Augmented Reality: Emergent Applications and Opportunities for Industry 4.0

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Abstract

As the industry evolves further into digitalization, companies grow interested in new solutions made possible by the technologies of the Industry 4.0. One such paradigm is that of Augmented Reality (AR), which has seen significant growth in recent years, but still with great room for improvement, and still with many people unaware of its potential benefits. In its implementations, AR has generated value across a wide range of applications that aim at reducing the frequency of human error, decreasing the training time of professionals, and improving workflow. The purpose of this study is to understand the existing uses of AR across different fields, including its current state-of-the-art applications in the industrial sector, and find ways in which its systems in production lines could be improved, with a focus on the interaction between the user and the system, presenting a series of proposed solutions. To conclude, possible opportunities that could aid industry professionals and operators of manufacturing systems supported by AR are presented and discussed.

Keywords: Augmented reality; Manufacturing; Assembly guidance

1. INTRODUCTION

Augmented Reality (AR) is a technology that can be applied to the Industry 4.0, and has recently experienced significant growth in various sectors. It has attracted considerable interest in the industry, being prominent in industrial fields such as manufacturing, maintenance, and warehouse logistics (Plakas et al., 2020), as well as in several other non-industrial fields. With AR, retailers and marketing teams are able to provide new entertaining and memorable experiences (Chylinski et al., 2020; Watson et al., 2018); healthcare providers have better operating tools and environments for richer practicing and training experiences (Vadalà et al., 2020); other professionals in fields such as design (Schumann et al., 2021), education (Thomas et al., 2019), architecture, and engineering (Chi et al., 2013) benefit from its applications.

The importance of the Industry 4.0 and the benefits of its applications are of great interest to companies. For example, market leaders like Bosch understand the needs to adapt to the quickly changing market requirements and Industry 4.0's role targeting this challenge (*Industry 4.0 | Bosch Global*, n.d.). Being a technology that makes part of the Industry 4.0, AR promises huge benefits to the industry, although it has not yet been widely implemented in this sector (Schumann et al., 2021).

Several papers published within the last five years were reviewed, describing recent applications of AR systems across different fields, to help understand how the technology is currently being used and explored. The goal of this study is to better understand the current capabilities of AR, as to find ways in which its applications within the industrial sector, namely within manufacturing and assembly systems, may be improved, rooted on the reality of its advances in different fields. To this end, applications of AR across different fields will be studied to better understand its current capabilities and limitations, and to identify possible improvements to AR systems in industrial environments rooted in that reality.

The research was conducted using the B-on and Springer platforms. For the overview of the technology, any document relating to AR and Industry 4.0 was considered when researching its characteristics, history, etc. Then, for identifying the state-of-the-art of AR, research were narrowed down to papers and articles published within the five years prior to the research (2016 to 2021), presenting a few that seemed to better represent the current state of the technology across a range of selected fields that have shown to benefit from the technology in recent years.

The study will begin with an overview of AR, observing its growth, related concepts, and general challenges in contemporary applications. Then we will proceed with an analysis of the technology as it is currently used in the industrial sector, taking a closer look at some state-of-the-art industrial applications, followed by an identification of some current applications across other domains, namely in the fields of retail, marketing, medicine, architecture, engineering, construction, design, education, and entertainment. Finally, solutions for improvement of the usage of AR in the industry will be proposed and discussed.

2. Augmented Reality Overview

Since its conception, authors have often described AR in different ways, some suggesting it is a variation or subset of the *Virtual Reality* (VR) or *Mixed Reality* (MR) (R. T. Azuma, 1997; Milgram, 2011) while others suggest it is a whole other technology, only similar to VR (Carmigniani et al., 2011; Edwards-Stewart et al., 2016). More recent studies identify AR as part of a group of technologies known as *Extended Reality* (XR), which also includes VR and MR as individual concepts (Andrade & Bastos, 2019; Benjamin Kenwright, 2021). XR is a term that often refers to all technologies whose goal is to create computer generated environments and actions which merge the real and virtual worlds (Fast-Berglund et al., 2018). Among such technologies, AR generally distinguishes itself in that it focuses on enhancing the user's perception over real-world environments by overlaying digital elements, which may be either visual or auditory, over their immediate surroundings (Cranmer et al., 2020; Edwards-Stewart et al., 2016).

As proposed by Azuma in 1997, it is still generally accepted today that any AR system has the following three characteristics: combines real and virtual environments, is interactive in real time, and registers elements in three dimensions (R. et al. Azuma, 2011; R. T. Azuma, 1997). AR systems rely on a group of *Enabling Technologies* to succeed in building AR environments, which include display, tracking, registration and calibration technologies (R. et al. Azuma, 2011).

In the past, AR was defined in a way that it required the use of *Head-Mounted Displays* (HMD) (R. T. Azuma, 1997). There are two types of HMS: *Optical See-Trough* (OST), that use transparent *Liquid Crystal Displays* (LCD) or half-silvered mirrors on which the virtual elements are projected directly over what the user is viewing; and *Video See-Trough* (VST), that capture and mix virtual elements with the video and then project the merged images back to the user within a regular display (R. et al. Azuma, 2011; Bimber & Raskar, 2006). Another method of head worn display is that of *Virtual Retinal Displays*, which forms the image trough projecting light rays directly into the user's eyes (Jang et al., 2017; Viirre et al., 1998).

Tracking the user and sensing the environment around them accurately and at interactive speed is essential for AR to function, and thus technology is required to measure the location and orientation of the user and any other object of interest as they move and interact within the environment (R. et al. Azuma, 2011; Rolland et al., 2001). There exist many methods to achieve this, ranging from attaching a coordinate system and tracking probes to the user's head and other key elements and comparing those to a reference coordinate system (Rolland et al., 2001), to video-based systems using cameras and algorithms to detect and interpret information from a two-dimensional fiducial markers with specific shapes and patterns (Y. Li et al., 2007), or yet more sophisticated algorithms capable of detecting tridimensional elements and tracking their positions and orientations in real time (Ahmadyan et al., 2020).

The growth of AR trends in the industry is generally attributed to the quick technological development of mobile technologies in recent years (Evangelista et al., 2020; Liu et al., 2019). The leading consumer mobile device technology – smartphones – is said to have reached its peak, with users not looking to replace their old devices, in turn causing big tech companies seeking new technologies in which to invest, the main of which have been the *Internet of Things* (IoT), *Artificial Intelligence* (AI), and *Extended Reality* (XR) (Andrade & Bastos, 2019). At the same time, the maturity of mobile technologies, as well as the emergent 5G networks, lead to current smartphones having advanced enough capabilities to handle the required functional operations of AR (Khan & Khusro, 2015). The successful release of the mobile game *Pokémon GO* in 2016 helped bringing awareness of AR into the mainstream and greatly raised public interest in these technologies (Alha et al., 2019; Liu et al., 2019). In the latter half of the last decade, big tech companies like Google and Microsoft started introducing new AR devices which opened up new flexible applications and possibilities for human-machine communication and interaction (Szajna et al., 2020).

However, AR's implementation in the industrial sector still faces some challenges, which could be as simple as a lack of awareness of its benefits from people in managing positions, or the difficulties of implementing and AR system, given the additional efforts and costs in integrating a relatively new emerging technology into the company's workflow (Schumann et al., 2021). As XR technologies hit the mainstream, some authors also raise to question it's ethical complexities, especially in regards to children who may come in contact with these systems, as they may be less likely to distinguish what is real from what is virtual, and could lead to issues such as stress, trauma, and exposure and desensitization to unethical behavior (Ben Kenwright, 2018; Southgate et al., 2017).

3. AUGMENTED REALITY IN THE INDUSTRIAL SECTOR

In the industrial sector, AR offers a wide range of solutions to increase work efficiency and reduce the frequency of human errors in machine maintenance, product assembly and manufacturing, data visualization, and simulations, among various others (Mourtzis et al., 2020; Schumann et al., 2021); Although the lack of knowledge regarding this technology, by one hand about its benefits or, by the other, about implementation, is one of the main obstacles preventing it from being more widely implemented in the industrial sector (Schumann et al., 2021), reinforcing the importance of understanding its current uses and benefits within this context.

The creation of assembly guided systems is currently one of the most valued areas for AR in the industrial sector (X. Wang et al., 2016). K. Wang et al. (2020) propose an approach for the identification of parts in an assembly in AR assembly guided systems, focusing more on the step of registering objects, based on CAD files and key points for identifying different parts of an assembly via algorithms, and then be integrating the data into the system. X. Wang et al. (2016) note how most applications of this type focus only on providing step-by-step instructions while overlooking the importance of providing these instructions in a timely manner, criticizing the reliance of these systems on external mechanisms, like keyboards and control sticks, to generate inputs. They suggest the implementation of an enhanced bare-hand interface, in which the user could interact with the interface using their hands, given the system would recognize their fingerprint positions and recognize when the user was attempting to perform an action within the virtual interface. Hořejší et al. (2020) describe how the solutions of AR instructions in head-mounted displays are an ideal replacement to conventional paper manuals, due to it enabling the worker to have easy hands-free access to clear instructions and its benefits to the training of operators. They compare the use of head-mounted displays versus a computer monitor or tablet with information gathered from external cameras, citing among the most common problems the system's cost, battery life, image quality, fragility, and potential damage to the eye and mental strain.

Mourtzis et al. (2020) propose a framework designed to feed AR applications with production data, to give production managers more interactive and intuitive experiences when analyzing it. The proposition would take advantage of digital platforms already existing in current production lines and bring the available data together into an AR cloud-based environment in which the user can interact with and monitor production schedules, aiming to quicken the identification of problems and application of changes to production schedules. The developed application used Microsoft's HoloLens.

Szajna et al. (2020) present an AR system to support the process of quality control. It connects to cameras and measuring devices, such as digital calipers with Bluetooth connection capabilities, and displays digital information and instructions to the user in real time. The user sees a dashboard with the expected values and the instructions, locations and activities required to perform the control task. The positions of the virtual elements are calculated in relation to the user's position and starting points determined by markers, which are recognized the moment the user first focuses their attention on them. It is noted in the study that these markers may be replaced by advanced image recognition techniques using AI and deep learning convoluted neural networks in the future.

Konstantinidis et al. (2020) present an application for mobile devices utilizing AR and *Computer Vision* (CV) which functions as an assistant for machine maintenance in the Industry 4.0. The system functions as a mobile application installed into the operator's mobile device and can locate components and display maintenance instructions for its corresponding failure modes. Maintenance steps are navigated using the mobile device's touch-screen, and a confirmation message notifies the user once the maintenance process is complete.

Xie et al. (2016) discuss the use of Radio-Frequency Identification (RFID) technology together with AR. The developed system uses RFID tags to label different elements with unique data, then the RF-signals are located using RFID-based localization methods, which allows the tracking of the tagged elements in real time. That information can then be paired with the AR system, which is equipped with an RFID reader, allowing it to track and visualize data from elements within view distance in real time.

4. AUGMENTED REALITY IN OTHER DOMAINS

The AR technology has attracted interest in many other domains in recent years. Understanding its use outside the industrial field could help find parallels and new ways in which to apply this technology in the industry.

4.1. Retail and Marketing

AR has enabled new techniques in retail and marketing, which provide the customer with engaging and rich experiences (Chylinski et al., 2020; Watson et al., 2018). This technology is rapidly evolving within the domain of retail and marketing, offering something different from any other available interactive paradigm (Javornik, 2016). It has the capacity to greatly transform the shopping experience and shape the way the costumer interacts with the product's advertising, increasing their satisfaction and willingness to interact with and purchase products (Poushneh & Vasquez-Parraga, 2017; Watson et al., 2018).

Watson et al. (2018) address Rimmel's "*Get The Look*" mobile application, which enables consumers to scan the faces in photos or real life models and virtually apply it to themselves using the mobile device's front-facing camera as a mirror, realistically following the user's movements in real time. The app also identifies the corresponding Rimmel products and redirects the costumer to their website to purchase them. In another study, Adikari et al. (2020) present a virtual dressing room using Microsoft Kinect V2 and the Unity 3D game engine. Kinect captures the user's body measurements, making a virtual recreation of the user's body. The user's mode is transferred into Unity, 3D cloth models are laid over them, and an image of the user with the superimposed cloth models is returned via the display in real time. The system also uses gesture recognition to allow the user to browse and try different clothes.

Cruz et al. (2019) propose a system to guide users within large commercial areas, using state-of-the-art AI and AR techniques to create a smart experience through a mobile application, which helps the costumer trough the shopping process. The application allows the user to search for an item, and captures images of the aisle where the user is located, communicating them to the commercial area's server, which trough AI algorithms will determine their position and then provide directions to a new position where the user may find the desired item.

Chylinski et al. (2020) discuss the practices and value of AR Marketing and its distinctions from other forms of digital marketing. AR allows the creation of embedded experiences, a digital experience that seamlessly integrates digital content into the physical environment. An example is given, of the use of devices like Microsoft's HoloLens and CV technologies to scan the user's living room and project realistic images of Ikea furniture over the user's view of the room, using Ikea's "*Place*" mobile application.

4.2. Healthcare and Medicine

AR and VR have played a significant role in providing learning environments for healthcare professionals in training, which has been shown to improve both teaching and learning experiences (Balian et al., 2019; Desselle et al., 2020). In addition, it has also greatly influenced the areas of telehealth and remote surgeries, as well as finding its way into other areas of the healthcare system (Desselle et al., 2020).

Vadalà et al. (2020) present a collection of AR surgical navigation systems to aid in spine surgery. These rely on cameras and *Computerized Tomography* (CT) scans to record the surgical field and create 3D reconstructions of the spine, and then, trough AR technologies, 2D and 3D images are superimposed over the surgical field to help in the identification and planning of screw insertions, and then visually trace drilling trajectories for those implants, having resulted in successful operations with increased accuracy. These systems are also used for tracking the position of tools in real time. Initial examples of this application used regular high resolution monitor, but more recent approaches utilize head mounted displays such as the Google Glass and HoloLens, and specialized AR headsets have been developed for surgical use.

Escalona et al. (2020) propose an AR system for at-home rehabilitation of patients who have suffered and injury, the aim being to aid them to recover mobility of affected limbs. The proposed system relies on a camera that captures the room, a "*trainer's mat"* used as a 3D reference on which to project a virtual trainer, and a screen to act as "the mirror in a gym". The user chooses an exercise and must mimic the trainer's movements throughout it. Trough deep learning algorithms, the system then identifies the positions of the user's limbs and body, traces its poses and movements, and compares them to those of the virtual trainer to give real time feedback, and each exercise is also stored in the system to be later replayed and analyzed by either the patient or the their therapist. Also regarding rehabilitation, Arpaia et al. (2020) describe an instrument based on a wearable *Brain-Computer Interface* (BCI) system, which translates electrical brainwaves into information, integrated with a head-mounted display AR platform for treatment of mental health disorders, such as *Attention Deficit Hyperactivity Disorder* (ADHD).

Klinker et al. (2020) present a hands-free AR smart glasses solution for healthcare professionals to document procedures while performing them. The system was tested on simulations in which the user had to measure the length of a wound, which could be accomplished through voice or blinking commands and a cursor at the center of the user's view allowing them to mark the edges of the wound and returning a distance, and when that distance was confirmed, a picture would be taken and saved for documentation. The system also allowed to give the user indications, such as a list of voice commands at the bottom of the user's view and directions to virtual screens or checklists, with which the user could interact via the gaze system.

4.3. Architecture, Engineering, Construction and Design

Numerous opportunities for integrating AR systems in architecture, engineering, construction, and facility management have surged in recent years, having become mature and versatile enough to be viable in this area (Chi et al., 2013).

X. Li et al. (2018) discuss the use of AR and VR in construction safety, going into a number of different applications, including hazard identification by sensing elements in the environment and providing feedback to the user, safety training and education through computer based simulations, and safety inspection by using AR to enhance the abilities of quickly recognizing safety risks.

Kido et al. (2020) present an AR solution for the simulation of the demolition and removal of structures during redevelopment processes, based on the paradigm of *Diminished Reality* (DM), a subset of AR whose objective is to virtually simulate the removal of objects rather than adding new elements, using AI technology and deep learning. The proposed system applies the DM principles in real time, detecting the structure to be deleted, the surrounding environment, and reconstructing the scene in a virtual 3D environment with a model mask applied over the structure.

Sánchez Riera et al. (2015) discuss AR's applications in the learning and teaching of architecture and engineering, and the technology's capacities of visualizing new building proposals and assess their impact on the planned construction site, showcasing a specific case using mobile devices with a camera, GPS and 3G connection to access a geo-location-based AR application that allowed them to visualize simulated models on the site of construction.

Sandu and Scarlat (2018) discuss the use of AR for interior design, showcasing IKEA's mobile application, which allows users to scan their room and virtually try out objects within it by overlaying 3D models in the room using their phones, and also detect objects and search for similar items in IKEA's catalogue. They compare IKEA's application to Houzz's and Homestyler's solutions, which include other functionalities, such as accurately detecting flat surfaces on which to place the furniture, and further customization features like resizing objects.

4.4. Education

As already addressed in previous topics, AR has various current applications in the education of professionals in the fields of healthcare (Vadalà et al., 2020), architecture, and engineering (Sánchez Riera et al., 2015). Researchers have shown that AR can effectively enhance the capabilities of learning, and with the easy access of AR applications through commonly available smartphones, it has found its way into all sorts of fields of education, ranging from math to history and art (Ali & Science, 2020).

Cieza and Lujan (2018) present a mobile AR application based on markers, developed with the Unity platform aimed at teaching children in kindergarten numbers and letters. The application works by detecting images programmed into the system and overlaying 3D models over those images when they are detected using the phone's camera. Although simple, these applications significantly improved the learning level and interest of children over four years of age.

Ali (2020) proposes a model for ethical education aimed at children in primary schools, consisting of an AR game played on a smartphone or tablet and flashcards, on which the AR integration allows the flashcards to play virtual animations according to the user's interaction with them in the real world, as well as provide real time feedback to the user. It also generates data relative to the student to help track their learning progress.

Furthermore, Thomas et al. (2019) present a wide variety of current AR applications in different areas of higher education: childbirth simulators allow medical students to practice child delivery using HoloLens; encouraging the learning of the English language or develop spatial skills with the help of applications similar to Pokémon Go; virtual training environments for welders, which reduces material consumption and preparation times, and greatly lowers the risk of accidents during training.

4.5. Entertainment and Leisure

The role of AR in entertainment cannot be easily dismissed. The mobile game Pokémon Go is said to have popularized AR among the general public, bringing a wider attention and interest in this technology (Alha et al., 2019; SANDU & SCARLAT, 2018), but the uses of AR in entertainment go beyond the obvious applications in video games.

Yamamoto et al. (2017) present an alternative to e-books to address the lack of the tactile sensation and weight of the paper associated with reading a real printed book. The system uses an AR head mounted display and a marker book. The system detects the marks on the book and superimposes the words and images of the e-book over the marker book's pages, which bend and curve in real time along with the paper.

Cranmer et al. (2020) explore the impact and value of AR in the tourism industry, analyzing its benefits and common uses for the provision of enhanced and user-tailored information, via applications that create an interactive and engaging alternative to brochures and videos.

5. PROPOSED APPLICATION

What follows is a theoretical proposition of a system equipped with a set of applications based on AR and complementary technologies, to be applied in the environment of a smart production line, with basis on the reviewed literature. Although many functions in lines of production have been automated, human operators still take a role in some tasks of the assembly, packaging, and quality control phases. The main goal of the proposed application is to aid human operators by providing an easy way to access information and directions using AR.

To highlight the benefits of a head-mounted AR application, some comparisons will be made between the proposed method focused on AR and a current assembly process as seen in Bosch Rexroth's showcase of their Industry 4.0 automated manufacturing line, which does not integrate such systems: after the robot finishes the automated process, the operator initiates manual assembly with the aid of a digital assistance system. The operator lays the product on the table, over which a projector displays work instructions. The operator must grab components from a shelf and mount them onto the product, and on each step the necessary component's shelf is visually highlighted. After each step is complete, the operator must trigger a switch on the table to proceed to the next step (*Industry 4.0 Production Line | Bosch Global*, n.d.; *Showcase Manufacturing I4.0 | Bosch Rexroth AG*, n.d.).

In general, the application relies on providing operators with an AR head-mounted display system for each proposed function, such as Google's Glass (*Glass – Google*, n.d.) or Microsoft's HoloLens (*Microsoft HoloLens | Mixed Reality Technology for Business*, n.d.). These are lightweight and comfortable devices which already have a sizeable set of applications whose implementations have been consistently identified in the reviewed literature. Furthermore, it's assumed the proposed system would be implemented in a factory with already a certain degree of technological maturity when it comes to the concepts of the Industry 4.0, as it would require devices to be wirelessly connected to one another and able to transfer data among themselves, including the automated machines that would constitute a smart production line. It would also rely on the company to have an accessible database of its products, their assembly procedures, and other information relevant to the functions and goals of the operators.

Using engines with AR capabilities such as Unity, it is possible to generate a virtual environment capable of keeping track of various registered elements over time (Szajna et al., 2020). When the user boots up the system, they gaze at markers in key positions, such as the location of a digital dashboard, shelves or drawers of components, the location where the robot drops the part, and the position where the assembled product must be placed. The system will virtually register the positions of these markers to later provide directions to the user. Noted, the mentioned points are assumed to be static positions, as for moving elements to be accurately tracked in real time they would have to constantly be within the range of the camera mounted on the user's headset, so the same principle could not be applied for instruments or components that may frequently be in varying positions outside the user's sight, for example. Alternatively, if it's deemed necessary to detect such elements and track them in real time, it's suggested to use external cameras for the specific purpose of locating these elements and share that information with the AR system, or alternatively to integrate RFID into these elements and equip the system with the capability to detect them, as AR has been shown to function alongside RFID systems in past applications (Xie et al., 2016).

The importance of providing easy and quick assembly instructions is further raised in cases of production lines which may produce products with customizable variations or bring completely different products within the same assembly line, as the operator may need to adapt to changes in the process, leading to a higher chance of error and delays. These systems also make the training of new operators much quicker, again because of the capacity to provide clear instructions.

By having access to a database of the factory's products and individual CAD files for each part, and using deep learning algorithms, the system may be able to detect the part (or parts) position and orientation in real time. Then, by identifying the current assembly progress, the system visually provides the appropriate assembly instructions for the current step, as represented in Figure 1. Compared to the used of projected instructions, this system has the advantage of allowing the user to freely move and rotate the part, potentially making the assembly process more comfortable and faster, as the user does not need the product to be placed on the table over which the instructions would be projected.

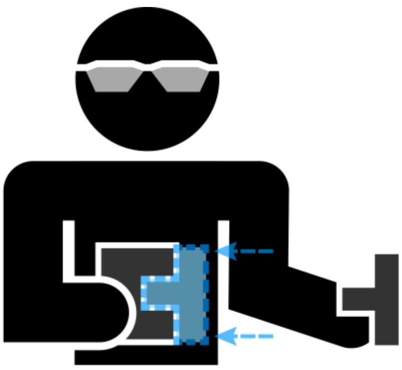

Figure 1 – Assembly instructions.

If for some reason the implementation of part recognition with deep learning is not possible, or proves to be too inaccurate or troublesome, a simple alternative would be to simply overlay a static image of the instruction over the user's display, on a spot where it would be clearly visible and not interfere with the operator's tasks by obstructing too much of their vision.

During assembly, the operator may be required to reach for a stored component, such as screws, inserts, or others made available on their workstations. Based on the virtual map generated during set-up, the system will provide visual directions and highlight the location of relevant components for each step, represented in Figure 2. Compared to the current light-based approach, the main advantage is the ability to overlay directions before the user looks towards the component storage location, as virtual arrows could point the operator towards it from anywhere if the system has registered its position.

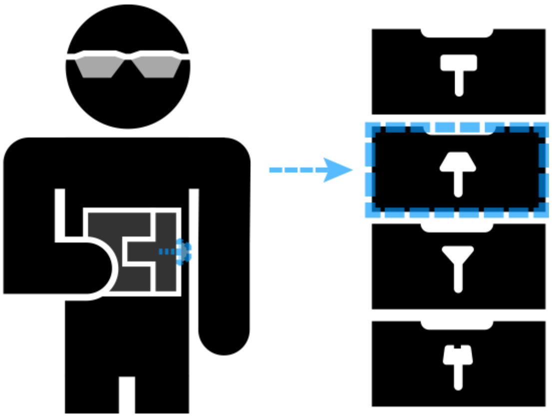

Figure 2 – Highlight component.

The tracking of objects which may frequently change positions and laid in different places may prove more challenging to integrate, but by recurring to the aforementioned methods of CV or RFID to keep track of those items in real time. This could be especially useful if the operator needs to use tools in the assembly, as it would quickly direct them to those tools, as represented in Figure 3, and shorten the time wasted in trying to find them. In some cases, applying the same method to the components themselves could prove beneficial in products with many components.

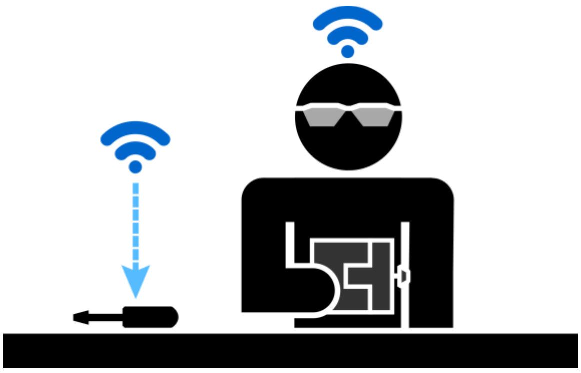

Figure 3 – Locating tools.

As the operator will likely have both hands busy throughout the assembly process, it would be ideal for them to be able to interact with the system in a hands-free manner, which would not require them to drop the product to, for example, advance to the next step of each instruction, as it happens in Bosch Rexroth’s case. Furthermore, the necessity to use an external mechanism to interact with the AR system is a common problem verified in assembly guided systems (X. Wang et al., 2016).

The proposed solution to this problem would be to use a virtual interface as we've seen in previous hands-free applications (Klinker et al., 2020), and represented in Figure 4, interactable via either a timed gaze function, activated when the user gazes at an interactable element of the interface for a defined amount of time; or voice commands, which would allow the user to interact with the system via a set of voice commands, with the added benefit that they would not need to gaze at the interface to interact with it, yet the reliance on voice recognition could prove troublesome in noisy environments.

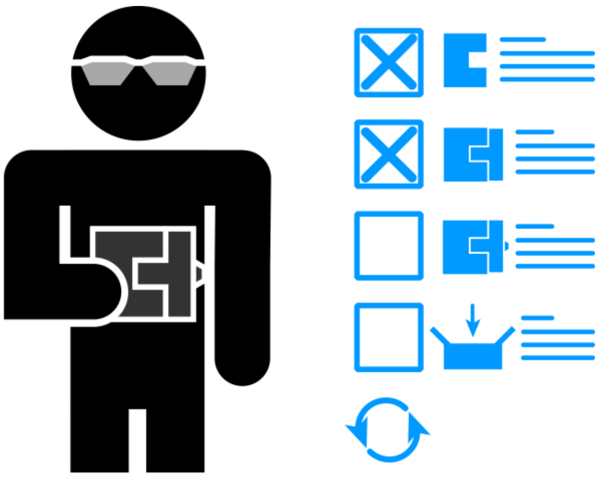

Figure 4 – Task's dashboard.

Alternatively, a more sophisticated approach using AI and deep learning could be implemented to automatically recognize when a task had been adequately performed. This solution would be more complicated and challenging to implement with success but would further speed up the workflow by eliminating the need for user inputs to skip each step along the process. This approach, relying on AI and deep learning technologies, would involve access to big data to successfully employ linear regression models and efficient statistical algorithms, and would require a longer time to implement than simpler solutions.

The system should also inform the user on how many parts have been assembled and packaged as to notify them when the desired number of parts has been placed into a box, exemplified in Figure 5, as companies usually intend for a precise number of parts to be contained in each box before shipping to the client. If a method of tracking the number of boxed products has already been implemented, simply enabling the AR system to receive that information would allow it to display that number and provide real time feedback of when the box is ready to be sealed or if the number of parts desired has been exceeded.

If a system to count parts inside each box has not been implemented, the AR system could still give this feedback to the user, by keeping track of how many parts have been successfully assembled, raising a counter every time the user gives the input that the process has been concluded, and resetting the counter by providing the input that the box has been sealed and a new box is being used.

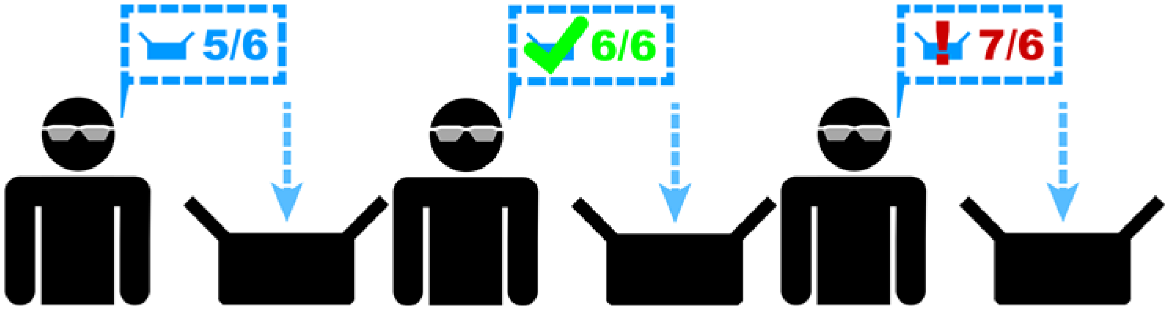

Figure 5 – Packaged contents notification.

Many companies already use software to monitor manufacturing processes in real time, which in smart factories allows them to track when a machine's cycle begins and ends, calculate cycle times, and identify failures and delays. Enabling that data to be shared with the AR system would allow the operator to know the precise moment when a new part has been delivered by the robot, which could help improve response time, but most importantly, it could quickly notify the operator when either a failure or significant delay has occurred, notifying them to intervene or seek immediate help if necessary, and report the occurrence.

Additionally, by equipping the crates with markers the AR system can recognize and having them gather information from the system, this could enable people in production management and control positions to quickly visualize the contents of sealed crates, along with detailed information regarding the production process, the time each part or the whole packaged contents took, the client, and the operator responsible, or any other information deemed relevant to be displayed this way, in a sort of virtual information sheet as represented in Figure 6.

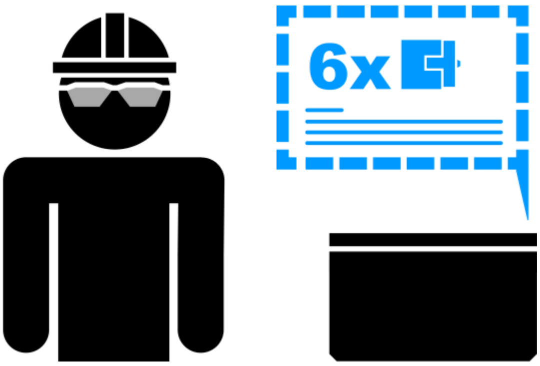

Figure 6 – Boxed content management.

6. DISCUSSION AND FURTHER WORK

Through this study, we could better understand the level at which AR is being applied to the industry and areas where it could provide increased value within the industrial sector. Although AR has the capacity to provide great benefits to the industry, its applications are still not well understood by the general public, only having gained mainstream attention in recent years, which is why it is important to understand it. Furthermore, its reliance on other emerging technologies such as AI deep learning algorithms, IoT networks, and Cloud computing could mean its implementations may not be easy for companies new to the concepts of digitalization.

Based on the literature of current uses of AR, an application was conceptualized with basis on what was understood to be within the reach of this technology, in a way that its use would provide benefits within Industry 4.0 smart production and assembly lines. The proposed application relies on prior experience within the context of digitalization concepts and would be better suited for companies with already some degree of maturity when it comes to the transition into the Industry 4.0.

Being that a hypothetical system has been conceptualized, the next step would be to produce a prototype to prove its application, and then seek to develop a case study to prove its benefits and usability.

Some difficulties from those attempts at implementation could arise, like reduced access to data services or storage and cloud access to manage big data could slow down or altogether impede the development of these systems. Another challenge may come from the lack of or difficult accessibility of the required hardware for its proper implementation. As discussed, the technology is still somewhat misunderstood by many people in the industry, and thus some companies may lack workers with qualification to work upon these systems or provide technical support, or even the lack of capacity to prepare people for those tasks.

If implemented with success, the proposed method could help streamline the assembly process and diminish human errors during production. Further development of AR systems and applications will likely generate increased value within the industrial sector in the near future.

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