Collaborative Network for the development of Non-Destructive Inspection Technologies: Elicitation requirements in an industrial environment

Joan Lario[1](✉), Javier Mateos[1], Raúl Poler[1] and Ángel Ortiz[1]

[1] Research Centre on Production Management and Engineering (CIGIP), Universitat Politècnica de València, Camino de Vera S/N, 46022 València, Spain
jlario@cigip.upv.es

Abstract. The development of Zero Defects and Zero Waste (ZDZW) solutions to implement in-process inspection technologies requires collaborative networks due to the involvement of several stakeholders. The quality assurance digital transformation in the EU industry demands the integration of non-destructive inspection technologies (NDIT) to boost manufacturing competitiveness and resilience. These engagements between the partners that conform to the collaborative networks are needed to provide competitive and innovative products in manufacturing quality assurance. The efforts of the subject matter experts will be focused on the definition of the engineering requirements based on the hardware, software (including artificial intelligence algorithms for defect detection) and data management. In this paper, the different elicitation requirements for developing NDIT solutions are categorised, quantified, and analysed to develop in-process control activities.

Keywords: Collaborative Network · Quality Assurance · NDIT · Zero Waste · Zero Defects · Elicitation.

1 Introduction

Recent industry developments in the European Union (EU) are focused on increasing sustainable production to foster profitability, and these require that manufacturing companies engage in collaboration networks for the digital transformation of the entire industrial ecosystem [1]. The integration of non-destructive inspection technologies in modern production lines to support in-process inspection requires the development of several enabling technologies, such as data storage, data analytics and digital twin [2]. Industrial companies that can integrate in-process inspection technologies based on Zero Defect and Zero Waste (ZDZW) solutions can provide more efficient and effective processes, resulting in a competitive advantage [3].

Employing an operational perspective, the use of NDIT solutions in the manufacturing process enhances the analytical and operational capabilities and thus optimizes defect creation and material consumption. The integration of ZDZW solutions such as Microelectromechanical systems-based Interferometric Optical Coherence

Tomography (MIR-OCT) on the lithography process or artificial vision at plastic injection molding, allows accessing inspection data in real-time and enhancing the reliability of the inspection. The integration of these non-destructive real-time monitoring technologies will reduce the workload associated with reprocessing and expenditures related to scrap. Real-time monitoring can reduce scraps and rework expenses and the associated workload [4].

The adoption of collaborative networks for the digital transformation of the quality assurance of the EU industry demands the integration of non-destructive technologies to boost manufacturing competitiveness and resilience. The cost of poor quality in the manufacturing industry is estimated to range between 5 and 30% of the total income since it is dedicated to covering the expenditures related to repair, rework, inspection, recalls and complaints [5].

This paper presents a collaborative approach between stakeholders and subject matter experts (technological providers, research centres and final users) to define the elicitation requirements to develop non-destructive inspection technologies in an industrial environment. The NDIT solutions will be based on a cyber-layer that acquires data from the sensor and applies data analytics to inspect the manufacturing process.

2 Non-Destructive Inspection Technologies

This section presents several non-destructive inspection technologies for a better understanding of in-process quality assurance monitoring (integrity, reliability, and accuracy) of parts fabrication. In the development of non-destructive inspection and data collection methods for industrial applications, it should be noted one of the main objectives is to align them with circular economy models that minimize environmental impact and align with sustainable development goals. Integration of these NDI technologies will help optimize production, reduce waste, and eliminate destructive sampling, keeping companies at the technological forefront. Figure 1 appears the schematic classification of NDIT according to their primary signal. Therefore, helping industries in this digital transition period has become a mandatory challenge within the R&D sector and manufacturing industry.

Quality assurance is an integral pillar of each manufacturing industry since it ensures that the products are produced in accordance with customer or regulatory specifications. The conventional methods are highly dependent on operators, where the level of detectability depends on human visual capacity and fatigue. These quality inspections are performed downstream, in batches, where parts have more added value, material, production resources consumed and energy consumption which is directly related to higher cost. The integration of these ZDZW solutions through the development of collaborative networks between customers and technological providers will boost the development of automatic inspection equipment and artificial intelligence algorithms for the early detection of defects [6].

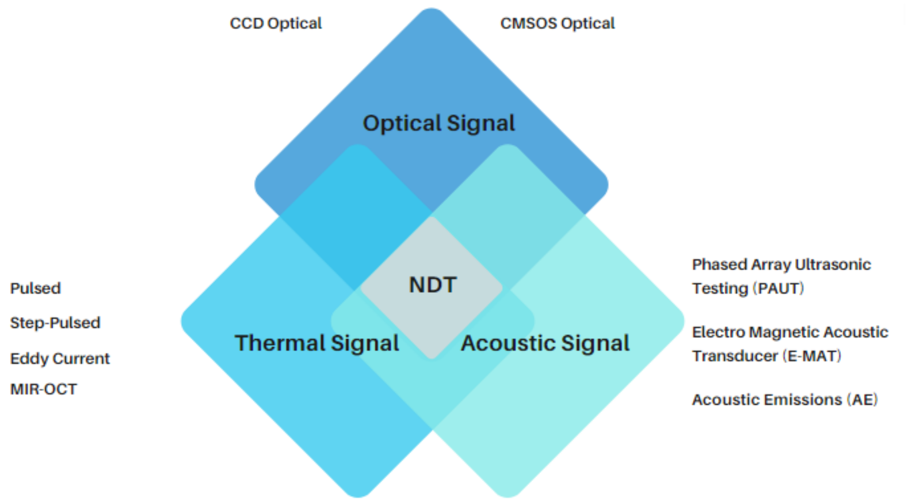

Fig. 1. Classification of non-destructive technologies and types of sensors employed.

The NDIT, together with AI algorithms and Digital Twin presents the ability to detect defects or lack of control on a real-time basis, and these solutions present an advantage for advancing sustainable production since improve the decision-making process and reduce the downstream quality inspection [7]. Through the identification of patterns and trends, the aim of the ZDZW solutions is to deploy artificial intelligence algorithms that help to prevent material and energy costs in the production process [8].

The ZDZW pursues this objective to obtain competitive advantages in terms of sustainable production by avoiding the propagation of defects at both lower and higher levels of the production process and to provide assistance in decision-making. Throughout the last decades, non-destructive testing technologies and recurring improvements in sectors related to it such as vision, thermography, OCT, and Acoustic Emissions have gained weight due to the numerous advantages they offer over conventional methods [9]. In addition, it must be considered that these techniques allow higher levels of scalability, easier data acquisition and analysis thanks to AI algorithms and mathematical models deployment.

2.1 Acoustic Emissions

The non-destructive inspection of acoustic emission (AE) method is based on the sampling of sound waves (pulses or echoes) emitted and detected by the same transducer or by another transducer that detects energy releases due to physical active phenomena (20kHz-1MHz range) [10]. By subjecting different objects and materials to tension stresses, plastic deformation, phase transformation and even fractures, the energy released within the process causes stress waves in the material, enabling discrete pulses to be captured during the process and employed for inspection purposes [11]. Any defect or anomaly in the material affects the linearity, direction, amplitude, and frequency of the wave generated and is transmitted thus enabling its detection by AE methods (Fig. 2). Therefore, performing adequate signal filtering which enables to reduction of ambient noise interferences combined with stress wave amplification in the materials, has become an indispensable requirement to obtain optimum signals and their subsequent analysis [12]. AE inspection method is a non-destructive method that allows non-contact inspection, and in several industrial applications is replacing interferometric laser systems as defect inspection technology [13].

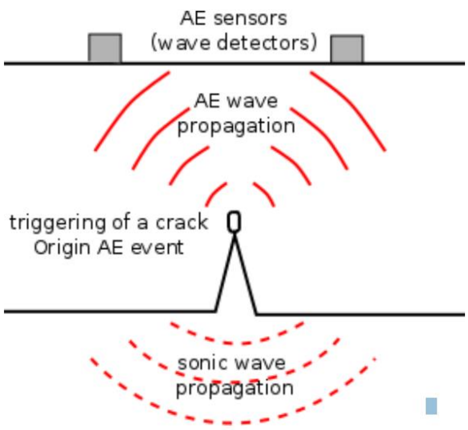

Fig. 2. Principle of the acoustic emission wave detection [14].

2.2 Infrared technology

Thermography is a non-destructive and non-contact technique that allows to detect the radiation emitted by an object. The IR sensors receive the emitted infrared waves from the surface of the material and convert them into electrical signals and subsequently into IR images [15]. Surface defects present an inhomogeneous heat distribution which translates into changes in the electrical signals detect by the IR sensors. Several anomalies or defects in parts can be detected in IR technology, such as voids, cracks, and inclusions, but with some limitations when it comes to pixel size and material depth penetration [16]. Moreover, using an infrared (IR) camera offers greater area capture depending on the application, faster frame-rate acquisition and higher accuracy when compared to pyrometers.

According to the different principles that are used with thermography technology, it can be divided into passive (without external excitation) or active (with external excitation) methods (Fig. 3). Passive infrared thermography relies on the relationship between object emissivity intensity and surface temperature. Based on the types of excitations, the active IR thermography collects data thanks to the material excitation provided by external sources such as pulsed laser thermography, step-pulsed thermography lock-in thermography, vibro-thermography, induced eddy-currents, and lamps [10].

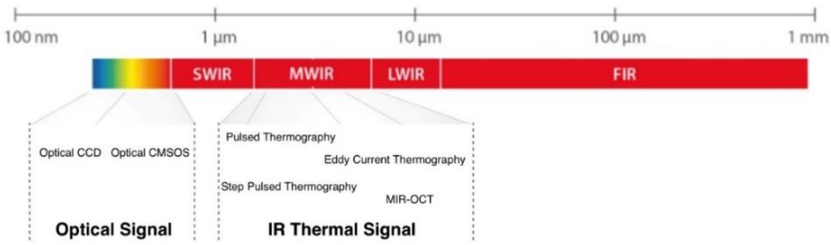

Fig. 3. Classification of sensor or non-destructive technologies according to electromagnetic spectrum.

2.3 AI Visual Inspection

Visual Testing inspection considers a wide range of methodologies and techniques, from human-based visual inspections to autonomous visual inspection processes with assisted AI algorithms for enhanced detection. It must be noted that all these methodologies may not fall within the visible spectrum wavelength but are regarded as visual testing techniques. The average size of a defect that can be detected by a human eye fall in the range of 1µm, but it will be conditioned to measurement subjectivity or interpretation, ambient conditions and visual fatigue among other external factors [17].

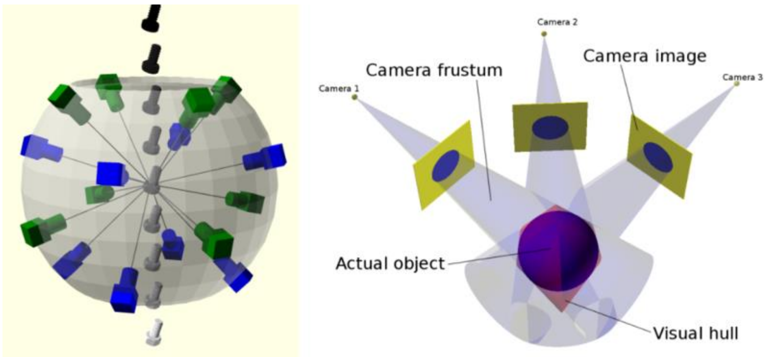

Fig. 3. Camera configuration. Objects fall free through the device, being captured in the center where the camera views converge and visual hull [18].

The implementation of automatic visual inspection equipment, with adequate lighting conditions, magnification optics, higher resolution cameras and software tools (dimensional measuring, defect detection, etc.) can be improved the visual accuracy, detectability, reliability and process speed inspection compared with human visual inspection methods (Fig. 3).

The last decade with the development of computer vision solutions combined with Convolutional Neural Networks (CNN) or other AI algorithms, has improved image interpretation by being able to extract regions of interest and detect previously unexposed features for a multitude of processes, from dimensional control to defect detection [18]. By achieving early detection of defects at an early stage of the production process, significant savings in both raw material and energy can be achieved. Both traditional and AI approaches can be easily integrated into the system on standalone hardware with IoT protocols, achieving a high degree of integration, versatility, and compatibility.

2.4 MIR-OCT

Optical Coherence Tomography (OCT) is a 3D imaging technique that relies on interferometry from different laser light sources coming from internal microstructures and material interfaces in which low temporal coherence light is used to create high-resolution three-dimensional models [19]. Through recording the different interference signals from return beams in the beam splitter as a spectrum, the light beam is then scattered with the help of diffraction grating and its interference pattern is later detected with a high-speed Charge-Couple Device (CCD) linear camera. Therefore, Fourier transformation is performed on the detected linear spectrum detected by the CCD camera and reflectivity is obtained as a depth function (Fig. 4).

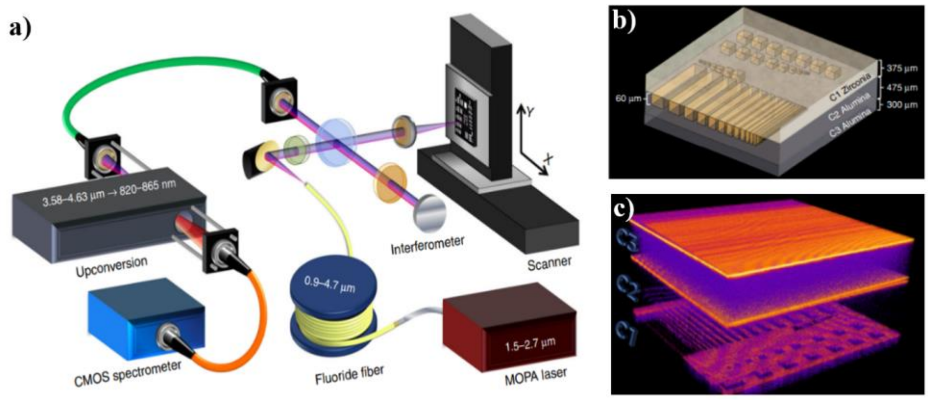

Fig. 4. OCT system. a) Overview of the 4-µm OCT system. b) Schematic of the sample consisting of three layers of ceramics. c) 3D 4-µm OCT volume visualizations of the sample [20].

Since it is a non-invasive, non-destructive inspection technique with high accuracy (detects anomalies within the range of 8-8.6 µm), it has become a technique that has gained a lot of attention in recent years [20]. More specifically, in the Additive Manufacturing (AM) industry of ceramics where unwanted cracks, bubbles and particles between layers are critical and must be identified and removed [21, 22].

3 A layered ZDZW platform

The integration of ZDZW solutions on the manufacturing shopfloor requires a reference architecture with a multi-stage system (Fig. 5). Eger et al. (2018) proposed a zero-defect manufacturing architecture based on six major pillars [2]. The lowest pillar "Data Acquisition System" consists of a set of sensors o NDIT which collect and synchronize data gathered in the production process. The in-process inspection solutions will provide quality information since there are capable of measuring some parts' characteristics or properties. Other sensors integrated into the machine or manufacturing process will provide information about the machine or production status. The data collected from the first layer will be deployed with the use of specific protocols (OPC-UA or XMPP) which allow the merging of data from different sources (second layer). From the second layer, data is fed to the "Data Management Platform", the function of this third layer is to store and update the acquired data in a structured way. Data Management infrastructure (third layer) allows users to construct and carry out complex queries to search for information, and therefore improve searchability, and should aim to at least meet FAIR data principles: Findability, Accessibility, Interoperability, and Reusability [23].

The fourth layer "Quality Assurance Engineering Platform" is designed to optimize the quality and production efficiency through defect detection, identification, and location by Artificial Intelligent (AI) and Machine Learning (ML) algorithms. The fifth layer consists in a customizable dashboard which provides aggregated and processed information about the production process and makes it readily available for everyone. The last layer connects the gathered data and decisions to the Enterprise Resource Planning (ERP), where the cyber-layer transmits decisions to the physical equipment to adjust the manufacturing process. The "Zero Defects and Zero Waste" (ZDZW) Horizon Europe project aims to develop non-destructive inspection technologies to cover the needs of several industrial sectors (energy production, consumer goods and health products), through the development of sensors, data acquisition and data analysis using artificial intelligence algorithms. Also, the generic architecture for the platform will be based on previous projects such as ZDMP and i4Q [9]. To develop such capabilities the collaborative networks, conformed by several stakeholders (NDIT providers, software developers, end users, research centres, etc.) should gather efforts to implement these ZDZW solutions into production environments [7]. The ZDZW Horizon European project can be considered a Virtual Organization Breeding Environments (VBEs) where all partners involved agree on common business principles, define rules for sharing and working methods, and provide a high level of mutual awareness about the competencies and resources [24].

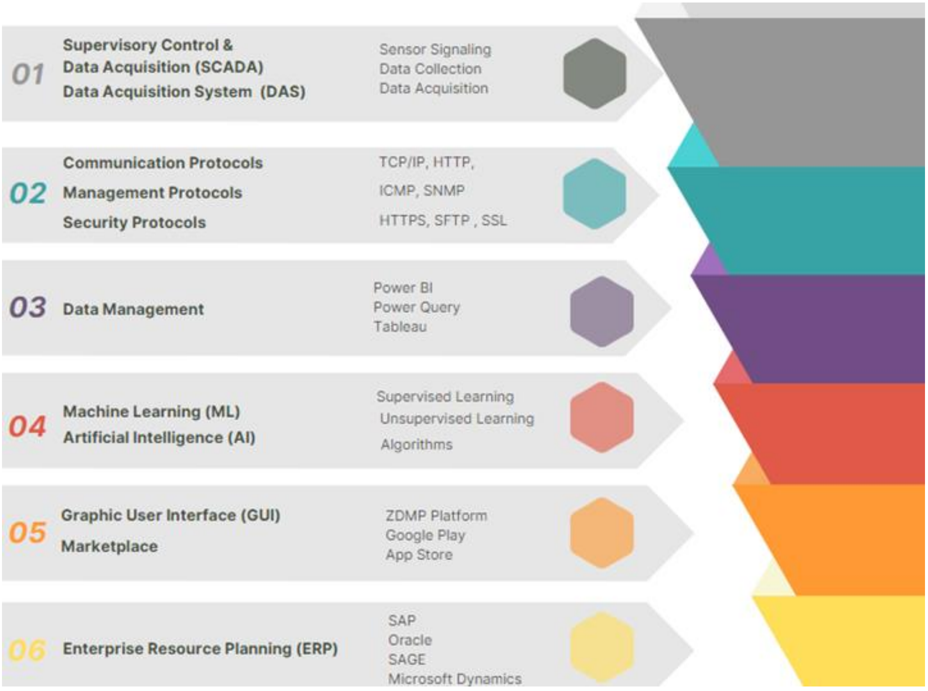

Fig. 5. A layered-level semantic platform for the implementation of automatic NDIT solutions.

4 Engineering requirements for the collaborative process

Recently, the connectivity of collaborative networks of non-destructive sensors, machines, data repositories, AI algorithms and digital twins has become a new approach for the creation of competitive advantage through the creation of added value, and at the same time brings some technological challenges. The adoption of VBEs allows to establish a long-duration commitment between partners, whose main objective is to boost collaboration, where members agree on business principles, define the rules for sharing and working methods, and provide a high level of mutual awareness about the competencies and resources [24]. By joining efforts during the definition of engineering requirements the members can share risks and resources, find synergies, smooth the customer integration, and join complementary skills and capacities while maintaining a high level of agility [25]. These engineering requirements and specifications for the collaborative process should be designed in terms of data communication, security, and management to fully support the different industrial scenarios where NDIT will be implemented.

The use of Zero Defects and Zero Waste solutions to automate any quality inspection process must be validated for its intended use, ensure accuracy, reliability, consistent intended performance and requirements, and the ability to discern invalid or altered records. When non-destruction inspection equipment is implemented in a production line the device manufacturer must ensure that it performs as intended use in their chosen application.

A requirement can be considered a specification, need, or expectation for an NDI system or its developed software. Depending on its industrial application, there can be many different types of requirements (e.g., functional, interface, communication, integration, data integrity, accuracy, etc.). ZDZW solutions requirements are typically derived from the system requirements for those aspects of system functionality allocated to software or system. Requirements are usually stated in functional terms and are defined, refined, and updated as a development project progresses. Success in accurately and completely documenting ZDZW requirements is a crucial factor in successfully validating the resulting solution or software. ZDZW solutions or related software requirements are typically derived from the overall system requirements and design for those aspects of the system that are to be implemented using these solutions.

The different stakeholders that form the collaborative network for the development of non-destructive inspection solutions for in-process quality control should focus their efforts on the following pillars:

- **Safety:** The development of ZDZW solutions should consider data security and data safety to avoid failures, since the manufacturing system employs in most cases their managed data that can be employed for regulatory purposes.
- **Reliability:** The non-destructive inspection technologies are currently employed in several stages of the manufacturing processes to provide product reliability and integrity of production quality [26, 27, 28].
- **Availability:** In the manufacturing context where the aim is to improve the first-time-right rate the availability of process and product data gathered by sensor or NDIT has created new optimization opportunities [9]. At the same time automated acquisition, high volume and several sources of information have increased the complexity of the cyber-physic system (CPS), which requires the use of collaborative networks to faster develop these technologies [27].
- **Resilience:** Current manufacturing and process industry companies need to increase their manufacturing resilience, to become more competitive, profitable, sustainable and intelligent with related effects, such as lower costs, lower energy consumption (per output), lower level of wasted materials and scrapped output, faster production processes making it flexible to adapt to changes, thus reducing the time required to bring quality at the designed levels in the event of change [9].
- **Security:** The Internet of Things (IOT) enables new security threads in the interconnected world, some of the major security and trust issues are network security, data security, access control, malware protection and privacy [12, 29].

5 Survey in elicitation requirements

For developing faster and more reliable NDIT or software solutions during the developing phase the elicitation requirements must be gathered from the final user, as well as the different partners involved in development activities. The use of a survey is a novel method to target, quantify and prioritise the requirements according to users' and developers' input. The goal of the survey is to identify the relevant requirements for each pillar (safety, reliability, availability, resilience and security), instead of going into depth on each sub-topic.

The key audience of the survey are software/electrical/material/R&D/quality engineers, as well as subject matter experts, which form part of the collaborative network required to develop NDI solutions which will be integrated into manufacturing environments. With the aim of preparing a technical survey, current work has performed a state-of-the-art analysis to elaborate the survey questionnaire [2, 6, 7, 9, 29, 30]. Surveys involve evaluating the elicitation requirement extracted for literature review against several options (not important "2", less important "4", important "8" and very important "10"), see Table 1 to review the questionnaire and the results for SME input. The analysis of the elicitation requirements NDIT survey aims to provide a research landscape of these development, guidelines, and identify relevant topics to consider during the development of the solutions.

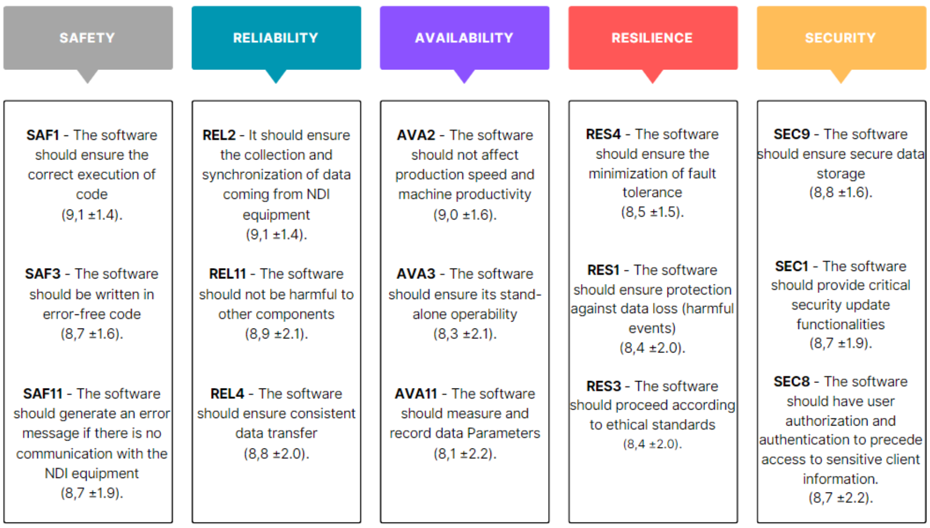

Fig. 6. Higher-scored topics in the elicitation requirements survey.

From the results, it can be seen how the code (SAF1, SAF2 and SAF3), data sharing (SAF11, REL2 and REL4), data record (AVA11, RES1 and SEC9), resilience (SAF1, REL11, AVA2, AVA3 and RES4) and security (SEC1 and SEC8) are the main elicitation requirements to consider when the ZDZW are developed (Fig. 6). While requirements related to standardization of files (SAF7, SAF13, REL7, AVA10), backup functionalities (REL14, RES7), compatibility (REL12, AVA7), access (SEC4, SEC5, SEC6) and monitoring (RES5) present the lower score and higher standard deviation.

6 Conclusions

The development of ZDZW solutions based on non-destructive inspection technologies will provide tools to ensure in-process quality inspections based on defect detection during manufacturing which will reduce material and energy consumption and improve efficiency and profitability. In this paper, an extensive review of ZDZW elicitation requirements has been presented for further research development of NDI system, as well as common challenges that need to be addressed are provided. The deployment of the cyber-physical system for production quality assurance will consider safety, reliability, availability, resilience, and security as the main pillars for the definition of the elicitation requirements to be employed for all the partners that conform ZDZW collaboration network.

The continuous evaluation of the requirements (records, communication, security, code, etc.) will be needed to ensure the efficient deployment of the solutions in the industrial environment. In the future, it is expected the integration of different layers (data acquisition, communication, data management, artificial intelligence, platform and ERP) for the implementation of automatic NDIT solutions for quality assurance purposes. The European industry, which currently faces continuous integration of emerging technologies, and lacks new skills to deal with it, can adopt collaborative networks for the agile development of NDI solutions for future quality assurance purposes. The development of the ZDZW platform, where NDI solutions will be available for commercial use, can bring an innovative ecosystem where small and medium enterprises can access them and integrate them into their manufacturing systems.

Acknowledges

The ZDZW project has received funding from the European Union’s Horizon Europe programme under grant agreement No 101057404. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Table 1. Survey questionnaire and results for ZDZW elicitation requirements.

Pillar	Feature	Results	Pillar	Feature	Results
Safety	*SAF1* - The software should ensure the correct execution of code.	9,1 ±1.4	**Availability**	*AVA1* - The software should ensure interoperability with other solutions.	6,8 ±2.8
	SAF2 - It should ensure the secure transfer and storage of factory and NDI data to a remote repository.	8,2 ±1.9		*AVA2* - The software should not affect production speed and machine productivity.	9,0 ±1.6
	SAF3 - The software should be written in error-free code.	8,7 ±1.6		*AVA3* - The software should ensure its stand-alone operability.	8,3 ±2.1
	SAF4 – It provides the capability of securely moving data from the factory level to the cloud level.	7,6 ±2.4		*AVA4* - It should provide a Data Visualization and Analytical tool to support Quality Assurance.	7,9 ±2.1
	SAF5 - The software should be written in an understandable way (according to coding standards).	8,3 ±1.9		*AVA5* - The software should (automatically or manually) update its libraries.	7,4 ±2.6
	SAF6 - In case a data repository will not be provided, the system should be able to read data from the Raw Log File.	6,6 ±2.8		*AVA6* - The software should provide Interface adaptability to the end user.	7,5 ±2.4
	SAF7 - The software should use proven and established libraries.	7,2 ±2.5		*AVA7* - The software should ensure its integration with other software systems.	6,1 ±2.9
	SAF8 - The software should be able to collect and save all part measurement data provided by measurement equipment automatically in digital format.	8,3 ±1.9		*AVA8* - The software should communicate with other manufacturing machines or software.	7,3 ±2.7
	SAF9 - The software should avoid losses and corrupt of data due to communication failure.	8,6 ±1.8		*AVA9* - The software should ensure the convenient processing of unseen data.	6,6 ±2.7
	SAF10 - The software should behave as from stakeholders intended.	8,0 ±1.8		*AVA10* - The software should communicate with other existing databases.	6,7 ±2.7
	SAF11 - The software should generate an error message if there is no communication with the NDI equip.	8,7 ±1.9		*AVA11* - The software should measure and record data Parameters.	8,1 ±2.2
	SAF12 - The software should generate an error message if there is no communication with the PLC.	7,9 ±2.3	**Resilience**	*RES1* - The software should ensure protection against data loss (harmful events).	8,4 ±2.0
	SAF13 - The software should contain information related to the software driver derived from a particular interface protocol and contains the data signals.	7,0 ±2.4		*RES2* - The software should ensure protection against data corruption (harmful events).	8,4 ±2.0
	SAF14 - The software should behave in interaction with other solutions as intended.	7,3 ±2.7		*RES3* - The software should proceed according to ethical standards.	8,4 ±2.0
	SAF15 - The software should ensure proper data exchange.	8,2 ±2.1		*RES4* - The software should ensure the minimization of fault-tolerance.	8,2 ±2.3
Reliability	*REL1* - The software should ensure appropriate storage capacity.	7,9 ±2.3		*RES5* - The software should include control/monitor processes for data input.	7,7 ±2.6
	REL2 - It should ensure the collection and synchronization of data coming from NDI equipment.	9,1 ±1.4		*RES6* - The software should be developed in connection to version controls.	7,7 ±2.2
	REL3 - The software should ensure data transformation and integration from digital sensors.	8,4 ±2.2		*RES7* - The software should provide backup functionalities.	7,4 ±2.6
	REL4 - The software should ensure consistent data transfer.	8,8 ±2.0	**Security**	*SEC1* - The software should provide critical security update functionalities.	8,7 ±1.8
	REL5 - The software should ensure consistent data formats.	8,1 ±2.2		*SEC2* - The software should be secured with administrator password in Certain fields.	7,9 ±2.5
	REL6 - The software should ensure stable operations.	8,7 ±1.6		*SEC3* - The software should ensure protection against data loss (human errors).	7,8 ±2.2
	REL7 - The software should synchronize data from sources with different sampling times.	7,3 ±2.5		*SEC4* - The software should ensure protection against data corruption (human errors).	7,8 ±2.2
	REL8 - The software should correlate current processing parameters with final workpiece quality.	7,8 ±2.0		*SEC5* - The software should include an authorized user login.	7,6 ±2.5
	REL9 - The software should ensure product conformity by examining data collected along the production line and the NDIT equipment.	8,1 ±2.3		*SEC6* - The software should protect the code with Programming user password.	7,7 ±2.9
	REL10 - The software should ensure the collection of data from quality-related sensors (time-stamped).	8,3 ±1.5		*SEC7* - The software should be restricted in its functionalities according to EU law.	8,1 ±2.2
	REL11 - The software should not be harmful to other components (Workload).	8,9 ±2.1		*SEC8* - The software should have user authorization and authentication to precede access to sensitive client information.	8,7 ±2.2
	REL12 - The software should work in different infrastructures (OS, Hardware).	6,3 ±2.6		*SEC9* - The software should ensure secure data storage.	8,8 ±1.6
	REL13 - The software should correlate associated inspection information with the production order (such as customer, batch number, etc).	7,8 ±2.5			
	REL14 - The software should provide backup functionalities.	7,1 ±2.7			

References

1. Colledani, M., Tolio, T., Fischer, A., Iung, B., Lanza, G., Schmitt, R., & Váncza, J. (2014). Design and management of manufacturing systems for production quality. CIRP Annals - Manufacturing Technology, 63(2), 773–796. https://doi.org/10.1016/j.cirp.2014.05.002

2. Eger, F., Coupek, D., Caputo, D., Colledani, M., Penalva, M., Ortiz, J. A., Freiberger, H., & Kollegger, G. (2018). Zero Defect Manufacturing Strategies for Reduction of Scrap and Inspection Effort in Multi-stage Production Systems. Procedia CIRP, 67, 368–373. https://doi.org/10.1016/j.procir.2017.12.228

3. Nicola Moosbrugger, Florian Maurer, and Jens Schumacher (2022 From Digitization to Digital Collaborative Service Designs: A Systematic Literature Review on the Categories, Concepts and Constructs of Industry 5.0. PRO-VE 2022, IFIP AICT 662, pp. 169–181, 2022. https://doi.org/10.1007/978-3-031-14844-6_14

4. Martha Orellano and Sanaa Tiss (2022). Impacts of Digital Transformation on Supply Chain Sustainability: A Systematic Literature Review and Expert Assessment. PRO-VE 2022, IFIP AICT 662, pp. 169–181, 2022. https://doi.org/10.1007/978-3-031-14844-6_14

5. Badreddine Tanane, Baudouin Dafflon, Mohand Lounes Bentaha, Nejib Moalla, and Vincent Ferreiro. Toward a Collaborative Sensor Network Integration for SMEs' Zero-Defect Manufacturing. PRO-VE 2022, IFIP AICT 662, pp. 169–181, 2022.

6. Caiazzo, B., Di Nardo, M., Murino, T., Petrillo, A., Piccirillo, G., & Santini, S. (2022). Towards Zero Defect Manufacturing paradigm: A review of the state-of-the-art methods and open challenges. In Computers in Industry. https://doi.org/10.1016/j.compind.2021.103548

7. Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2021). Equipment Design Optimization Based on Digital Twin under the Framework of Zero-Defect Manufacturing. Procedia Computer Science, 180(2019), 525–533. https://doi.org/10.1016/j.procs.2021.01.271

8. Ding, H., Gao, R. X., Isaksson, A. J., Landers, R. G., Parisini, T., & Yuan, Y. (2020). State of AI-Based Monitoring in Smart Manufacturing and Introduction to Focused Section. IEEE/ASME Transactions on Mechatronics, 25(5), 2143–2154. https://doi.org/10.1109/TMECH.2020.3022983

9. Psarommatis, F., Sousa, J., Mendonça, J. P., & Kiritsis, D. (2022). Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper. International Journal of Production Research, 60(1), 73–91. https://doi.org/10.1080/00207543.2021.1987551

10. Shaloo, M., Schnall, M., Klein, T., Huber, N., & Reitinger, B. (2022). A Review of Non-Destructive Testing (NDT) Techniques for Defect Detection: Application to Fusion Welding and Future Wire Arc Additive Manufacturing Processes. Materials, 15(10). https://doi.org/10.3390/ma15103697

11. Manterola, J., Aguirre, M., Zurbitu, J., Renart, J., Turon, A., & Urresti, I. (2020). Using acoustic emissions (AE) to monitor mode I crack growth in bonded joints. Engineering Fracture Mechanics, 224(October 2019), 106778. https://doi.org/10.1016/j.engfracmech.2019.106778

12. Zhang, L.; Basantes-Defaz, A.C.; Ozevin, D.; Indacochea, E. Real-time monitoring of welding process using air-coupled ultrasonics and acoustic emission. Int. J. Adv. Manuf. Technol. 2018, 101, 1623–1634.

13. Rohringer, W.; Heine, T.; Sommerhuber, R.; Lehmann, N.; Fischer, B. Optical Microphone as Laser-Ultrasound Detector. Avail- able online: https://xarion.com/itrfile/_1_/27059ddf4f50b42f54dd6dc08d3f1fe0/XARION_DAGA_2018.pdf.pdf

14. Calabrese, L.; Proverbio, E.A Review on the Applications of Acoustic Emission Technique in the Study of Stress Corrosion Cracking. Corros. Mater. Degrad. 2021, 2, 1–30. https://doi.org/10.3390/cmd2010001

15. Andonova, A.; Todorov, D. Thermographic NDT System. Annu. J. Electron. 2013, 78, 139–143.

16. Lopez, A., Bacelar, R., Pires, I., Santos, T. G., Sousa, J. P., & Quintino, L. (2018). Non-destructive testing application of radiography and ultrasound for wire and arc additive manufacturing. Additive Manufacturing, 21(January), 298–306. https://doi.org/10.1016/j.addma.2018.03.020

17. Sharratt, B. M. (2015). Non-Destructive Techniques and Technologies for Qualification of Additive Manufactured Parts and Processes: A Literature Review. Department of National Defence of Canada, 55(March), 91–127.

18. Perez-Cortes, J.-C.; Perez, A.J.; Saez-Barona, S.; Guardiola, J.-L.; Salvador, I. A System for In-Line 3D Inspection without Hidden Surfaces. Sensors 2018, 18, 2993. https://doi.org/10.3390/s18092993

19. Koller, D. M., Hannesschläger, G., Leitner, M., & Khinast, J. G. (2011). Non-destructive analysis of tablet coatings with optical coherence tomography. European Journal of Pharmaceutical Sciences, 44(1–2), 142–148. https://doi.org/10.1016/j.ejps.2011.06.017

20. Israelsen, N. M., Petersen, C. R., Barh, A., Jain, D., Jensen, M., Hannesschläger, G., Tidemand-lichtenberg, P., Pedersen, C., Podoleanu, A., & Bang, O. (2019). optical

coherence tomography. Light: Science & Applications. https://doi.org/10.1038/s41377-019-0122-5

21. Ornik, J., Sakaki, M., Koch, M., Balzer, J. C., & Benson, N. (2021). 3D Printed Al2O3for Terahertz Technology. IEEE Access, 9(3), 5986–5993. https://doi.org/10.1109/ACCESS.2020.3047514

22. Petersen, C.R.; Rajagopalan, N.; Markos, C.; Israelsen, N.M.; Rodrigo, P.J.; Woyessa, G.; TidemandLichtenberg, P.; Pedersen, C.; Weinell, C.E.; Kiil, S.; et al. Non-Destructive Subsurface Inspection of Marine and Protective Coatings Using Near- and Mid-Infrared Optical Coherence Tomography. Coatings 2021, 11, 877.https://doi.org/10.3390/coatings11080877

23. Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., et al. (2016). The FAIR Guiding Principles for Scientific Data Management and Stewardship. Sci. Data 3 (1), 160018–160019. doi:10.1038/sdata.2016.18

24. Camarinha-Matos LM, Afsarmanesh H (2022). The Evolution Path to Collaborative Networks 4.0. Advancing Research in Information and Communication Technology, IFIP. ISBN 978-3-030-81700-8. https://doi.org/10.1007/978-3-030-81701-5

25. Camarinha-Matos LM. Collaborative networked organizations in manufacturing. IFAC Proceedings Volumes, Volume 40, Issue 19, 2007, Pages 187-198. https://doi.org/10.3182/20071002-MX-4-3906.00032

26. Wang, K. S. (2013b). Towards zero-defect manufacturing (ZDM)-a data mining approach. Advances in Manufacturing, 1(1), 62–74. https://doi.org/10.1007/s40436-013-0010-9

27. Brierley, N., Tippetts, T., & Cawley, P. (2014). Data fusion for automated non-destructive inspection. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 470(2167). https://doi.org/10.1098/rspa.2014.0167

28. Charalampous, P., Kostavelis, I., & Tzovaras, D. (2020). Non-destructive quality control methods in additive manufacturing: a survey. In Rapid Prototyping Journal (Vol. 26, Issue 4, pp. 777–790). Emerald Group Holdings Ltd. https://doi.org/10.1108/RPJ-08-2019-0224

29. Vargas, C., Bürger, J., Viertel, F., Vogel-Heuser, B., & Jürjens, J. (2018). System evolution through semi-automatic elicitation of security requirements: A Position Paper ∗. 51(10), 64–69. https://doi.org/10.1016/j.ifacol.2018.06.238

30. Camarinha-Matos LM, Fornasiero R, Ramezani J, Ferrada F. Collaborative Networks: A Pillar of Digital Transformation. Applied Sciences. 2019; 9(24):5431. https://doi.org/10.3390/app9245431.