6th ICOPEV – International Conference on Production Economics and Project Evaluation
Guimarães, Portugal
14-15 November, 2024

Impact of the Metaverse on Humans: Physical Exertion and Perception Shifts.

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KEYWORDS

Metaverse, Virtual Reality, Digital Twin.

ABSTRACT

Massive digitization in the industry has caused a distancing of the human from the production processes. This fact is due to the limitation of collaboration between humans and machines within the digital ecosystem. For this reason, new interfaces and technologies have been developed, such as Virtual Reality (VR), where human immersion is increased. Virtual environments allow the interaction of humans with machines enabling training and supervision activities. However, the industrial metaverse goes a step further where human-to-human interaction is achieved through advanced interfaces. In the metaverse, the performance of humans has been evaluated, however, the discomforts associated with humans such as dizziness, physical effort or the alteration of reality have not been explored. For this reason, a case study has been conducted where individuals have been surveyed about their experience in the industrial metaverse. This way, the possible correlations between nonconformities with other variables such as individuals' experience or performance are sought. Therefore, this study proposes actions to minimize the impact of disconformities to improve humans' experience in the industrial metaverse.

INTRODUCTION

Industry 4.0 is characterized by the digitization of industrial assets through Cyber-Physical Systems (CPSs), which enable more efficient and collaborative production (Serôdio et al. 2024). These goals are achieved through the connectivity, sensing, and information processing capabilities of CPSs. As a result, CPSs establish a bridge between the physical and digital worlds, optimizing the management of the entire value chain.

However, simulating CPSs in production processes presents a challenge due to the dynamic and complex nature of the industrial environment. To accurately determine the behaviour of CPSs, it is necessary to employ Digital Twins (DTs), which enable the virtualization of CPSs within a completely virtual environment. This approach allows for the configuration of CPS parameters across various scenarios entirely virtually, without the need to consume physical resources (Martínez et al. 2023; Mourtzis 2023).

The use of these industrial technologies creates a separation between humans and the manufacturing environment, excluding them from the integrative and collaborative processes characteristic of the Industry 5.0 paradigm. Therefore, it has been encouraged to include humans within the technological framework to endow the virtual environment with new capabilities (Alves et al. 2023).

To achieve effective human integration into the virtual environment, VR is employed to provide an immersive and highly realistic experience (Hepperle and Wölfel 2023). This approach ensures that human perceptions are closer to reality, resulting in more natural reactions.

However, developing a connected framework that integrates industrial technologies (e.g., VR, DTs, CPSs) poses a challenge due to their heterogeneity. To overcome this challenge, the literature proposes interoperability platforms

and hyperconnectivity platforms (Martínez-Gutiérrez, Díez-González, Verde, Ferrero-Guillén, et al. 2023). This convergence of technologies can be applied to numerous use cases, such as operator training.
Operator training, like manufacturing plant processes, requires interaction not only between CPSs and humans but also among humans themselves. This necessitates the virtualization of humans which are commonly referred to as avatars. Additionally, the interaction between humans and objects in a fully virtual ecosystem is known in the literature as the metaverse (Mystakidis 2022).
The use of the industrial metaverse for operator training allows for decentralized training, reduced resource requirements and improved safety in the use of machines by inexperienced operators. In this context, a previous study (Martínez, et al., 2024) evaluated the performance of humans and avatars in an industrial challenge that required interaction with an Autonomous Mobile Robot (AMR). This study evaluated activity times, VR headset performance, and included a survey on the graphic realism of the industrial metaverse. The results demonstrated statistically that users with prior experience achieved similar performance in both real and virtual environments.
However, the difference in performance between the real world and the metaverse may also be due to other factors such as physical and mental strain, altered reality and even health problems such as dizziness (Widyanti & Hafizhah, 2022). For this reason, a more detailed analysis of how inadaptations affect the performance of avatars in the metaverse is needed. In this human-centred way, the aim is to provide new data from the surveys carried out, as well as their comparison with the time taken to solve the challenges both in reality and in the metaverse.
Therefore, the main contributions of this research are:

- Analysis of survey data on user disconformities when using the industrial metaverse.
- Determine possible relationships between non-compliance with other metrics.
- Propose actions that can mitigate nonconformities.

METHODS

The industrial metaverse is characterised by the interaction between humans and CPS within a virtualised context. To facilitate experimentation, a case study has been defined in which humans must cooperate and request assistance from an AMR to overcome a challenge. This challenge consists of transferring coloured geometric objects from a shelf to a workbench, simulating an assembly operation. To achieve this, operators at separate workstations must communicate, because two pieces each must be transferred. These two parts must be transferred one at a time via the AMR, allowing both operators to complete the task.

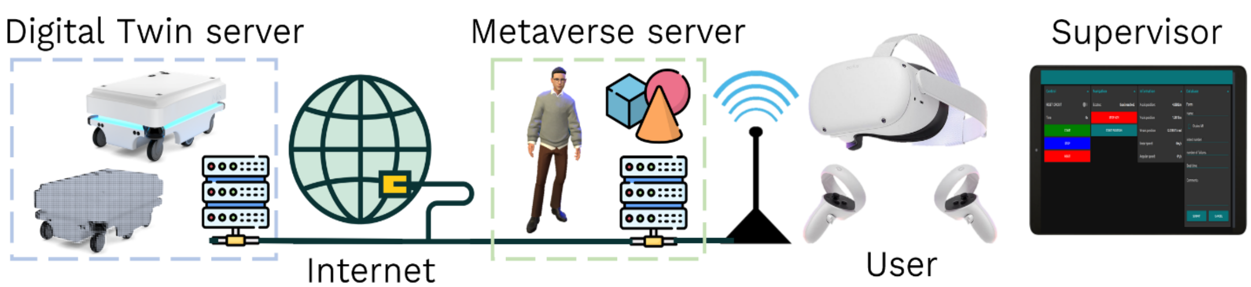

Figure. 1 Metaverse Platform used to develop and obtain Key Performance Indicators (KPI).

To implement this case study in the industrial metaverse, the development of a platform where all the associated technologies converge is required. According to Figure 1, the platform consists of: (1) a metaverse server to centralise communications over the virtual environment, (2) a DT to determine the navigation paths according to the environment and the goals established, (3) a web interface for the visualisation of Key Performance Indicators (KPIs) and modification of DT parameters as well as the physical parameters of the virtual environment, and (4) the wearables that allow the immersion of users in the industrial metaverse.

Metaverse server: this server facilitates the exchange of information among the multiple wearables, storing variables such as pose (i.e., position and orientation), together with the attributes assigned to the objects in the virtual environment (e.g., geometric shapes). For this purpose, the server is based on a client-server philosophy under the WebSocket communication protocol which provides a real-time and bidirectional (i.e., full duplex) communication.

Moreover, this protocol is more efficient due to the persistent connection being key in the performance of portable devices such as VR glasses. Furthermore, from this server, access to a third party's VoIP services is managed in order for humans to have a more natural communication.

Digital Twin: this service is dedicated to virtualising and simulating the behaviour of the AMR (Wang et al. 2024). For this purpose, the Robot Operating System (ROS) ecosystem is used, where the geometric characteristics and mobility restrictions associated with the AMR model MIR100, which is available, have been introduced. Furthermore, the uncertainty of the sensors has been modelled in this same environment, as well as the parameters of the navigation algorithms used (Bai et al. 2023). Furthermore, this DT communicates with the rest of the assets using ROS-TCP to transmit the AMR pose, and to receive the missions or the modification of parameters from the web interface.

Web interface: The purpose of this interface is that the training supervisor can observe KPIs on avatars or parameter modification using visual elements. This interface can run on any browser and any hardware device (i.e., responsive).

Virtual Reality Glasses: This type of Wearable allows the immersion of the user in the virtual universe through visual, acoustic, and haptic senses. In this case study, the VR Glasses used are the Oculus Quest 2 from the company Meta, which incorporates a 1,920 x 1,832 display per eye with a refresh rate of 72 Hz and a weight of 503 grams. In addition, these glasses come with two controllers that detect the position and orientation of the hands, enabling the recreation of avatars' postures. Communication with the server is facilitated via Wi-Fi 6, ensuring the low latencies essential for an optimal user experience.

The industrial metaverse platform has been developed (Martínez-Gutiérrez et al. 2024) to implement the same virtual scenario as in reality in order to carry out the case study. For this purpose, a random population (N=60) was selected and grouped into pairs (P=30) and then divided into two groups (G=15) according to the first activity performed (i.e., real environment or metaverse). After each group performed the two activities, each individual answered an individual survey on the experience, insights, and perceptions comparing the two activities. Based on the attained times in both activities, and the survey responses, the following results have been obtained.

RESULTS

Following the completion of collaborative tasks in the industrial metaverse and real-world settings, participants were surveyed about any discomforts they may have experienced. The questions, answered digitally by all participants, were as follows:

- Have you previously used Virtual Reality (VR) headsets? – Yes, or No
- Which activity was physically more demanding? Similar, Metaverse, or Reality
- Do you feel your perception of reality was altered after experiencing the metaverse?
- Indicate the degree of dizziness you experienced while using the VR headset – None, slight, moderate, or severe.

Once the information from all the surveys had been compiled, the data were analyzed and represented according to the type of discomfort: dizziness, alteration of reality and physical effort made. Each discomfort has been related to several variables such as previous experience at individual level, the experience of the couple, the sex of the individual and the time difference.
The previous experience of each individual was selected as a variable because the difference in performance between the real and virtual world was found to be statistically significant in a previous study (Martínez-Gutiérrez et al. 2024). In addition, the existence of inexperienced, experienced and mixed pairs also has a high correlation with performance, which is why it has also been analysed. In this way, it is intended to evaluate whether performance is related to disconformities, which is why the time difference between metaverse and real performance has been established. For better representation, the population was divided into quartiles, with quartile 1 being the group with the smallest time difference between the two worlds. Another parameter analysed was the sex of the individuals, given the psychological differences (Curry et al. 2020) the perception of non-conformities may be different.

Figure 2 shows the results obtained using bar charts which are presented in the form of a matrix. In the columns are problems associated with human use of the industrial metaverse such as physical problems, physical difficulty or altered reality. In the rows are variables which may have some relationship to the problems such as previous individual and couple experience, gender or individual performance.

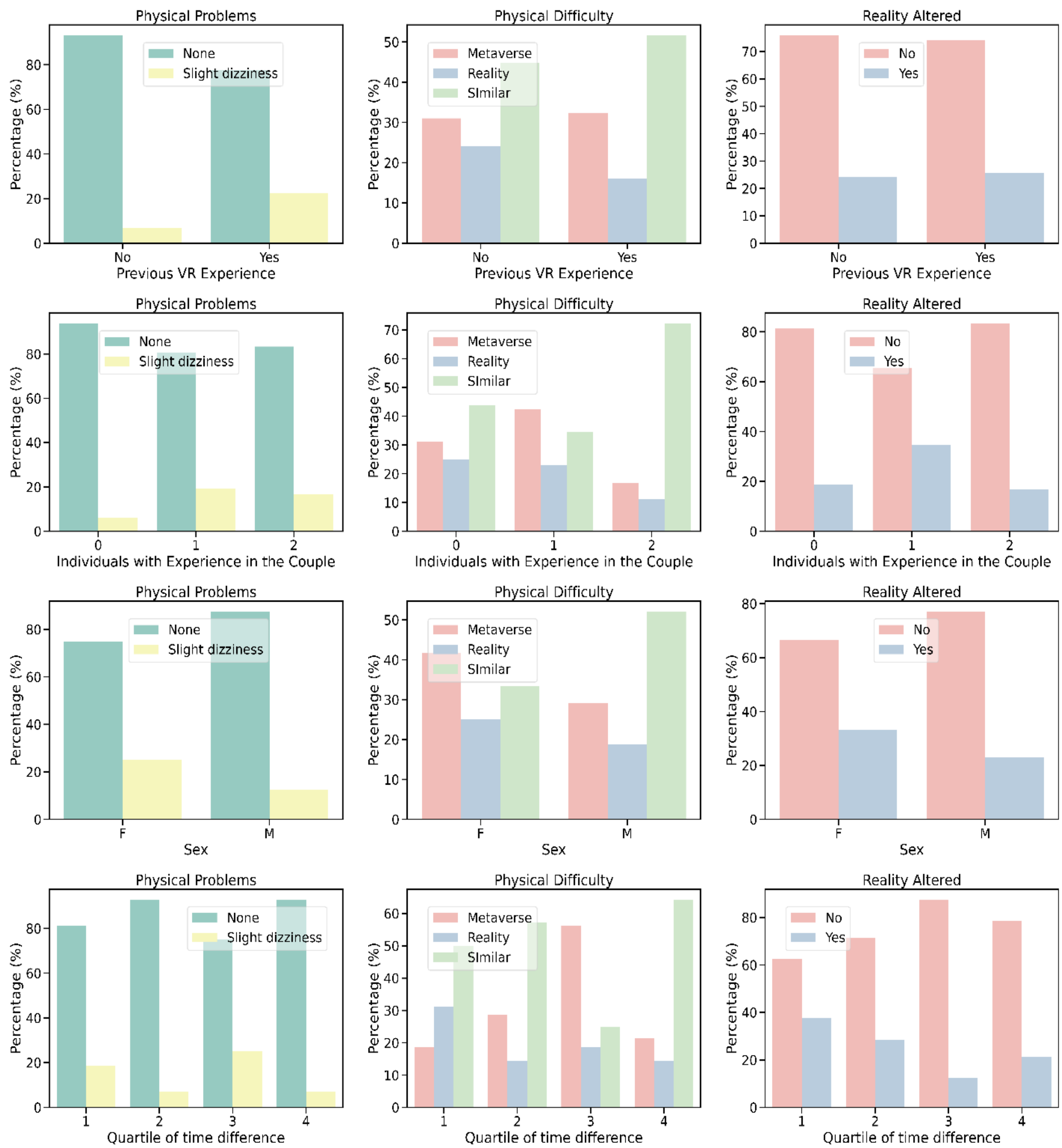

Figure. 2 Graphs on individuals' dizziness, physical difficulty and Reality altered as a function of previous individual experience, partner experience, sex, and time improvement.

DISCUSSION

In this study we have analysed the discomfort related to motion sickness, observing that no individual of the entire experimental population suffered moderate or incapacitating motion sickness to perform the collaborative activities in the metaverse. This indicates that the generation of the environment embedded in the VR goggles avoids major dizziness due to the low latency and high refresh rate of images (Geris et al., 2024). In addition, the implemented technological approach only exchanges information about the position of moving objects minimizing bandwidth and therefore lower latency. With these low latencies, the user experience is not only better, but also the motion sickness is considerably reduced. However, the first graphs of the first column in Figure 2 show that users with previous experience have a higher percentage of slight motion sickness. However, this same group is the one that achieves the most similar results between the two worlds according to the previous study conducted. Although these two statements indicate a relationship between slight dizziness and similarity of times, in the last graph this relationship is discarded where quartiles 1 and 3 present a slightly higher incidence than the average.

Regarding the alteration of the perception of reality after performing the activities in the metaverse, no significant differences were observed between individuals with and without previous experience. However, there is an increase in the number of cases of hybrid couples compared to those with and without experience. In terms of the division by sex, women present a greater number of cases compared to men. The last graph in the third column shows that individuals who present these problems are related to better performance in the virtual world. This fact suggests that greater immersion and concentration in the performance of collaborative tasks implies a greater impact when removing the VR goggles. For this reason, it may be beneficial to include a lobby or break area after the activities and before the exposure to the real world in order to limit the impact of this discomfort.

CONCLUSIONS

The digitalization of industry enables the use of new technologies that allow the generation of added value. The convergence of all these new technologies generates a new paradigm of intelligent and efficient production. However, this ecosystem can alienate humans from the production processes, which means a limitation in the transfer of skills. For this reason, it is necessary to integrate humans into the digital environment through advanced interfaces in order to provide the manufacturing plant with a higher capacity for greater awareness in decision making. Moreover, these abilities need not only be human-to-machine but also human-to-human thus reaching the industrial metaverse. However, the implementation of these advanced interfaces in humans for a use framed in collaborative actions between humans and machines may involve a disagreement. Therefore, it is necessary to analyze different metrics such as performance, as well as the perception of individuals who have carried out a case study in the industrial environment. These metrics have been selected according to previous work where the relationship between previous experience and performance was statistically significant. In addition to these variables, we have analyzed others that have never been related before and obtained novel results. One example is the alteration of reality which increases with smaller differences in performance between reality and the metaverse. Furthermore, in the sex distinction it has been determined that women tend to perceive more discomfort associated with the use of VR goggles. Therefore, it is necessary to extend future research to encompass a broader range of technical and psychological parameters, enhancing our understanding of the factors contributing to discomfort in virtual reality. This study represents a significant advancement in both industrial production systems and human development, highlighting the intertwined nature of technology and well-being.

FUNDING

This work was partially supported by the Spanish Research Agency (AEI) under grant number PID2023-153047OB100; the Universidad de León; “Ministerio de Universidades, Real Decreto 1059/2021, de 30 de noviembre, por el que se regula la concesión directa de diversas subvenciones a las universidades participantes en el proyecto “Universidades Europeas” de la Comisión Europea” and “European Education and Culture Executive Agency, Project: 101124439 — EURECA-PRO 2.0 — ERASMUS-EDU-2023-EUR-UNIV”

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