Using Mixed Reality as a Tool to Assist Collaborative Activities in Industrial Context

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Abstract: The transition process from industry 3.0 to 4.0 results in need to develop interconnected systems as well as new interfaces for human-computer interaction with these systems since it is not yet possible or allowed to automate these processes in all industrial contexts fully. Therefore, new technologies should be designed for the workers' interaction with the new systems of Industry 4.0. Mixed Reality (MR) is an alternative for the inclusion of workers, as it allows them to have their perception increased through information from the industrial environment. Consequently, the use of MR resources as a tool for performing collaborative activities in an industrial context is promising. This work aims to analyze how this strategy has been applied in the industry context and discuss its advantages, disadvantages, and characteristics that impact the performance workers in Industry 4.0.

1 INTRODUCTION

The Fourth Industrial Revolution or Industry 4.0 defines a new level of organization and control over the production chain aimed at meeting increasingly specific customer demands (Rüßmann et al., 2015). This process occurs through the integration of equipment and systems using technologies such as the Internet of Things (IoT) and machine learning. Visualization technologies like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) present themselves as promising for making information about the industrial park available to industry operators and managers, in particular as an interface to provide information and support the decision making.

The availability of wearable mixed reality devices allows the development of advanced interfaces for interaction with industrial equipment, as well as with other human operators collaboratively. This fact supports the construction of new computational interfaces to perform collaborative activities in the industrial context. Mixed Reality can be defined as the combination of virtual elements with the real world at different levels with technologies such as Augmented Reality and Augmented Virtuality within its limits (Milgram and Colquhoun, 1999). The Google Glass[1], the Microsoft Hololens[2], the Gear VR[3] and the HTC Vive[4] are examples of more well-known devices for MR.

This work focuses on discussing the use of collaborative activities in an industrial context. Collaborative activities can be defined as a joint work between two or more actors to perform an activity (Graham and Barter, 1999), where these actors could be a human or a machine combination for the development of several activities in the production chain. However, in the current stage of the industry, we still find contexts where it is not possible to have complete automation, which means only machines operating in an integrated manner to perform an activity. Hence in these contexts, human intervention as part of collaboration can be essential for the proper execution of activities in these specific contexts.

The applications of MR devices in the industry require evaluations from the perspective of HCI (Human-Computer Interaction) due to the novelty of

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[1]More information about the device at: bit.ly/2uiMf8L, accessed on 02/20/2020.
[2]More information about the device at: bit.ly/2T2EsEB, accessed on 02/20/2020.
[3]More information about the device at: bit.ly/2SN1qjW, accessed on 02/20/2020.
[4]More information about the device at: bit.ly/32gFalG, accessed on 02/20/2020

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the technologies, their interaction model, and applicability.

This paper aims to discuss aspects related to how can the use of Mixed Reality enhance collaborative activities in Industry 4.0. In our methodology, we present discussions based on learning through theoretical reasoning, prototype development, and mixed reality technology analysis for collaboration. We hope that the discussions and contributions presented in this paper will assist as a basis for further researches and practitioners towards the integration of the human in the processes of Industry 4.0.

This document has the following structure: Section 2 presents some concepts related to this work, and some tools applied to these concepts. Section 3 discusses aspects of the use of handheld and hands-free devices. Section 4 presents a proof of concept of the proposed solution for collaborative activities in the industrial context. Section 5 shows the positive and negative points of the proposed approach. Finally, Section 6 presents the conclusions of this work.

2 BACKGROUND

This section presents the concepts of mixed reality and collaboration. In the end, it presents an overview of mixed reality technologies that can be used as a tool to perform collaborative activities in the industrial context.

2.1 Mixed Reality

The concept of Mixed Reality (MR) does not have a consensus in the research community. Some researches understand MR as a broad classification that contains differents technologies such as Augmented Reality (AR), Virtual Reality (VR), and Augmented Virtuality (AV). In our work, we understand MR as defined by Milgram and Colquhoun (Milgram and Colquhoun, 1999) that define MR by characteristics such as the degree of virtuality and the level of modeling used. The authors also define a spectrum where the Real Environment (RE) and the Virtual Environment (VE) are not two distinct entities, but two opposites poles in the Reality-Virtuality Spectrum. This spectrum is similar to the Extent of World Knowledge Continuum (EWK), which defines the degree of modeling that a system knows about a given world, in other words, how much the system knows about the rules that describe a given world. In EWK Spectrum, on one side, the system does not know any modeling about the world, and on the other side, the system known all about the model that describes the world. Figure 1 shows the relationship between these two spectra, where the real world is a world with no known modeling and the virtual world, a world with fully known modeling.

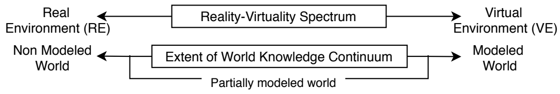


Figure 1: Reality-Virtuality Spectrum and its relationship with the Extent of World Knowledge Continnuum adapted from (Milgram and Colquhoun, 1999).

Between the RE and VE extremes of the Reality-Virtuality Spectrum, there is the partially modeled world in which locates technologies such as Augmented Reality (AR) and Augmented Virtuality (AV). The difference between both technologies is the degree of virtuality in the world with which they work. Figure 2 presents a representation of the distribution of these technologies in the spectrum, which contains technologies that have some degree of virtuality, such as AR and AV.

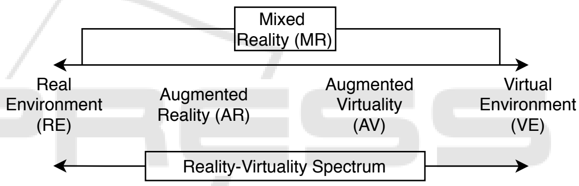


Figure 2: Reality-Virtuality Spectrum and its technologies adapted from (Milgram and Colquhoun, 1999).

Although MR is composed of AR and AV technologies, the boundary between them is blurred because both use combinations between the virtual and the real at different levels. However, we can define that AR extends the real world with virtual resources, while AV extends the virtual world with real-world resources (Milgram and Colquhoun, 1999). In another way, closer a technology is to one extreme of the spectrum, higher is the difference between an AR and an AV technology.

2.2 Collaboration

Graham and Barter (Graham and Barter, 1999) define **collaboration** as a relationship where two or more stakeholders bring together resources to achieve goals that neither party could achieve alone. There are terms with similar meaning, as (i) **partnership**, which Rodal and Mulder (Rodal and Mulder, 1993) define as an agreement between two or more parties that have agreed to work cooperatively to achieve shared and/or compatible objectives; and, (ii) **coop-**

eration which Hord (Hord, 1986) defines as an aid to the achievement of specific goals of each party involved. Therefore, these concepts differ from **collaboration** because characteristics of task objective, since for collaboration, they are shared and common to both stakeholders. While, for cooperation and partnership, they either may be individual or not common to both stakeholders (Graham and Barter, 1999).

In the industrial context, a collaborative activity is a partnership between a **Actuator** and a **Consultant** to achieve a common goal, which can be an inspection, the maintenance of equipment or any other task in that context. Figure 3 exemplifies how the interaction between the parties can be assisted by technology in this context. In this case, **Actuator** interacts with the process location and interacts with **Consultant** via a MR device while **Consultant** interacts with **Actuator** through a desktop.

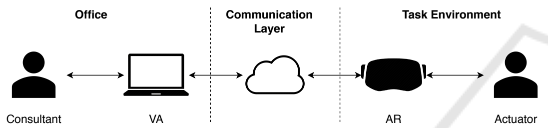


Figure 3: General Structure of Technology-Assisted Collaboration.

As defined by Graham and Barter (Graham and Barter, 1999), collaboration is a relationship between parties with a common goal. In the industrial context, these parts can be both people and machines, thus characterizing three possible collaboration scenarios:

- **Human - Human Collaboration:** Where two or more people interact to perform an activity, through communication mechanisms;
- **Human - Machine Collaboration:** Where one or more people interact with one or more electronic equipment to perform an activity, through communication and interaction mechanisms between them;
- **Machine - Machine Collaboration:** Where two or more machines interact with each other to perform an activity, using communication protocols between machines.

The machine-machine collaboration describes a complete automation environment, where the equipment operates in an integrated manner and independent of human interaction to perform its activities. However, there are processes in the industrial context that mechanisms are not yet known to provide complete automation. An example of this is the regulation for piloting UAVs (Unmanned Aerial Vehicles) not allowed in some countries (Nascimento et al., 2017) due their current legislation does not allow completely autonomous flights. Therefore, for these contexts, activities must be performed out through collaboration between people or between people and machines.

In the scenario shown in Figure 3, the roles of **Consultant** and **Actuator** can be performed by either a person or a machine.

2.3 Available MR Tools for Collaboration

In order to achieve the interaction shown in Figure 3, it is necessary to use tools with MR capabilities. This section describes examples of technologies available for collaborating through mixed reality.

Currently, some tools are available on the market, such as Vuforia Chalk[5]. It is an application for remote assistance, which allows a remote user to interact with a local user through mobile devices. The application allows the users to make a video call and insert 3D elements into the scene that are tracked by mapping the environment. This mapping means that three-dimensional markings are drawn on canvas and mapped to the real world. In case the local user moves, the markings remain in the correct position. Accelerometer and gyroscope are used to estimate this mapping for smartphones.

Team Viewer Pilot [6] is an AR solution similar to Vuforia Chalk, however, developed by Team Viewer [7]. Unlike Vuforia Chalk, it does not require two mobile devices to function, requiring only the local user to have a mobile device. Given that the remote user can interact through the TeamViewer tool on a computer.

Another model of interaction is demonstrated by Remote Assist[8] for Microsoft Hololens. Where the application offers an interaction similar to the applications already described, that is, it offers visual resources in three dimensions for the interaction. However, the local user uses an HMD (Head Mounted Display) to capture, transmit, and display data while using the equipment.

[5]More information at: bit.ly/2VbLARC, accessed on 02/19/2020.

[6]More information at: bit.ly/2SLTAai, accessed on 02/19/2020.

[7]More information at: bit.ly/2SPqaIq, accessed on 02/21/2020.

[8]More information at: bit.ly/3bXifAd, accessed on 02/19/2020.

3 HANDHELD AND HANDS-FREE TECHNOLOGIES

As described in Section 2, MR is a concept, so there are several ways to implement this concept. In general, there are two types of equipment that offer MR features, namely the handheld devices, such as smartphones, and hands-free devices, such as HMDs. The handheld devices are those that the user must hold in their hands for interaction. Most common handheld devices are smartphones, tablets that have a camera attached to capture data from the real environment. Hands-free devices are those that can be attached to the human body and leave the hands of operators free. In general, HMDs are wearable equipment such as helmets and glasses with a real-world view through screens or optical lenses.

Each of these devices has its pros and cons individually. However, in a general assessment, the hands-free devices present greater freedom of movement for the user since the user's hands are free to interact with the environment. However, this type of equipment is usually uncomfortable and presents a complex interaction model since it does not use any widely known standard (keyboard or touchscreen). An example is the interaction model used by Microsoft Hololens that uses a limited set of gestures. Other devices like Google Glass use trackpads that can be located in its structure or presented as an extension of the equipment in the case of Epson Moverio[9]. However, in this case, at least one of the user's hands are occupied.

The handheld devices do not offer this freedom to the user's hands. However, as they are generally devices such as smartphones and tablets, users are already naturalized to the use of this equipment so that interaction with it and the system is more straightforward than hands-free devices. Thus, it is possible to build more complex interaction models with these devices since the user already has some pro-efficiency with this interaction model.

4 PROOF OF CONCEPT

Based on the technologies and concepts presented in Sections 2 and 3, a proof of concept of a tool to aid collaboration in MR is presented in this work. The development of this proof of concept has two objectives: (i) allow discussion on collaboration aspects using mixed hands-free reality and (ii) use the developed tool for experiments on the HCI perspective. Although this is not the focus of this paper, we consider this to be future work.

Figure 4 shows the architecture of this tool. It consists of two applications, one for Microsoft Hololens, whose the primary function is to provide an interface for user drawing and communication capabilities in AR. The application was named *HoloDraw*, how we refer it from here in this text. Furthermore, an application to receive the streaming from the user in the field, which acts as an AV application to view the *HoloDraw* camera capturing and interacts through this stream. Each application is described in the sections below.

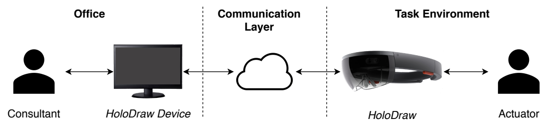


Figure 4: Apps Communication Structure.

4.1 HoloDraw

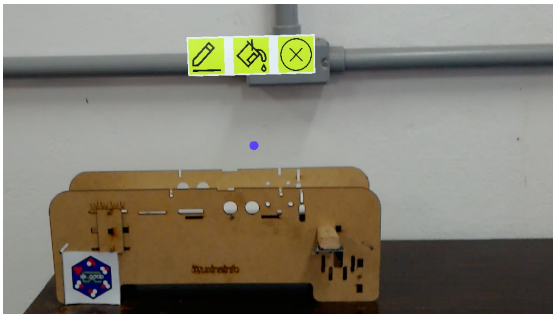
The application developed to run into Microsoft Hololens was named *HoloDraw* and was developed using the Unity environment configured for UWP (Universal Windows Platform) applications. The application has a simple HUD interface that presents all the necessary information in the user's view. Besides that, this interface does not overburden the user with complex interactions, since the equipment uses gesture recognition, which in general, the user is not used to it. Therefore, a simple HUD interface is needed because complex interaction would increase the user difficult to manipulate the equipment.

Figure 5a shows the application's base interface. These images were generated using the Microsoft Hololens camera so that they may present some distortions to the actual visualization since they are treated as fixed elements in a 3D space so that a change in the user's position results in a different visualization of these virtual elements.

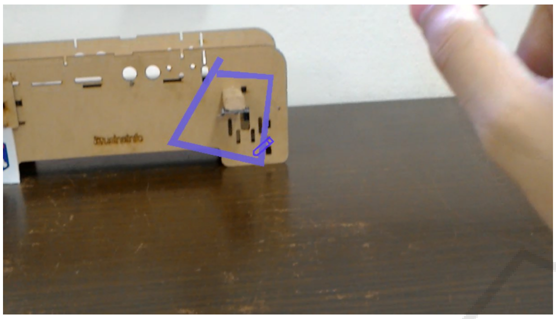
The tool has an action bar with three options (from left to right): drawing, recoloring, and end a line. Also, a focus indicator was placed in the center of interface. This indicator works as a reference point for the center of the application camera operating as a guide from where the point will be drawn.

Figure 5b shows an example of lines drawn by user in a belt conveyor. For that, it is necessary to use the functions available in the application (draw, recolor, end). Finally, the video available at URL: bit.ly/2QL65BG presents a complete example of using *HoloDraw*, demonstrating how the application

[9]More information about the device at: bit.ly/2v5Zave, accessed on 02/21/2020.



(a) Base App Interface



(b) Highlighting a Region

Figure 5: HoloDraw.

works.

4.2 HoloDraw Device

The software of *HoloDraw Device* was developed using the Unity environment configured for Windows OS applications. Similar to *HoloDraw*, this application was also designed to have fewer elements in the user's field of view since all the necessary information is generated in the local user's view and viewed through the generated stream. In this way, the remote user can see what the local user is doing and assist him. Thus, the view of the remote user is similar to the view of the local user, as shown in Figure 5.

5 DISCUSSION

This section discusses some topics related to the use of MR in collaborative activities in an industrial context based on the established concepts and the development of the proof of concept presented in Section 4.

5.1 MR Devices for Work Safety

The use of handheld or hands-free devices for MR interaction can impact workplace safety issues. Since the insertion of a new element in the process implies that this element will not pose any new risk for the user. However, the devices used for this purpose do not make it clear as to their suitability for international and local safety standards. Thus, it is necessary to develop or adapt those devices so they can be classified as Personal Protective Equipment (PPE) without generating new risks to the user.

Another factor that needs to be observed about the use of hands-free devices is the type of see-through display (Azuma, 1997) that the equipment presents. If it is a video see-through display, in case of equipment failure, the user will be completely blind in a hazardous environment. So for the **Actuator** context (as shown in Figure 3), it is safer to use an optical see-through device to avoid this type of problem.

5.2 Interaction Mediated by MR Devices

Another aspect affected by technology is that the implementation of these solutions also impacts the user's ability to solve problems. Seeing that allows users to be more efficient because these devices can reduce the ambiguity of oral communication and offer better resources for this interaction. Reddy et al. (Reddy et al., 2015) demonstrate that the use of a shared 3D model of a car reduces the problems generated by the ambiguity of verbal communication in carrying out an inspection task to trigger car insurance.

Furthermore, it is necessary to analyze these solutions in addition to the quantitative gains. Since in addition to bringing benefits, these solutions must also be well accepted by their users. Works like Datcu et al., Orts-Escolano et al., and Kim et al. (Datcu et al., 2013; Orts-Escolano et al., 2016; Kim et al., 2019) have different formats of interaction between their users. However, most of these interaction models are different from habitual (keyboards or touchscreens). Therefore, these models need to be evaluated from the user's perspective, trying to ensure that the user has a good experience and reducing the impact of inserting these tools in the context of the activity performed.

Therefore, it is possible to use different evaluation methods, as demonstrated in the works of Datcu et al., Orts-Escolano et al and Kim et al. (Datcu et al., 2013; Orts-Escolano et al., 2016; Kim et al., 2019), which use techniques such as SUS, SMEQ, Co-presence, NASA-TLX, and AR Questionnaire.

5.3 MR System Development

The popularization and diversification of MR devices and technologies in recent years has led to the development of several SDKs (Software Development Kit) for AR and development environments to meet this demand. Within this variety, these technologies can be divided into three groups: (i) Android-based systems, such as applications for Epson Moverio; (ii) systems based on SDKs for AR, such as applications developed using Vuforia or ARToolKit; and (iii) other system architectures, such as applications for Microsoft Hololens.

However, even with this technology variety, development environments such as Unity can be adjusted to work with these different technologies, such as importing an SDK or an application parser in the Unity framework for the target architecture. Some works in the literature (Piumsomboon et al., 2019; Kim et al., 2019; De Pace et al., 2019; Choi et al., 2018) use Unity to generate applications for Microsoft Hololens, Oculus Rift, Smartphones, Notebooks, and other types of HMDs.

Although this cross-platform behavior from Unity brings some advantages, the unification of these technologies in a single environment also brings some problems. At the development level, a collaborative application that needs to run on two different platforms can present completely different levels of difficulties from each other. As an example, the proof of concept presented in Section 4 developed two applications, one for Microsoft Hololens, using Unity to UWP platform, and one to the Windows platform. However, even with both devices running on similar Windows architectures, the applications are different and, in turn, generate several compatibility problems caused either by specific equipment characteristics or because of the adaptation that Unity performs to export these applications.

Also, it is necessary to consider the original purpose of the Unity platform is game development, which allows the platform to be well adapted for the development of VR applications. However, for the MR context, it ends up generating problems due to the APIs and interactions with the development environment itself.

5.4 Why Use or Not Use 3D Mapping

One of the main situations when imagining the use of MR systems is the ability of virtual elements to behave as real elements through 3D mapping. So, in general, 3D mapping is used when the virtual objects need to behave and interact with the environment. However, if the interface is something similar to a fixed HUD, the mapping is optional.

Despite, obtaining a good result when using a 3D mapping is directly related to the context of use and the equipment used. Since the mapping quality is related to the devices' sensors quality used to capture and update the map and the characteristics of the environment. For example, a teaching laboratory environment for chemistry where are several benches, piping for transporting liquids and gases, and other characteristic structures. If this environment is mapped, the noise level generated by the structures ends up limiting or even hindering the use of MR devices. When visualizing this situation in an industrial environment whose noise is much higher than a teaching laboratory, it must take great care so that the noise does not prevent the use of the application.

Besides, not all types of MR devices cope well with the idea of 3D mapping. Devices like Epson Moverio and Google Glass are built like glasses, but unlike Microsoft Hololens, they do not have a fully immersive screen, which, although it is possible to use applications such as 3D mapping ends up making it impossible to use this technology well. Thus, this type of equipment ends up using a game HUD-style interfaces, where they present their information in the user's peripheral field of vision without directly interfering with the world view, thus guaranteeing the user's safety.

6 CONCLUSION

This work presented a proof of concept and a discussion about the pros and cons of using MR as a tool to assist collaborative tasks in the context of industry 4.0. We can see that there are some possible solutions developed by both the market and the academy. However, it is still necessary to develop and evaluate these solutions from the users' point of view so that it is possible to insert these solutions in the industrial environment, thus bringing benefits to both the worker and the production process.

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