a minimum of nine impacts with a Schmidt hammer at a minimum of nine different test locations. During data collection, all rebound values need to be recorded. Based on the standard, outliers need to be identified and median rebound values calculated. So far, such procedures have been manual and, therefore, error-prone.

**Complicated data interpretation:** In analyzing measurement results of tomographic technologies, competence in analysis and therefore the quality of the findings can vary greatly between operators. While experts often rely on unprocessed data to reach experienced conclusions, non-experienced users prefer processed and graphical images to interpret the results. Another example can be provided by the use cases of contemporary rebar locators and cover meters with eddy current technology. These devices struggle with the influence of neighboring and second layer rebars lying within the field of detection, leaving a lot of room for interpretation errors up to the user.

**Incomplete traceability:** Until today, NDT equipment operators have had to manually document measuring procedures in such a way that they can prove the required guidelines have been followed, and the instruments and the probes being used have been properly calibrated and verified. So far, this type of activity has been entirely manual. Furthermore, it has suffered from fragmented sources of information, a lack of overview of the step-by-step workflow of the operator, and of any changes or deviations from the original procedure. These issues lead to a lack of traceability along the process.

**Obstructed data sharing:** One of the most time-consuming tasks today is to process the results after a day of collecting data in the field. Observations have disclosed that the time spent on this task can be a factor between one and two times the actual time used for the measuring task. Communication of results has become an important element when interacting with colleagues on a large investigation site, the back office, suppliers, or customers. In addition, the amount of data collected, especially when using tomographic technologies such as radar, ultrasonic or eddy current array solutions, has significantly increased. Thus far, data has been typically stored on paper, in the NDT device itself, or on removable storage. Some devices have relied on manual export of data using said storage, followed by post-inspection analysis of the data after importing it into tools on a PC.
5 Innovating in NDT with wireless sensors, A.I., and the IoT

Real-life examples are presented below, of how recent innovation and breakthroughs in NDT around wireless sensors, A.I. and IoT address NDT users’ pain points in concrete rebar and flaw detection, and in metal hardness testing.

5.1 Increased ease-of-use with user-friendly and intuitive user interfaces

Many instruments used in NDT are complex in use and require days, weeks and even months of training. Similarly, photos cameras used to be expensive and restricted to experienced users who attended courses to achieve decent results. Today, mobile devices show how taking photos and even selfies has been simplified to a level where children as well as non-experienced individuals can make use of them.

Figure 1 demonstrates how tomographic structural investigations can become as easy as “looking into concrete” using the equivalent of a mobile device camera, thanks to a thought-out user experience and intuitive user interfaces. This allows businesses to send out operators with less application know-how to execute the measurements on-site, ideally combined with access to the data by experts remotely from the office, using IoT.

Figure 1: iOS camera vs. Proceq GPR Live user interface. The large photo screen on the left is optimized to show the entire image, while the zoom slider on the left, the trigger button on the right and the toolbar and settings menus are easily accessible and intuitive to understand. On the right, radar technology data are shown in a colored ‘depth slice’ view, in this case displaying a clear rebar pattern. The slider on the left is used to display shallow or deep data, similarly to the zoom slider, the trigger button is used to record, and the toolbar on the right facilitates easy augmentation and processing of the data.

5.2 Higher accuracy and efficiency by reducing errors and rework

The accuracy of the tomographic test result usually depends on the precise positioning of the probe on the object. State-of-the-art solutions for ultrasonic tomography of concrete are now equipped with an optical positioning system and A.I.-supported software algorithms. These allow a precise identification of the probe position during a measurement procedure.
As such, the probe can be randomly placed along the line of the ruler tape, and the user can rest easy that the imaging software will accurately stitch the single measurements together into a panoramic view, as shown in Figure 2.

As another example, the latest generation of Original Schmidt concrete hammer relies on technology running on a mobile device app to reduce the lead time of the NDT workflow, as shown on Figure 3. Verification of the hammer is now done using a verification wizard, which is integrated in the logbook to prove that the hammer is in a standard-conforming state when the measurements is done. The measurement itself is easy even in dark environments as one can use not only read from an analogue but also a digital hammer display, or even the mobile device display and voice output. All data are recorded and automatically processed on-site according to any given international standard, and the report is automatically generated with just a button press rather than using Excel back in the office after transfer of the data to the PC. Sharing of data and reports even straight from the site is easy via a WLAN access point or 3G/4G. Remarkably to stress also is that often more than one user used to carry out tests in the past, where the second person manually recorded data or prepared and reviewed results; in contrast, the Original Schmidt Live hammer has been designed for one-person usage.
Figure 3: Increased productivity using the latest generation Original Schmidt vs. the traditional rebound hammer. Whilst the preparation time to the measurement is very similar, the time to do verification and actual measurements are greatly reduced using latest onboard technology. Reporting and IoT significantly reduce the time-to-reporting as well as ease of data sharing.

4 Supporting the user with data interpretation for accuracy and actionable insights

Beyond high-resolution touch displays, modern mobile devices also offer high computational performance that enables on-site data-processing and visualization supporting the user’s work (see Figure 4). Such features can be used to eliminate the interpretation differences between operators by applying advanced signal analysis algorithms to interpret the graphical data in various ways befitting the user’s needs and skill level. As a result, objects such as a backwall of a concrete structure can already be identified with high probability. Further A.I.-enabled algorithms are in development to support users in identifying objects such as reinforcement bars, pipes, delaminations, with less ambiguity for higher accuracy, as shown in Figure 5.

Figure 4: Views of different complexity of reinforcement in concrete. Whilst early GPR devices only provided the left grey-scale ‘non-migrated B-scan’ images, often less clear than shown here, today’s Proceq GPR Live allows live recording of ‘migrated B-scan’ heatmaps (middle image). Even the intuitive 3D topographic image of the data on the right is displayed instantaneously upon finger swipe.
Figure 5: Easy-to-use object identification on the Proceq GPR Live. Contingent objects are tagged automatically using the product’s A.I. feature, and can then be confirmed or removed by the user.

Another example is provided by the reduced error of rebar locators and cover meters that now utilize A.I. algorithms. Figure 5 showcases the reduced error in rebar cover estimation of Proceq’s A.I.-enabled Profometer 6 AI compared to industry benchmarks. The product utilizes a correction algorithm to the cover based on an A.I. model that was self-trained on more than 1’600 different configurations. In the actual product usage, the A.I.-enabled correction compensates for the influence of additional rebars in the detection range. The result is a significant reduction of measurement error.

Figure 6: Increased accuracy for the cover estimation is achieved through an A.I.-enabled correction to cover meter and rebar locator measurements.
5 Traceable procedures with less effort and potential for errors

Recent product additions to the NDT market now log all activities and relevant change of settings performed by the user. Figure 7 shows how this “Logbook” works in the Equotip Live metal hardness tester.

Information stored by the Logbook includes user identification, settings, all measuring data and changes and can be complemented by geolocation, pictures, and audio comments. This functionality allows a supervisor to retrace the complete measuring process, if necessary, and ultimately to check data consistency and prevent data manipulation.

Figure 7: Logbook example of the Equotip Live metal hardness tester tracking measuring process. The comprehensive logbook describes the device and names the user, it logs settings and measurement parameters, and records readings and exclusion of readings. Moreover, it permits adding photos and notes.

6 Enabling unobstructed data sharing for collaboration and quality assurance

Latest generation instruments make use of secure cloud storage solutions to back up in real-time the results collected on-site. In combination with wireless communication through either a cellular network or WLAN, this has become a powerful tool to immediately sync the data with other collaboration partners or to distribute reports to external parties. Additionally, a browser-based software product allows access to the data independent of location, time and hardware platform, as shown in Figure 8.

Within the secure network consisting of wireless probes, mobile devices and a cloud storage, raw data is exchanged. Predefined templates for common export file formats such as PDF or CSV are used to
share results outside the protected ecosystem. Direct report generation and immediate access to the investigation data has been proven to enhance not only collaboration, but also to result in the time savings shown in Figure 3.

Figure 8: The Equotip Live ecosystem diminishes manual data entry and reporting effort and enables real-time data sharing and collaboration between users. Wireless probes are connected via Bluetooth 4.0 to the mobile device, which connects to the data backup system wirelessly via WLAN or 3G/4G. Reports, webtool access and collaboration options are facilitated.

7 Conclusions

Several processes served by NDT have been lagging behind in productivity levels, less trained staff is available to fulfill the jobs, and the safety of people is addressed through more and more regulations leading to increased inspection needs. The quality of objects is important to keep societies and daily life running, and obstacles cost a lot of money. Furthermore, outdated formats for data capture and sharing mean that traceability is often lost.

Today new IT instruments and aids permit to overcome such shortcomings and boost the usefulness of NDT. New technology standards such as IoT can support NDT, since NDT traditionally already employs computing devices with sensors, whose data are used in reports. We are therefore concluding that the NDT industry is, in principle, ready and well-suited for adoption of wireless sensors, A.I. and the Internet of Things. It has been shown that this technological progress opens new opportunities to address chronic pain points of NDT use cases. The main achievements of future-proof NDT are increasing ease-of-use with user-friendly and intuitive user interfaces, higher accuracy and efficiency.
by reducing errors and rework in workflows, supporting the user with data interpretation for accuracy and actionable insights, establishing traceable procedures with less effort and potential for errors, and enabling unobstructed data sharing for collaboration and quality assurance.

Whilst the step to wirelessness, easy sharing of data between various platforms, and connectivity through the web can today be established rather easily everywhere, speed of adaptation has been too slow to keep the industry healthy and competitive, and established workflows require updating. There is hesitation that, in the opinion of the authors, can best be overcome with a task group of experts who understand opportunities and shape the future with such technical advancements, and propagate in clearly laid out showcases what’s in wireless connectivity, A.I. and IoT for NDT users.