Immersive Systems in Human-Centered Manufacturing: The Informational Dimension

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Abstract. The rise of smart manufacturing environments, characterized by high quantity of data/information available, contributes to a growing interest and research towards the use of immersive technologies not only in factories but also across entire value chains. New immersive technologies and devices are being developed to improve cooperation within Collaborative Networks (CNs), especially in the human-machine hybrid networks context. The application of these technologies in such complex environments expands substantially the modes how information is delivered and used, which may exacerbate one of the oldest problems of cognitive ergonomics: information overload. Therefore, this work presents applications of immersive technologies in manufacturing into the perspective of "information work" and "immersive human-centered manufacturing systems". A framework is proposed to be developed in a FabLab to understand the worker needs and interactions. This FabLab aims to demonstrate the potential/real application of immersive technologies, towards the enhancement of the human worker cognitive capabilities.

Keywords: mixed reality, augmented reality, virtual reality, industry 4.0, human-worker, human-centered manufacturing, information management.

1 Introduction

In the context of industry 4.0 (i4.0), "the continuing convergence of the real and the virtual worlds will be the main driver of innovation and change in all sectors of our economy" [1]. This convergence is achieved by creating multiple digital data and information flows between different systems/machines, between those systems and workers, between workers and systems/machines in a kind of human-machine hybrid network. The socio-technical context can be characterized by intra and inter organization's collaboration-intensive processes in a human-machine hybrid network - human-to-machine, machine-to-machine, and human-to-human - requiring operational information as well as codified knowledge for learning. Information can be communicated through different channels, and managed by a variety of systems, both implemented through several technologies like immersive technologies using virtual reality (VR), augmented reality (AR) or mixed reality (MR). Even though only recently have companies and researchers started exploring the practical applications of these technologies in the manufacturing sector, these have been around longer than we might expect [2, 3]. Immersive technologies together with other more mature technologies, when combined with IoT, data analysis and artificial intelligence (AI), enable the creation of tools aimed to help and support workers in their individual and collaborative work [4].

The main contribution of this paper is put the application of immersive technologies in manufacturing into the perspective of "information work" and "immersive human-centered manufacturing systems". A framework to be developed in the context of a FabLab is proposed, using of the concept of information work and information work analysis to understand the worker needs and their interactions with information infrastructures, systems and machines.

The paper starts to review the potential of immersive systems applications in manufacturing. Secondly, it addresses the importance of manufacturing systems centered in the human worker as a context to a perspective of the development and adoption of immersive systems as an informational problem, originated in the informational needs of the worker. Finally, this perspective is used to structure and inform the technological architecture of the Immersive Human-Centered System (IHCs) demo and training approach in a context of a FabLab.

2 Immersive Systems in Manufacturing

The potential of immersive systems can be aggregated in diverse applications typically executed within different teams from different companies working virtually and collaboratively, such as product design and development, operations support, maintenance and remote assistance, inspection and quality, learning, and training.

Product design and development are processes that normally involve a lot of communication and reviews among all stakeholders [5]. Immersive technologies can support these processes by increasing and improving the quality of their tasks, simplifying collaboration, and communication between different parties [5-7]. People involved can interact in collaboration with the process even though they are geographically dispersed [5]. Conventionally, designers use 2D CAD models to test and experiment with mainly 3D products. Physical prototypes are used to test the product design for products that need to be tested in real-time [7]. They are challenging to produce and difficult to redesign for testing and retesting, so this is very expensive and it consumes more time and, in turn, lengthens the Time To Market [7]. Using VR, designers can design products in a 3D space and test them in simulated environments until the design is final and approved. In addition, VR also offers the ability to test products under normal conditions and identify design flaws that cannot be found using conventional testing methods [7]. This ensures that the final products have a higher quality and live up to what was specified, minimizing requests for changes and other complaints from the customer [8].

Regarding operations support, traditionally, work instructions were made available in PDF files printed or displayed on screens [9]. That way, workers always have to look to the side to know what the instruction is or to consult the information and look again at the part/area where they are working. The use of AR allows the information of work instructions to be displayed in real-time and in the workers' field of view [10, 11]. This eliminates the need to consult documents alongside or on other devices outside the human field of view. In the context of collaborative network (CNs), this kind of technology may support the dissemination and communication of best practices and guidelines for manufacturing operations support. This can be essential to guarantee high quality and high-performance of entire value chains.

In maintenance and remote assistance, it is known that equipment or machinery failure is a problem that causes unexpected downtime and requires immediate responses. Sometimes, maintenance teams may not be "close" to solve the problem and restore the equipment, in time to avoid a significant loss of productivity [12]. Viewing data and information regarding the performance of production equipment can allow maintenance teams to identify equipment integrity problems that are often overlooked. The use of immersive technologies, namely AR, to guide workers with less experience in equipment maintenance is a solution that helps solving equipment failure, ensuring that production stops much less time [9, 10, 12]. AR can allow maintenance teams to identify equipment needs and malfunction problems [12], eliminating incorrect assumptions, reducing the risk of breakdowns, and allowing faster and more effective maintenance [9].

Regarding the assistance, technicians can obtain the details of parts of a product during production and after its implementation, connecting the product in a network. This information helps the support engineer to obtain historical product performance data in its context and environment for its configuration [12]. With the use of AR applications, together with videoconferencing and notes recorded in 3D representations, the maintenance task is facilitated reducing the costs of support and assistance [9, 13]. Thus, in the context of CNs, the ability to get knowledge and information from companies with expertise in machine maintenance is essential for a quicker reaction in order to solve problems and reduce downtime. Also, taking advantage of a more digitized manufacturing environment, capable of streamline both vertical and horizontal data integration, it is possible to propagate data related to the product.

While companies are looking to maximize productivity, they are also looking to increase the quality and conformity of their products [14]. To ensure product quality and compliance and to apply automated test methods, technicians need to inspect hundreds of units for defects or non-conformities [14, 15]. Due to human limitations, technicians are unaware of subtle indicators of non-compliance [14]. The use of AR combined with artificial intelligence and sensing technology can support the detection of these subtle deviations, thus increasing the quality of the product [15]. Concerning the quality inspection of materials needed for production, the products can be inspected and compared visually with the information provided by the supplier [14]. All divergences may be highlighted in a way that is overlaid on reality [15]. The information about the product being inspected can be displayed in the operator's field of view. For CNs, immersive technologies can support the inspection and quality analysis of products in which parts and components are manufactured and assembled within a distributed network of companies. Exploring artificial intelligence and these technologies, it is possible to provide an effective way of continuous product inspection to guarantee that product quality is assured along the entire value chain.

Training is vital for production workers to perform their tasks with maximum effectiveness and efficiency [16]. This process takes time, and the allocation of inexperienced people to perform critical operations can compromise the quality of work or even lead to safety problems [17]. Training new workers in a VR environment can allow them to gain experience and proficiency in their tasks without compromising the productivity, quality, and safety [18]. At the same time, proper application of AR means that workers can be trained, protected, and informed without wasting resources because they do not need an experienced worker guiding them [16, 17]. Workers can be conducted step by step, with guidance information overlaid on real and physical world parts and assemblies, in their field of view, thus time needed to improve the worker's skill set is shorter [16-18]. CNs in manufacturing are characterized by a high diversity of products, sometimes customized for a specific customer, with a low quantity of production (single lot size). Therefore, to guarantee the easy dissemination of training material, focused on operators' needs, immersive technologies should be seen essential for virtual and collaborative network performance.

3 Information in Human-Centered Manufacturing Systems

Production focused on the human worker has become increasingly important for organizations and, therefore, sparked research interest in order to achieve more sustainable production [19-20]. This interest stems from studies suggesting that this approach helps to increase competitiveness, especially taking into account the new social challenges that i4.0 represents. Thus, companies must use new information and production systems to help older workers, with physical difficulties, more experienced, and inexperienced in improving the performance of their tasks in the factory. The new production systems should be characterized by cooperation between machines and human-workers and designed not to replace the skills and abilities of human workers, but to help them to be more efficient considering this cooperation [19]. The design of these systems must be centered on the human worker, going beyond those that are the traditional human factors that focus only on helping organizations to manage the workload healthily and safely. On the contrary, the design should evolve to a higher human level, considering factors such as job satisfaction or the experience and competence of workers [20].

The literature suggests that, to date, most of the research production systems performance is focused on operational functions, disregarding the effect of human factors that can also affect system performance [21]. In fact, more research is needed to develop intelligent and adaptable systems to optimize production systems considering the characteristics of the human worker regarding cognitive issues (in addition to physical ones) such as his subjective impressions, individual needs, skills, abilities, and resilience. Although immersive systems promise to be disrupting in the production industry, research is not completely convincing on the centeredness of the human-worker. If, on the one hand, these systems work as a substantial improvement in the physical ergonomic aspects, on the other hand, it is not so clear how these systems address the aspects related to cognitive ergonomics. One fundamental dimension of cognitive ergonomics in industrial applications is how information is captured, organized, delivered, and used by the human workers. Immersive systems expand substantially the modes how information is delivered and used that, together with the velocity and volume of data creation, may exacerbate one of the oldest problems of cognitive ergonomics: information overload.

As stated in [22], "Identifying and gathering the right data, deploying it for the right purposes and effectively analyzing it will be critical to make the right Industry 4.0 decisions". Therefore, information management is needed to enable the efficiency and effective use of information alongside the value chains' tasks and processes, particularly in the shop-floor applications fostered by immersive systems [23, 24]. Nonetheless, current management and information management tools reside in a logical-physical dichotomy, which prevents the development and use of all the ingenuity, creativity, and know-how by human-workers [25]. Consequently, a socio-technical change is needed in order to consider this problem when designing and implementing immersive systems.

It is a common place to state that for an organization to be successful, it needs to deliver to its workers the necessary information, at the right time and in the right place so they are able to complete their work tasks [26]. The main challenge in solving this issue related to information organization is not in identifying which worker needs information, or what information is necessary to provide or even for which task it is necessary to provide information. The real challenge is to make all these aspects converge productively for the worker and, consequently, for the organization. As a way forward to research this problem, we propose applying the information work analysis approach [26] whose main objective is to analyze in detail the interface between work information and the information infrastructures and systems used to organize knowledge and information. With this approach it is possible to investigate, through work information, human work in context, establishing premises to relate the notion of "information work" and "immersive human centered manufacturing systems" (IHCs). The IHCs act as systems of organization of information and knowledge that will contribute for the task of creating useful information, to be delivered to the right worker and at the right time. Thus, it is important to understand human workers, information work and information systems as components of an inclusive and holistic system of human work, with unique aspects in terms of characteristics and qualities [26]. To understand and develop this holistic system and to make work possible, it is necessary to understand the people (workers), the machines, the information, the interactions and their associated behaviors and the notions of the purpose, meaning and values related to the work [26].

4 Immersive Human-Centered Manufacturing Systems Research in Lab

Understanding the real impact and return of investment of immersive and human-centered technologies is today a complex task for manufacturing companies. Few companies are able to invest significant amounts of money and time to implement and validate a technology within a real industrial scenario. As a consequence, Fab Labs have been designed and developed as a near-real industrial environment where research institutes, universities and industry can work together to implement, test, demonstrate and evaluate innovative and emerging technology. In line with this vision, INESC TEC has been investing and developing a Fab Lab, the iiLAB Industry and Innovation Lab, where different technologies from robotics and flexible logistics, industrial cyber-physical systems (Internet of Things) and new communication technologies (e.g. 5G), to human-centered technologies are combined within an Industry 4.0 compliant architecture. Here it is possible to carry out demonstrations in the form of a showroom, experimentation and prototyping space for technological companies, and to offer advanced training courses for manufacturing companies.

The assets and information system architecture are maintained based on the research work performed by the research center and based on the strategic partnerships with the technology companies. The following image (Fig. 1) provides a high-level vision on the technology and architecture that is being developed in the iiLAB.

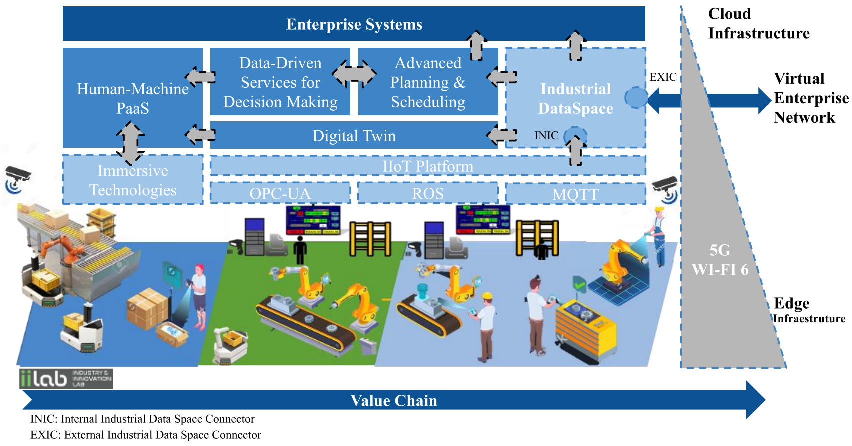

Fig. 1. iiLab Technology Vision Architecture

The FabLab objective is to represent an industrial infrastructure that belongs to a complex and distributed value chain. Therefore, not only the vertical interoperability is important, but also the capability to share information within the virtual network (horizontal integration). In the shop-floor, different digital technology such as AGVs, robotic arms, conveyors, vertical and automated warehouses, advanced machines (e.g. CNCs) and quality control stations, work in a collaborative way. In order to manage and control such digital technology, cognitive-enhanced operators are considered, exploring human-machine technologies based on immersive reality.

As previously explained, the use of immersive technologies in i4.0 plays a key role in supporting workers throughout their tasks in the plant. Operators become able to use tablets, head-mounted displays and other technology solutions to enrich the reality with information and intelligence that enable them to improve their performance and enhance the overall system performance, as well as directly interact with the production system.

It is therefore essential that these solutions take the production system complexity as a starting point, and focus on the workers' needs, namely by knowing their context and the situations in which their activity takes place (Fig. 2). The context is formed in layers, is dynamic and involves several situations. These layers are composed of various types of data and information, such as environment data; operations data; worker physiological data; and organizational information (e.g. products, process information). On the other hand, a situation fits into a context, as each situation is characterized by a set of contextual factors. A situation can also be considered an action that occurs in a specific time and space, for example, a specific interaction of the worker with a machine. The concept on which this iiLab architecture is based considers the worker as the central element of the production system which, in turn, must not only be able to understand the surrounding context and production environment, but also the situation in which the production operation takes place.

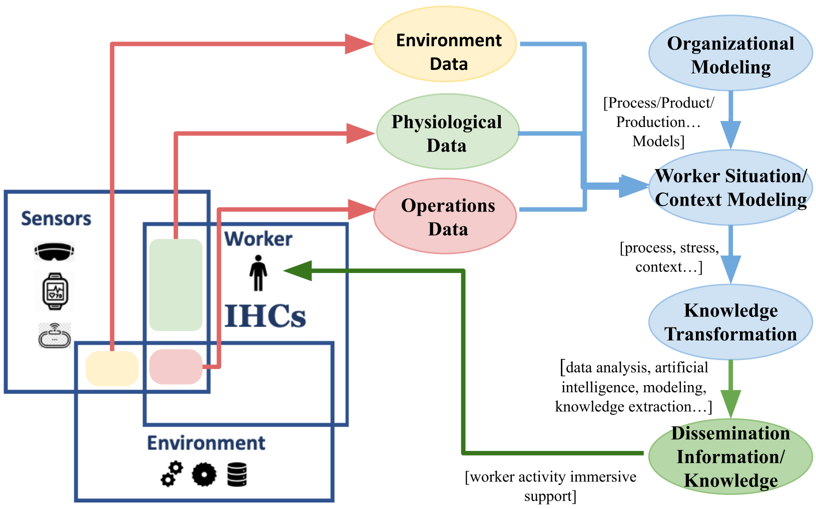

Fig. 2. Immersive Human-Centered System (IHCs) Approach

The necessary data and information can be collected by various sensors (which are installed along the factory floor) and wearables (which can be used by operators). In this way, it is considered the sensing of the environment, the sensing of the worker and the sensing of the operations, i.e. the worker's behavior towards the environment and vice-versa. Firstly, it is essential to capture this data as well as the organizational information, namely the information on processes, products and production. Then it is necessary to model both the context and the situation of the worker and its work needs (Worker Situation/Context Modeling). This is a crucial phase and is important to use the information work analysis, previously described, to provide workers with the information needs as presented in this diagram (Dissemination Information/ Knowledge) (Fig 2).

In order to achieve this level of interoperability between machines, assets and operators, the iiLab Technology Vision Architecture (Fig. 1) previously referred was designed, based on the i4.0 framework and standards. In the first level, an Industrial Internet of Things (IIoT) guarantees data interoperability with the shop-floor, with specific customized agents that enable bi-directional communication with every cyber-physical system. In order to have a holistic and integrated vision on the data and information extracted from the shop-floor, as well as guarantee a full and safe integration with external entities of the value chain, an Industrial Data Space infrastructure was adopted. This IDS platform allows the definition of a meta-model for the information management in the iiLab, exploring a federation structure of databases located inside and outside of the institute.

The information based on this meta-model is then used to build a reliable and effective Digital Twin of the FabLab. This modular and flexible Digital Twin provides the necessary structured information to extract knowledge and transform it, through techniques and technologies of data modelling and analysis as well as artificial intelligence, capable of analyzing high amounts of data to extract knowledge, following the Knowledge Transformation referred in model of Fig. 2. Thus, it becomes possible to share this knowledge, generating information that will be made available directly to the worker (Dissemination of Information/Knowledge), supporting their activity through immersive reality environments, according to their needs, and in real time (Fig. 2).

The Human-Machine Platform as a Service (PaaS), fully integrated and fused within the Digital Twin context, is responsible for the virtualization of the reality within a 3D environment, capable to be rendered in AR/VR devices (smartphones & tablets or on AR glasses such as HoloLens, which allow hands-free usage), taking advantage of 5G networks low latency.

5 Conclusions and Future Work

We reviewed how immersive technologies are being developed, suitable to be applied in several industrial applications, from product design to operations instructions and maintenance as well as on training and technical knowledge management and visualization. These technologies are being addressed to empower humans with tools, worker-oriented interfaces, and better working conditions to continue performing accordingly within complex and knowledge-intensive industrial processes. However, some challenges are not being addressed regarding the design, implementation and adoption of these technologies. Manufacturing companies are still not able to understand how these technologies can have a direct impact on their daily business and overall performance. This is a reality, mainly because most of the recent research is focused on technological aspects, leaving behind the information management aspects, fundamental to deal with the organizational context, and for the success and sustainability of the immersive systems applications.

In order to cope with these challenges, this paper proposes the design and development of a digital platform, fully aligned with the Industry 4.0 standards, within a FabLab that represents a near-real complex manufacturing scenario, where massive data can be correctly gathered and handled in order to generate information capable to be correctly modeled and managed to feed the different immersive technologies available. This FabLab will have an important role in demonstrating the potential and the real application of the immersive technologies, towards the enhancement of the human worker cognitive capabilities, with direct impact on the overall production system performance.

As future work, the information system architecture here presented will be installed and validated in the iiLab infrastructure. In parallel, different demonstrators, representative from the opportunities previously identified for immersive technology applications, will be identified, described and implemented. From an information management perspective, models capable to represent and relate the information needed to clearly represent the context and the situation where the demonstration will take place, will be defined. These demonstrators will not only represent internal operations but will also explore the needs for horizontal integration within the entire value chain. This will provide relevant contribution of research in CNs domain, focused on the new generation of networks leveraged on the collaboration between humans and machines / robots. These challenges are already identified in different research papers [27, 28] as significant topics of study and validation for the near future.

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