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Exploiting Extended Reality under the Manufacturing as a Service paradigm

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Abstract

The advent of new technologies and concepts such as Extended Reality (XR), Cloud Manufacturing, Digital Twin, Industrial Internet of Things is completely changing the manufacturing landscape. Innovative digital tools are available to increase the competitiveness and efficiency of companies. The XR can support the Smart Operator in production, maintenance and training activities. Similarly, Manufacturing as a Service, which is a variation of Cloud Manufacturing, can make corporate architectural systems more flexible and scalable. In this paper, some preliminary results relating to the European 5G-ERA project and the synergistic work that the companies CAL-TEK, TWI and HAL Robotics are conducting is shown. An XR-oriented architecture is proposed, whose usefulness is emphasized by the use of the MaaS concept, and the implementation of a Mixed Reality application is shown, to support an on-site operator. Future developments concern the implementation of a Virtual Reality application for the off-site operator, and the use of the 5G-ERA middleware to exploit the potential of the MaaS paradigm.

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Keywords: Extended Reality, Manufacturing as a Service, Smart Operator, Smart Factory, Cloud Manufacturing

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1. Introduction

The manufacturing sector is going through deep changes, dictated by the advent of Industry 4.0/5.0 [1]. Novel concepts such as Digital Twin, Blockchain, Big Data, Cloud Manufacturing, Internet of Things (IoTs), Extended Reality (XR) are offering new opportunities and at the same time new challenges. Cloud Manufacturing is the manufacturing delineation of Cloud Computing and aims to significantly increase flexibility in offering manufacturing services. More specifically, in recent years the concept of Manufacturing-as-a-Service (MaaS) has been emerging to indicate the possibility for users to request on-demand manufacturing services [2]. XR is an umbrella term, which includes Mixed Reality (MR), Augmented Reality (AR), Virtual Reality (VR) [3]. With the growing adoption of 5G technology, XR experiences are becoming increasingly seamless and real-time. XR can support the Smart Operator (Operator 4.0) for training purposes, for assisted maintenance activities, to increase safety at work, and for much more [4], [5].

This research work shows some preliminary results from the 5G-ERA (5G Enhanced Robot Autonomy - https://5g-era.eu/) Project, which is still ongoing and received funding from the European Union's Horizon 2020 Research and Innovation programme (grant agreement No. 101016681).

The remainder of this paper is organized as follows. Section 2 reviews the literature about the main existing contributions in terms of Smart Operator and XR, and the MaaS paradigm. In Section 3, a new XR-oriented architecture is proposed and described, and it is explained how it can be exploited through the MaaS paradigm. Section 4 shows some preliminary results and describes possible future scenarios, while conclusions are shown in Section 5.

2. State-of-the-art

2.1 Smart Operator and XR

As part of Industry 4.0 and 5.0, the human operator is undergoing a significant transformation in the way they interacts with advanced technologies, automation systems, and data within smart factories [6]. Nowadays, smart operators collaborate with intelligent machines and robots, which handle physically demanding and repetitive tasks, leaving the human space to focus on higher-level responsibilities, which require creativity, as well as problem-solving and decision-making skills [7]. Frequently, smart operators are equipped with XR technologies, which can provide multiple advantages [5]. Through AR and MR devices, it is possible to superimpose digital information, such as diagrams and instructions, onto the real world, aimed at minimizing errors and increasing productivity. At the same time, VR enables the creation of digital twins, which serve both as training environments and for real-time monitoring and control. Several scientific contributions have been emerging in recent years, confirming that this topic is of great interest. Longo et al. [8] proposed a general-purpose and ontology-based architecture to support the smart operator through the use of MR. It has been successfully tested and validated through two case studies in the manufacturing sector concerning (i) scheduled maintenance and alarm management, (ii) customer order management. Mourtzis et al. [9] presented a cloud-based and MR-based framework to support engineers in the design phase of new components and subsequent manufacturing, emphasizing the possibility of interacting via hand gestures, through the adoption of MR devices. MR has also been used successfully for fault detection in manufacturing assembly, as it helps the operator avoid errors caused by manual inspection [10].

On the other hand, VR also appears extremely promising to support the operator in the manufacturing field. Pérez et al. [11] recently studied the use of commercial gaming technologies to create a fully immersive VR-based environment, also including a robot controller interface. Then, they demonstrated that this type of system can be successfully used for training and simulation, minimizing risks and waste, offering a cost-effective solution. Peruzzini et al. [12] proposed a VR-oriented methodology to efficiently create virtual manufacturing simulations, with the aim to design assembly lines in compliance with ergonomics constraints. They successfully used Unity 3D for virtual environment building and HTC VIVE as a device to immerse the user in the virtual world. According to Brunzini et al. [13] VR significantly helps operators increase performance and reduce errors.

Although various extended reality applications are spreading with undoubted benefits, there are still several challenges to face. A recent and very impactful literature review [14] claims that there is a need for further case study applications of worker assistance systems (especially MR) in manufacturing. According to Sahoo and Lo [15], immersive technologies are not very common in most manufacturing sectors, leading to a significant gap between the conceptual smart manufacturing system and the existing manufacturing system.

2.2 From monolithic to distributed architectures: the MaaS paradigm

Over the years, information technology has witnessed a significant transformation from traditional monolithic to distributed architectures [16]. This change was motivated by the need to flexibly deal with increasingly uncertain and constantly evolving environments. In distributed architectures, subsystems are physically separated and exchange resources via standard interfaces. Distributed architectures involve spreading resources and functionality across multiple geographic locations or compute nodes. In the context of Cloud Manufacturing, this means that production resources, such as machines, sensors and control systems, can be distributed across different production sites and connected via a network. This allows you to use resources more efficiently and flexibly. Cloud Manufacturing and distributed architectures are complementary and mutually reinforcing to optimize efficiency, agility and flexibility in production processes [17]. This combination allows companies to make the most of available resources and information, while ensuring greater resilience and better data management. In recent years, more and more approaches regarding Cloud Manufacturing and MaaS are spreading. Cloud Manufacturing has been recently used for logistics planning and manufacturing service composition [18]. Furthermore, the integration between Cloud Manufacturing and Deep Reinforcement Learning can be very useful for solving production scheduling problems [19]. More specifically, a paradigm is spreading in the era of Industry 4.0/5.0, called MaaS. It is a model in which manufacturing capabilities are offered as a service through digital platforms, allowing companies to manufacture products without directly owning or managing the manufacturing infrastructure. Therefore, it concerns a transition from a model based on the purchase and management of equipment to a model oriented towards flexibility, connectivity and access to a large set of resources [20], [2].

The MaaS paradigm is not yet sufficiently mature, therefore approaches are needed that demonstrate its validity and push its diffusion on a larger scale. One of the aims of this paper is also to show how the MaaS paradigm can be exploited in a specific case study, with reference to the brazing process.

3. XR and MaaS

This section describes how XR can be leveraged through the MaaS paradigm. Regarding XR, a conceptual architecture is proposed in Figure 1 and is being tested within the 5G-ERA project. It can be divided into three main parts:

- Physical world: we are referring to a modern industrial plant, equipped with sensors that continuously generate data and information. Of course, every type of entity such as machines, robots, operators can generate data.
- Back-end: it concerns all the logic that guarantees the functionality offered to the end-user. Through appropriate Application Programming Interfaces (APIs), the data generated by machines, robots and operators are transferred to a server/database and can be exploited by the user.
- Front-end: it includes a set of Layers. The APIs Layer ensures the exchange of data with the back end, therefore with the real world. The Applications Layer includes a set of applications. Substantially, within the 5G-ERA project, the same information can be accessed in different ways: web-application, mobile-application, wearable-application. The latter is the focus of the project, in the sense that it can be used both by an on-site operator (smart operator) and by an off-site operator. Different devices can be used such as Microsoft HoloLens for the onsite application and Head Mounted Displays (e.g., HTC Vive) for the offsite application.

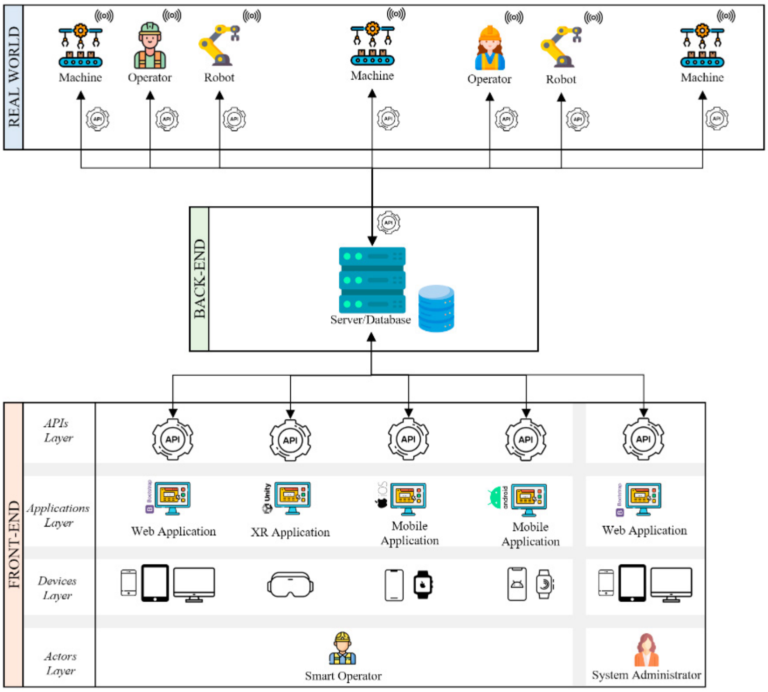

Fig. 1. XR software and hardware architecture

In order to take advantage of the MaaS concept, MR and VR applications are exploited through a microservice network architecture. Designing the network architecture as a suite of distributed microservices will allow these applications to be deployed across servers at TWI, Cal-Tek and HAL Robotics, as well as leveraging powerful cloud computing resources, to enable computationally intensive operations such as robotic reprogramming and computer vision applications to provide results rapidly. This will provide an adaptive, responsive system for the application, which the on-site operator and off-site engineer can interact with and collaborate on in real time. The communication between these services, distributed across a range of servers and locations handled securely on a single network using an OpenVPN Server, which will be managed by HAL Robotics, with OpenVPN Clients at each partner location, to handle and secure 5G and internet-based network traffic. How this suite of distributed microservices will communicate with each other, and with the translation layer applications deployed at the edge, is handled by the 5G-ERA middleware. The 5G-ERA middleware is the orchestration software responsible for linking all the network application elements together, providing the powerful infrastructure which underpins the entire project. The power of the 5G-ERA middleware will allow communication with the wider range of applications being developed under the 5G-ERA consortium project, expanding the scope for collaboration.

4. Case study and preliminary results

4.1 Case study description

The conceptual proposal contained in Section 3 is being tested as part of a specific case study, which concerns a brazing cell at TWI Limited. Brazing is a widespread process in the manufacturing sector, which concerns the joining of materials through the use of a braze filler metal (BFM), which has a lower melting point than the pieces to be joined. It usually consists of the following phases:

- Cleaning: all components to be brazed are carefully cleaned to remove any impurities. This can be done mechanically or chemically.
- Assembly: the pieces to be joined are brought together. The BFM, which can be in the form of paste, foil or wire, is applied or positioned between the parts to be joined.

- Heating: the pieces are heated, this can be achieved through many mediums such as a furnace, flame torch or induction. The heat must be sufficient to melt the BFM but as the melting point of the BFM is lower than the components being joined, the components will not melt.
- Cooling: once brazing is complete, the entire assembly is left to cool. During cooling, the BFM solidifies, creating a joint.

The ultimate goal of the case study is to show how a labour-intensive brazing process can be automated using XR and MaaS.

4.2 *First preliminary results*

The 5G-ERA project is ongoing and will be completed in 2024. However, the first preliminary results are already available. The on-site application has been designed and developed, so that the on-site operator can interact with the real environment through the Microsoft HoloLens. Figure 2 shows the operator wearing the Microsoft HoloLens accessing the application using credentials. Figure 3 shows a possible path for the on-site operator, while using the application. Basically, once an object has been accessed, a menu appears with a list of useful functionalities: description, photo, video, audio, files, data. All this data adds knowledge to the on-site operator. Figure 4 shows instead the real use case brazing cell at TWI Ltd.

Fig. 2. User wearing the Microsoft HoloLens®, inserting the login credentials

Figure 3 shows a possible path for the on-site operator, while using the application. Basically, once the object has been accessed (e.g., by scanning a QR-Code), a menu appears with a list of useful functionalities: description, photo, video, audio, files, data.

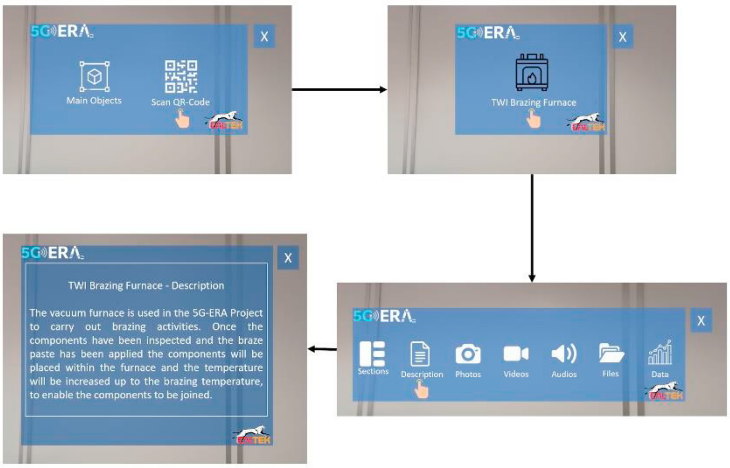

Fig. 3. Microsoft HoloLens® menus

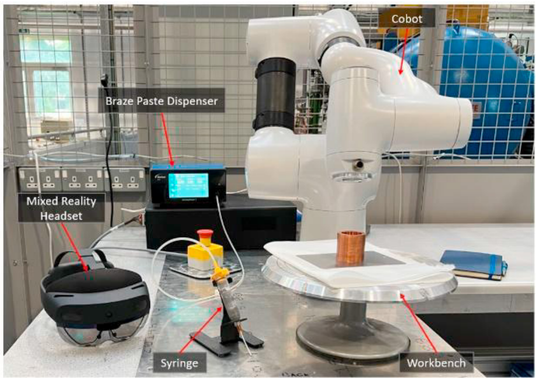

Fig. 4. Use case brazing cell at TWI Ltd

The first experiments demonstrate that the on-site operator is able to be more efficient, taking advantage of the information available within the Microsoft HoloLens.

5. Conclusions

Significant and rapid changes have been affecting the manufacturing landscape in recent years. The new technologies of Industry 4.0/5.0 are revolutionizing business processes and offering great opportunities to improve competitiveness on a global level. Extended Reality, if properly exploited, can significantly improve the performance of the smart operator, who has more information to perform the various tasks more easily and efficiently. In this challenging context, one of the main aims of the European 5G-ERA project is to leverage new technologies to support the deployment of robust and highly flexible manufacturing, supporting both SMEs and large-scale companies. In this paper, an XR-oriented architecture was proposed to support the smart operator through various applications (i.e., web, mobile, wearable). Furthermore, the link between this architecture and the MaaS paradigm was explored. The preliminary results are promising and show the successful implementation of the MR application to support the Smart Operator. Future research developments concern the implementation of the Virtual Reality application for the off-site operator and the overall digitalisation of the brazing process, with the aim of assessing the benefits compared to the "as is" situation, in which the process was carried out without any support from an XR and MaaS perspective.

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