Guest editorial: Opportunities and threats in providing remote access to manufacturing-related environments

1. Introduction

Recent and ever-increasing advancements in information and communication technologies (ICTs) have been representing an actual "game changer" in almost all economic sectors, as well as in our everyday lives. The use of ICTs to change business models and provide novel revenues and value-adding opportunities is often referred to as digitalization. This process has also modified, and hopefully improved, operating conditions in workplaces, and it has also helped to integrate and streamline the operations within supply chains. Amongst the numerous digital technologies that have become integral parts of a typical production setting we may recall artificial intelligence (AI), Internet of things (IoT), cloud computing (CC) and cyber physical systems (CPSs). The new production paradigm that fully leverages and exploits the above-mentioned technologies is also known as Industry 4.0 (I4.0). This technology- and data-driven paradigm shift has shown, and it is showing, the potential to unleash a new era of higher productivity, better utilization of production and natural resources and reduced harm to the environment as a whole.

If many are the potential benefits stemming from this new scenario, practitioners and academic communities in various knowledge domains and industry sectors are still working to gain insights about the new challenges ahead and to derive the best deployment and operational conditions. These technological advancements and their integration into workplaces and our everyday lives helped in guaranteeing continuity to operations and boosting recovery after the spread of the COVID-19 pandemic.

As a consequence of enhanced communication and integration between physical objects and the digital world, an important and rising area of research is the one dealing with the possibility of providing remote-access to physical resources such as shop floors, warehouses, plants and teaching or research laboratories. This research domain turns out to be at the same time vast and multidisciplinary, because of the various issues it involves.

Most of the existing research in this field, however, deals with the concept of virtual and remote labs for educational purposes (Heradio *et al.*, 2016). These labs differ substantially from the traditional hands-on ones, as they exploit ICT advances and often make use of the concept of lab network, that is a set of two or more labs that cooperate for a certain amount of time with a common purpose, or that benefit by sharing resources, or by using a common organization, platform, or architecture (Esposito *et al.*, 2021). Unfortunately, the long-established literature on virtual and remote labs does not match with an analogous and structured research effort tackling the problems of remote access to other equally important physical resources such as shop floors, warehouses and production plants. In general, when facing the problem of remotely accessing and controlling a physical resource, several design and implementation issues are to be tackled, such as automation of equipment, configuration of a proper network architecture, safety of operators, people and assets and data security.

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From a manufacturing point of view, there are several concepts that can be linked to remote-access to physical systems: as an example, the concept of cloud manufacturing has emerged in the last decade, which refers to on-demand access to a shared collection of distributed manufacturing resources through the integration of new generation ICTs with advanced manufacturing methods, such as networked and virtual manufacturing systems (Thames and Schaefer, 2016). Other important research streams involve reconfigurable and flexible manufacturing systems, as well as the concept of servitization, that is the integrated offering of product and services, with a clear emphasis on the latter one (Baines and Lightfoot, 2014; Reverberi *et al.*, 2022). Servitization, also linked to the various "as-a-service" approaches, appears to be both a pivotal element in modern economies, and a growing and competitive strategy for manufacturing companies. All these concepts and trends have been anticipated and practiced by virtual and remote labs and lab networks, and therefore this special issue (SI) has the general objective of contaminating, complementing and integrating this research field with the broad stream of manufacturing research.

Consistently with the aforementioned objective and in order to start the journey toward the creation of a systemic foundation for remote access to physical systems, this SI gathered experiences, researches and case studies belonging to diverse contexts and geographical areas. While providing a systematic and unifying research effort, the practical implications of this SI are expected to benefit and effectively speed up the overall process of providing remote access, operability and control of physical systems. Moreover, the analogy of problems faced in very different settings would serve as a common denominator for transferring knowledge across various domains.

The remaining part of this paper, which is intended to introduce this SI, is organized as follows. Section 2 presents the factors according to which it is possible to classify and frame the various contributions in an organized way. Section 3 briefly reviews the contributions and Section 4 closes this contribution with brief conclusions.

2. Discriminating factors for organizing the contributions to the special issue

The discriminating factors used for categorizing the contributions to this SI are the following: (1) the research methodology; (2) the problem domain; and (3) the context of application.

The first factor that we considered is the **research methodology**. We start by discriminating between quantitative and qualitative research. According to Haq (2014), quantitative research collects numerical data and analyzes them by means of statistical methods to find relationships between variables with the main aim of verifying or nullifying one or more theories or hypotheses. Qualitative research, on the contrary, is used when little is known or where a significant uncertainty about a phenomenon exists. In this field, qualitative research argues that there is no pre-existing reality, and it pursues the overall aim of building theory and defining new variables. With this premise, the research methodologies involved in this SI can be summarized as follows:

(1) Action research with experimental validation (qualitative), i.e. a family of research methods that studies action with the goals of making that action more effective and efficient, increasing empowerment and participation and developing scientific knowledge (Yang and Miller, 2008).

(2) Single or multiple case study analysis (qualitative), i.e. the in-depth examination of one or a few cases, aiming more at the criterium of providing an analytic validity, rather than a statistical one.

(3) Design science and iterative research (qualitative), i.e. a constructivist approach based on multi-stakeholder interaction and iteration that combines relevant literature and empirical data to highlight research gaps and try to fill them.

(4) Simulation based research (quantitative), i.e. the construction of an artificial environment within which relevant information and data can be generated, collected and analyzed (Nallaperumal, 2014).

By **problem domain**, we mean the area of expertise or application that needs to be examined to solve a problem. The problem domains tackled by the contributions to the present SI are:

(1) Monitoring and maintenance, i.e. the use of methods and tools to enable easy data collection and processing for controlling production assets and supporting suitable maintenance activities.

(2) Servitization and smart production: with the term *servitization*, we mean "the process of building revenue streams for manufacturers from services," (Baines and Lightfoot, 2014) whereas with the locution *smart production* we mean the intensive application of IT at the shop floor level and above to provide infrastructures that respond to new industrial scenario solutions such as agile innovation and environmental sustainability (Davis *et al.*, 2015).

(3) Virtual reality (VR) and augmented reality (AR), i.e. the creation of a completely artificial visual environment (VR) or the integration of digital information within the visual perception of the user's environment in real time (AR).

(4) Digitalization, i.e. the use of digital technologies and digitized information to create company value in new ways and to benefit from them (Gobble, 2018).

Lastly, we considered the **context of application**, that is the fact that the SI contribution tackles a research problem that can chiefly be related to a single organization, be it connected to its manufacturing activities or to support services, or to supply chain integration. Therefore, the three possible contexts of application that we considered are:

(1) Single organization: manufacturing activities.

(2) Single organization: support services.

(3) Supply chain integration.

In the next Section we will summarize the contributions to this SI while in Table 1 we classify these contributions according to the above factors and we briefly report their research questions and main results.

3. Summary of the SI's contributions

Although the basis of digital transformation are ICTs and their shop floor implementation, also supported by remote connection, a pivotal role in future production systems will still be played by humans and by their interaction with the systems for monitoring and control purposes. The first contribution we present for this SI is Petrillo *et al.* (2023). In this paper, the authors apply action research with experimental validation. The aim of this contribution is to introduce a new IoT-based cloud-assisted monitoring architecture for smart manufacturing systems able to check the production status of the system at any time and, hence, to understand if some anomalous events occur. Alongside with a monitoring architecture, the authors also present an anomaly detection and classification algorithm that leverages AI to identify and localize production abnormal events, thanks to the combination of the proposed technique with human expertise. The tackled problem domain in this contribution is smart monitoring and maintenance of a manufacturing system, and the proposed architecture is tested in a specific case study, that is the production phase of solar thermal high-vacuum flat panels. Thus, the context of application of this study are the manufacturing activities of a

Table 1. Overview and classification of the SI contributions (note that the original authors' research questions are enclosed in quotation marks)

Reference	Research questions and/or aims	Research methodology	Problem domain	Context of application	Results
Petrillo *et al.* (2023)	It advances the application of AI in manufacturing control contexts	Qualitative: action research with experimental validation	Monitoring and maintenance	Single organization: manufacturing activities	It proposes an Internet of Things-based and cloud-assisted monitoring architecture for smart manufacturing systems to evaluate their overall status and detect the occurrence of potential anomalies and the related risk classification for possible interventions
De Luca *et al.* (2023)	It aims at overcoming the limited and constrained use of deep learning approaches to predictive maintenance applications in real-world internet of things scenarios	Qualitative: action research with experimental validation	Monitoring and maintenance	Single organization: support services	It proposes a deep learning framework for predictive maintenance task, which leverages a multi-head attention mechanism to deliver an accurate estimation of remaining useful life and high efficiency in terms of model memory storage requirements
Fattouh *et al.* (2023)	'What are the key challenges in the remote integration process of advanced manufacturing technologies and how do companies mitigate these challenges?' 'How can companies apply and realize the remote integration process of advanced manufacturing technologies into their production systems?'	Qualitative: single case study analysis	Servitization and smart production	Single organization: manufacturing activities	It extrapolates an integrated framework for the remote integration of advanced manufacturing technologies into a production system
Tedaldi and Miragliotta (2023)	'What is the state-of-the-art of MaaS platforms (prototypes excluded) which are currently operating?' 'What are the deployment models currently used by these platforms?' 'How can we measure different levels of development of MaaS platforms?'	Qualitative: multiple case study analysis	Servitization and smart production	Single organization: manufacturing activities	It provides a picture of what MaaS offers today in term of capabilities, what are the deployment models, and proposes a framework to assess diverse levels of development of MaaS platforms

(*continued*)

Reference	Research questions and/or aims	Research methodology	Problem domain	Context of application	Results
Aquino *et al.* (2023)	Can Augmented Reality tools be leveraged to enable remote collaboration in industrial services? Is it possible to establish a guide for the definition of the right hardware features, software functions and technical requirements of AR tools for specific application?	Qualitative: design science and iterative research	Augmented reality	Single organization: support services	It proposes a model encompassing the factors relevant to the selection, design and configuration of AR technologies in the contexts of industrial services
Kammerlohr *et al.* (2023)	'Can the effectiveness of digital lab transformation be adequately described in a maturity model and thus used as a tool to support the sharing economy?'	Qualitative: design science and iterative research	Digitalization	Single organization: support services	It delivers a maturity model for digital lab transformation
Grida and Mostafa (2023)	'Are smart contracts too smart for supply chain 4.0?' It addresses the limited applicability of blockchain and smart contracts to supply chain operations	Quantitative: simulation-based research	Digitalization	Supply chain integration	It provides a blueprint that can be instanced into a blockchain system to control an ecosystem in the context of operations and supply chain management (OSCM)

Table 1.

single organization: the experimental results of this specific case study confirm that the proposed solution can capture products' health state and, at the same time, maintain the human-centric aspect and improve process' resilience and products' sustainability.

Full decision-making autonomy of the equipment in an I4.0 environment often clashes with a limited computing capacity of the production system components. Hence, to fully reap the benefits provided by IoT technologies, it is necessary not only to integrate them with artificial intelligence, but also to calibrate such applications to the remote computing capacity of the individual entities of the production ecosystem. To overcome this limitation, De Luca *et al.* (2023) propose a particular deep learning architecture for predictive maintenance, and they also design an AI model capable of estimating remaining useful life from different types of measured equipment data. This study also applies the action research methodology with experimental validation to the smart monitoring and maintenance problem domain. Indeed, the authors start by providing the definition of the predictive maintenance task, and then present the model architecture, with a focus on a specific core part, i.e. the introduced attention module. The major novelty behind the proposed framework is to leverage a specific mechanism that both provides interesting results in estimating the remaining useful life and low memory requirements, providing the basis for a possible implementation directly on the equipment hardware. An experimental evaluation and comparison are then provided by using the well-known Turbofan engine degradation dataset from NASA, so that the context of application of the present study is related to support services within a single organization.

The results of the evaluation show that the performance metrics and the overall accuracy of the proposed model are fully comparable with the best techniques available in the literature. Furthermore, these results have been achieved by a model that has far fewer parameters, a much lower storage size and a faster training stage. For these reasons, the trade-off between efficiency and effectiveness of the proposed architecture is very promising, disclosing possible future pilots in industrial contexts where the relationship between allocated resources and achieved performances is vital.

The paper by Fattouh *et al.* (2023) deals with flexible and reconfigurable production systems, which are an important driver for competitiveness. Within the I4.0 paradigm, future production systems could take big steps forward in terms of reconfigurability and flexibility through the remote integration of advanced manufacturing technologies. The aim of this study is to examine the remote integration process of advanced manufacturing technologies into the production system and identify key challenges and mitigation actions for smoother integration. Specifically, the two research questions addressed by this study are (1) 'What are the key challenges in the remote integration process of advanced manufacturing technologies and how do companies mitigate these challenges?', and (2) 'How can companies apply and realize the remote integration process of advanced manufacturing technologies into their production systems?'

As such, this contribution applies a single case study methodology to the problem domain of servitization and smart production. The authors argue that the case study design, in fact, is methodologically appropriate for answering to their two research questions, namely for understanding and mapping activities of manufacturing technology adoption processes and exploring and identifying challenges and ways to improve them. The selected case study is a Festo cyber-physical factory at an industrial technical center, thus the context of application are the manufacturing activities on a single organization, and the answers to the two research questions are synthesized into an integrated framework, which the authors claim to be a valuable tool for effectively managing the remote integration of advanced manufacturing technologies. Also, the authors claim that their study deepens the understanding of remote integration in a previously unexplored context, i.e. the integration processes of advanced manufacturing technologies, and that their findings are particularly interesting for both industry and academia.

The following contribution in our SI also deals with the same promising ICT-enabled development in manufacturing, that is the transformation of production activities into services and the subsequent process of building revenue streams for manufacturers from services, also termed as servitization. This development provides benefits both on the customer side in terms of production variety, but also on the supply side through increased saturation of production resources. The possibility of deploying Manufacturing as a Service (MaaS) models has been investigated by Tedaldi and Miragliotta (2023). The goal of this study is to analyze the state of currently operating MaaS platforms and the deployment models currently in use in these platforms, and to question how different levels of development of MaaS platforms can be measured. The study applies qualitative research methodology, with multiple case studies supported by a cross-case analysis on different platforms developed by enterprises. As such, it analyzes the problem domain of servitization and smart production in the context of supply chain integration. The results of the paper are summarized in a framework to assess different levels of development of early adopters under 7 different dimensions.

The paper by Aquino *et al.* (2023) scrutinizes the factors to be considered when introducing AR to provide support services. The set of enabling technologies in the context of I4.0, in fact, is very broad, and the adoption of such technologies, even when adequately integrated, must undergo appropriate evaluation. Thus, the aim of the study is to develop a model supporting the introduction of AR technologies in industrial services. The paper applies the qualitative research methodology in an iterative way, that is by combining relevant literature with empirical data stemming from selected interviews to some large industrial companies appropriately selected. The problem domain here is of course connected to VR and AR, with a specific focus on the latter one, and the context of application is related to the manufacturing activities of a single organization. The outcome of the study consists in a model, which encompasses the relevant factors to the processes of selecting, designing and configuring AR technologies to deliver industrial services. More specifically, the model groups 18 different factors into four categories, which provide a ready-to-use integrated framework that could serve as a starting point for future studies and applications of AR tools, as well as of I4.0 and digital technologies, in general.

The role of education and training are becoming even more crucial in achieving the hoped-for digital transformation. In such a context, laboratories may represent very effective tools toward this goal, and they can also benefit from the new possibilities offered by digital technologies. In this sense, just as maturity models have been formulated for the I4.0 paradigm implementation, Kammerlohr *et al.* (2023) develop and validate a maturity model for the digital transformation effectiveness in laboratories for education and research purposes. The authors also suggest their model as a valuable tool to foster sharing economy platforms, by addressing the relevant factors for an effective digital labs' transformation. The paper applies design science research methodology, combined with experts' workshop and interview sessions, and it tackles the problem domain of lab digitalization, applied to the support services of single organizations; the paper in fact applies the proposed maturity model to six different use cases. This model contributes to the literature on digital lab transformation by describing, organizing and evaluating relevant dimensions, items and levels; the strengths and weaknesses of the model are presented in the study, alongside with its applicability and the areas for improvement, and with practical recommendations, to provide added value in assessing lab functionalities and sustainability.

Lastly, just according to the order of the contributions in our SI, Grida and Mostafa (2023) deal with the topic of smart contracts. The connection between entities in an I4.0 context does not only concern resources within a factory, but also different economic operators within a general supply chain. The possibility to smoothen the functioning of the supply chain through direct customer-supplier connection requires the development of appropriate operational tools. In the context of I4.0, because of unassured records' liability, the application of blockchain and smart contracts to supply chain issues is still rather limited. The aim of Grida and Mostafa (2023) is to address this aspect by introducing trust as a digital asset that is encapsulated inside the blockchain, to provide a good level of integrity for the exogenous records originated outside the boundaries of automation in permissioned blockchain ledgers. The main research question here is to investigate whether smart contracts are too smart for supply chain 4.0. The study provides a blueprint framework, instanced into a blockchain system, to control an I4.0 and integrated supply chain ecosystem with a mechanism to validate the non-digitally verified "exogenous" transactions through a rewarding system. By applying a quantitative methodology and leveraging system dynamics simulation, the paper tackles the digitalization problem in supply chain integration, and its results prove the relevance and potential of using smart contracts for supply chain 4.0 through the mutual advantage achieved for all parties. Although this work is a conceptual framework, the authors suggest that future work might be dedicated to implement and experiment the proposed framework for different supply chain 4.0 systems.

4. Conclusions

This SI drew upon the concept of virtual and remote labs as interesting and promising examples of how to effectively exploit ICT advances to provide remote-access to physical resources. Unfortunately, the organized literature branch on virtual and remote labs is still not corresponded by a comparable research effort tackling the provision of remote access to other physical resources. With the aim of contributing to fill this gap, the present SI presented and discussed seven articles on the mentioned topic: these contributions turn out to be diverse and complementary.

As expected, we observed a clear dominance of qualitative research methodologies, in accordance with the significant uncertainty and the lack of a pre-existing amount of contributions on research and applications about remote-access to physical resources. Indeed, only one paper used quantitative methodologies (Grida and Mostafa, 2023), whereas the remaining six studies used different qualitative research methodologies. With respect to the problem domains, the present SI tackled monitoring and maintenance, servitization and smart production, AR and digitalization. Also, in terms of contexts of application, the above-mentioned problem domains were applied to the manufacturing activities or to the support services of single organizations, and to the supply chain integration.

As concluding remarks, we would like to note that, to achieve a sufficiently wide perspective on such a complex and multifaceted topic such as that of providing remote access to physical resources in manufacturing, one single issue of a journal could never suffice. Nevertheless, we hope that this SI could represent a thought-provoking starting point toward such an ambitious goal. Indeed, if we tried to distill the proposed research questions of the contributions to this SI in an attempt to single out an overarching objective, we would note that most of them investigated frameworks or models, such as maturity or implementation models, either to understand the (pre-)conditions or factors to be considered for the implementation, and/or the implementation model for integrating, exploiting, or exceeding the limits of a selected solution in a specific problem domain. With respect to this latter point, we would like to note that the results achieved by most of the contributions are models or frameworks which not only answer the above-mentioned research questions, but also operatively enable, ease, or empower remote-access to some physical object or resource.

Lastly, the strong prevalence of qualitative research methods confirms the fact that this research area is still quite blooming, and it corroborates the opportunity of providing incentives and stimuli to a line of research that, we are sure, will become increasingly comprehensive, complex and populated with contributions in the near future.

Happy reading!

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