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Augmented reality-based guidance in product assembly and maintenance/repair perspective: A state of the art review on challenges and opportunities

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ABSTRACT

Manufacturing industries are currently experiencing the fourth industrial revolution with the rapid advancements in immersive technologies for human–machine interaction (HMI) and flexible manufacturing systems (FMS). Product variance is limited due to barriers in the knowledge transfer between the stakeholders that existed in the pre and post-manufacturing phases. Augmented reality (AR) is a promising technology that can offer a high degree of adaptability and independence to support knowledge transfer at the most crucial manufacturing stages such as assembly, repair & maintenance. This article is focused on presenting the state of the art literature on AR technologies in product assembly and disassembly from the Maintenance/Repair perspective. The working of various modules in AR technology on facilitating a user-friendly guiding platform and its applications are discussed with suitable illustrations. The critical difficulties, such as tracking and rendering techniques for estimating human movement and environment experiences are observed to extend the adaptability of the technology. Future research potential, such as enhancing the virtual interface for reality, identifying worker behaviours, and enabling sharing and collaboration between multiple streams in an industrial context are analyzed.

1. Introduction

Nowadays, the industries in the manufacturing domain are experiencing significant changes in the context of the industry 4.0 revolution, with the objective of high-quality products, customized products and mass production in minimum time to release into the consumer market by improving the flexibility of exchanging knowledge in real time between various process in development of product life cycle management (Phuyal, Bista, & Bista, 2020; Sigov, Ratkin, Ivanov, & Xu, 2022; Wang, Ong, & Nee, 2017). Researchers stated that 30–40 % of manufacturing time, 20–40 % of manufacturing costs are dependent on the decisions taken in the assembling phase of the product development stage (Bahubalendruni & Biswal, 2018). Assembly aspects significantly influence the other stages in the product life, such as repair& maintenance and end of life. The worker personnel at the repair & maintenance stage are facing severe technological barriers to understanding the product design due to its variance according to the demand and customer requirements. Adopting AR technology can eliminate the identified problem and improve product life, supporting technology transfer at various stages in product life (Blaga & Tamas, 2018; Safi, Chung, & Pradhan, 2019).

The rapid advancements in technologies and complexity demand the flexible process of maintenance/repair and assembly guidance to the worker in the industrial environment (Gavish et al., 2015; Ghandi & Masehian, 2015; Inkulu, Bahubalendruni, Dara, & SankaranarayanaSamy, 2021; Santi, Ceruti, Liverani, & Osti, 2021; Zhu, Ong, & Nee, 2014). One of the crucial examples is the recent switch from BS4 to BS6 Engine technology, which necessitated extensive training for the assembly workers. Further, the mechanics must receive adequate training in the assembly and disassembly of the product for maintenance tasks in order to perform them successfully during the repair phase (Palmarini, Erkoyuncu, Roy, & Torabmostaedi, 2018; Siew, Chang, Ong,

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& Nee, 2020). Despite of the cost, the reduction of dwell time is considered a prime objective in areas such as repair & maintenance, assembly and warehouse management (Cohen, Faccio, Galizia, Mora, & Pilati, 2017; Cohen, Naseraldin, Chaudhuri, & Pilati, 2019; Zhen & Li, 2022). Although cost adjustments are varied from one application to another, it is identified that the maintenance expenditures of aircraft account for 80 % of the total cost and are projected to be $54 billion in total in recent years. In contrast, cars require 4 % of its overall expenses. However, maintenance expenditures for aircraft can account for 80 per cent of the total cost of ownership, and they are projected to rise to $54 billion in total in recent years (Young & Rai, 2021).

Today's industrial tycoons are working to adopt technology that could satisfy the 21st-century population's demands for quality, functionality, and aesthetics (Blaga & Tamas, 2018; Urbas, Vrabič, & Vukašinović, 2019). Adopting technology at the maintenance/repair stage can remove the obstacles to producing a wide range of products with uncompromised quality in a short amount of time (Bottani & Vignali, 2018; Kullīyāt al-Taqnīyah al-ʻUlyā (United Arab Emirates) & Institute of Electrical and Electronics Engineers, 2019). The requirement for real-time information exchanges and smooth task coordination among the numerous nodes in a product development life cycle, such as design, setup planning, scheduling, machining, assembly and it is expanding with the trend toward a globally integrated manufacturing environment (Egger & Masood, 2020; Ong & Huang, 2017; Osborne and Mavers, 2019; Qiu, Zhou, Liu, Gao, & Tan, 2019). Therefore, to keep up with evolving technology and meet industry 4.0 criteria, manufacturers have revised their product-making processes (Kaviyaraj & Uma, 2021; Mourtzis, Samothrakis, Zogopoulos, & Vlachou, 2019; Rejeb, Keogh, Wamba, & Treiblmaier, 2021). However, AR technology can help workers to get over these obstacles and difficulties by providing assistance, simulation, and support for enhancing industrial processes prior to adoption in a production environment. As a result, production costs will be reduced, as well as the time required for assembly and maintenance/repair tasks (Agati, Bauer, Hounsell, & Paterno, 2020; Ciuffini, Di Cecca, Ferrise, Mapelli, & Barella, 2016; Lu & Yang, 2016).

Retailers were the first to promote their products and services to clients using immersive technologies like AR and Virtual reality (VR) (Pai, Yap, Md Dawal, Ramesh, & Phoon, 2016). However in recent years, various applications field has begun to use immersive technologies due to improvements in software algorithms and reduced costs of AR/VR equipment (Blaga, Militaru, Mezei, & Tamas, 2021; Karomati, Chu, & Wang, 2020). Semi-skilled workers need to be guided and trained using AR/VR technology in order to efficiently perform difficult activities (Doolani et al., 2020; Lee, Han, & Yang, 2011; Reljić, Milenković, Dudić, Šulc, & Bajči, 2021). Viewers may encounter a dominant sight of the real world in augmented reality (AR), where computer-generated digital information or virtual objects are superimposed on actual objects (Fraga-Lamas, Fernández-Caramés, Blanco-Novoa, & Vilar-Montesinos, 2018). In addition, AR technology enables users to interact with several human senses, including vision, hearing, and haptics (Ladeveze, Fourquet, & Puel, 2010; Siew, Nee, & Ong, 2019; Webel et al., 2013;).

However, to visualize the virtual scene in the actual world, specific equipment is required. There are three types of AR visualization tools: spatial projection devices, see-through hand-held displays, and head-mounted displays (HMD) (Sigov, Holm, & Syberfeldt, 2020; Evans, Miller, Iglesias Pena, MacAllister, & Winer, 2017). The augmented virtual scene can be superimposed over the actual surroundings using the equipment, which then exposes it to the user. Depending on whether the virtual scene is represented by symbolic or pictorial data, the information of the virtual scene overlayed over the real environment is either additive or masking. In addition, this AR-based interactive experience blends in flawlessly with the actual surroundings, giving the user a realistic experience of being in the real world (Brown, Hicks, Rinaudo, & Burch, 2021; Fang, Ong, & Nee, 2014; Maly, Sedlacek, & Leitao, 2016).

VR is one of the immersive technologies which totally switches the user's experience from the actual world to a world that is completely virtual (Berg & Vance, 2017; Jayaram, Vance, Gadh, Jayaram, & Srinivasan, 2001; Stark, 2022). It allows the users to experience all of their human senses in a prominent virtual scene in a virtual world,“ is how the term ”virtual reality“ is defined (Monica Bordegoni & Ferrise, 2013; Ng, Wang, Ong, & Nee, 2013). The Sensorama simulator is the first VR machine that is recognized as the first fully functional VR device, which enables the user to explore a realistic, interactive immersion experience (Heilig, 1962). Further, VR technology enables the users may have hands-on experience with computer visualization, manipulation, and interaction in a realistic, immersive virtual environment (Bamodu & Ye, 2013). Additionally, VR provides users with realistic interactive graphics for non-visual senses such as touch, sound, and feedback, enabling them to experience the presence of a real-world environment (Tao, Lai, & Leu, 2021; Wang, Ong, & Nee, 2015). This technique draws a lot of experts' attention towards the creation of numerous concepts and prototypes.

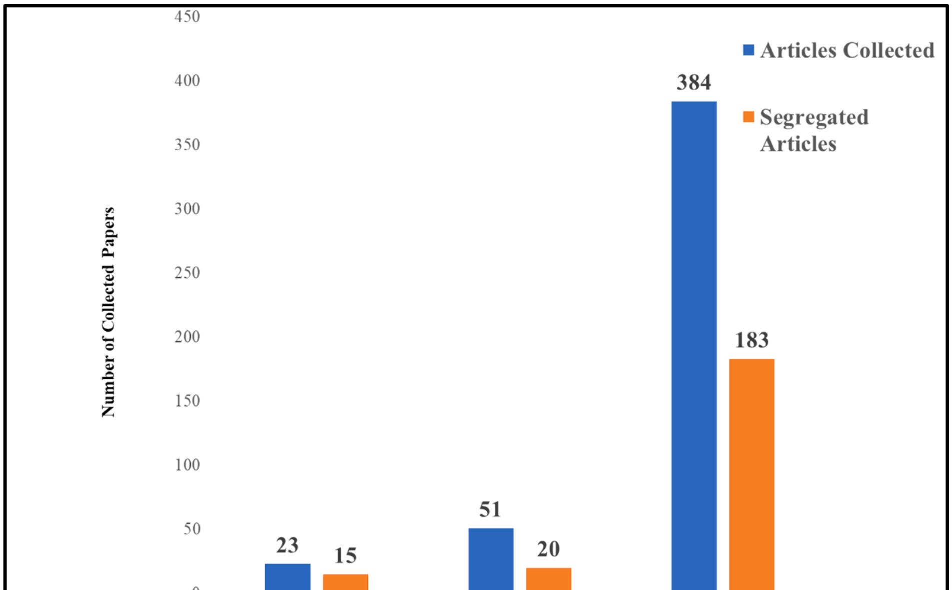
The term “mixed reality” (MR) has also been used to refer to the combination of a real-world and virtual environment scene (Choudhry & Premchand, 2021; Gustavo et al., 2020; Ungureanu et al., 2020). According to Milgram's definition of the “virtuality continuum,” it is the combination zone of augmented reality (AR) and augmented virtuality (AV), with augmented reality covering a scene of the real world more prominently in the user's field of view than overlaying digital content or computer-generated virtual 3D scene information or context (Bordegoni & Caruso, 2012; Milgram & Kishino, 1994). Azuma et al. conducted a comprehensive analysis of emerging augmented reality technology and explored the Reality-Virtuality Continuum's function (Azuma, 1997). A further rapidly innovative technology in industry 5.0 is called extended reality (XR), which is used in various fields like assembly line monitoring, maintenance, remote support, health education/training, and so on (Gong, Fast-berglund, & Johansson, 2021). According to Reddy et al., improved edge computing, high precision computation capabilities, and highly capable devices can increase the usability of XR in industrial 5.0 (Maddikunta et al., 2022).

The last two decades have seen advancements in AR technology, including marker-based and marker-less virtual object positioning methods as well as mobile context-aware platforms that can integrate AR into mobile and manufacturing factory environments (Adrianto, Hidajat, & Yesmaya, 2016; Katiyar, Kalra, & Garg, 2015). This innovative technology has been successfully applied in numerous fields, such as medicine, maintenance and repair, education and cultural heritage, thanks to the efforts of numerous global firms like Google, Sony, HP, and IBM (Reljić et al., 2021). In particular, Google Glass, an optical see-through monocular display that is small and light, offers two crucial augmented reality features: free and quick access to information by sticking it on in the surrounding environment.

1.1. Criteria for collection and segregation of articles

The review is aimed to present state of the art over articles published related to augmented reality in assembly, and disassembly applications. The keywords such as augmented reality, mixed reality, virtual reality, assembly, disassembly, remanufacturing, industry 4.o, and immersive technologies have been given to reliable databases such as Scopus, web of science and publishers such as Elsevier, Springer, IEEE, Emerald, Willey etc. Nearly 460 articles were found as a result of the given inputs, whereas 218 articles were segregated, specifically relevant to current discussions. Fig. 1 represents the criteria for collection and segregation of the articles for the timeline from 1991 to 2022 (recent).

The chronological order describes the significance of AR/VR in assembly and other aspects of product life. By introducing the elements in AR/VR technologies, its architecture in the manufacturing environment is explained by presenting the six modules, such as the production of manufacturing applications instruction, simulating entire manufacturing operations in the CAD platform and real-world environment capture, tracking, rendering of virtual scenes, and real-time



	Year: 1991-2000	Year: 2001-2010	Year: 2011-2022
Articles Collected	23	51	384
Segregated Articles	15	20	183

Fig. 1. Publications on augmented reality in the past three decades.

interaction. The working of each module on facilitating a user-friendly teaching platform and its application of AR in guiding assembly, disassembly for repair & maintenance operations are discussed. The obstacles and challenges to adopting the versatile technology to achieve higher productivity in less time are presented as scope for research to improve in those directions.

The organization of the current paper are as follows. Section 2 provides the main constituent of AR technologies associated with assembly and maintenance/repair applications. Section 3 details the system's architecture for AR-assisted applications in the manufacturing industry. The methods of AR/VR in manufacturing activities are covered in Section 4. The comprehensive analysis of how AR/VR technologies are used in assembly and maintenance/repair tasks is covered in Section 5. Section 6 discusses the challenges and demands of AR/VR-assisted manufacturing techniques. Finally, Section 7 ended with a detailed discussion of the conclusion.

2. Elements of AR/VR technologies

Although AR/VR technology has advanced significantly over the past 20 years, most systems developed to date for manufacturing systems are lab-based implementations (Evangelista et al., 2020; Sorko, Trattner, & Komar, 2020). Real-time tracking and computing are crucial in this AR/VR technology since the synchronization between the real and virtual worlds must be created in the shortest amount of time possible (Huang, Ong, & Nee, 2015; López, Navarro, & Relaño, 2010; Philip Chen, 1992;

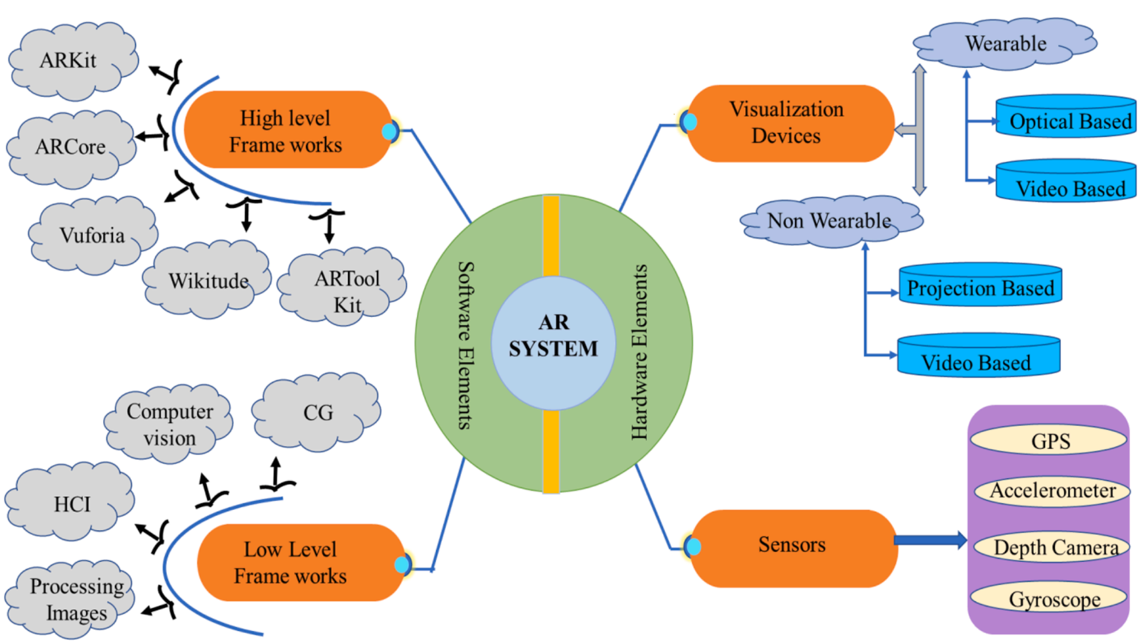


Fig. 2. Hardware and Software Elements of AR Associated Manufacturing System.

Wang, Wang, Song, & Su, 2020). In order to address some of the most critical issues in AR/VR technology, substantial research has been undertaken globally. Numerous hardware and software components are included in AR/VR systems, allowing users to successfully perform and finish tasks in the industrial arena (Gattullo, Evangelista, Uva, Fiorentino, & Gabbard, 2022). The contemporary market provides various commercially available hardware and software tools (Cruz-Neira, Sandin, & DeFanti, 1993; Ni, Yew, Ong, & Nee, 2017; Ong, Yuan, & Nee, 2008; Santos, Fleisch, Graf, & Stork, 2003). Fig. 2 highlights the manufacturing industry's key components of AR assistive systems. The two main components of the AR system are hardware and software. A hardware system for augmented reality includes tracking devices, tactile and force response rendering systems, display devices, and sensor technologies. HMDs are frequently used in AR applications because the eye-level display enables users to experience the unified AR scene in real life (Itoh, Langlotz, Sutton, & Plopski, 2021). As a result, wearing these HMD devices for a long time leads to users' experiences not being comfortable and can lead to neck pain and fatigue (Evans et al., 2017; Funk et al., 2017). Researchers have recently looked into several display technologies, including handheld devices and projectors. With a broader field of view (FOV) and high-resolution displays like SXGA (1280 × 1024) or SVGA (800 × 600), the majority of the new HMD types developed in 2020 are lighter than their predecessors (Gavaghan, Peterhans, Oliveira-Santos, & Weber, 2011). Some HMDs have cameras and sensors that can capture images and show a virtual scene in the correct location even while the user is moving around (Cheng, Wang, Hua, & Talha, 2009). Additionally, thorough research was conducted, and they recommended a few customization options for optical systems, such as optical see-through (OST) and video see-through (VST) HMDs, which work with a variety of video input configurations (DVI, VGA, composite, etc.) (Zheng, Liu, Li, & Xu, 2010).

Zheng et al. established an off-axis optical device using relay lenses with a polynomial surface (Fang, Zheng, & Xu, 2017), and Cheng et al. investigated the use of freeform prisms and lenses to produce a broad FOV for HMDs (Wang et al., 2021). Caruso and Re have concentrated on the development of interaction and visualization techniques in a design review system. Additionally, a video see-through HMD with automatic camera convergence was developed using two motor-driven video cameras (Caruso & Re, 2010). This self-adjusting technique addresses the issue of distortion in a virtual prototype (VP) image, which typically happens when it is placed too close to the designer in a typical VST head-mounted display (HMD).

Nowadays, the primary focus of AR studies is mobility, which can be attained by using handheld devices (HHD), which are commercially reachable or specially framed for the intended purposes. High-performance hardware, including an accelerometer, high-resolution camera, and a responsive screen are found in these mobile devices (Billinghurst, Hakkarainen, & Woodward, 2008; Stutzman, Nilsen, Broderick, & Neubert, 2009; Zhang, Lu, & Wang, 2018). AR Applications can also be employed with standard smartphones. These HHD have constrained internal storage and processing power. Several researchers have utilized a client–server design to attain real-time performance (Siriwardhana, Porambage, Liyanage, & Ylianttila, 2021). Compared to smartphones, PC-based tablets are favoured and better suited to produce 3D rendering scenes.

The usage of spatial projectors by the manufacturing sectors for AR-assisted production activities has eliminated the need for users to wear head-mounted displays to view the augmented virtual scene in real surroundings. This projection-based AR setup is therefore known as spatial augmented reality (SAR) in the industrial context, according to the experts (Siriborvornratanakul, 2018). Based on installation techniques, there are two categories of projector use in augmented reality: permanent installation and portable installation. Few researchers employed fixed-SAR configuration AR technology in the early design stage to blend the real-world texture with digital photos and project the resulting texture onto a physical model for design evaluation (Saakes & Stappers, 2009). Haptic and force feedback are being researched for AR technology to enhance the user's interactive and immersive environment (). Researchers have employed wearable data gloves for applications on desktop and mobile operations, including design, assembly, maintenance/repair etc. (Ong, Shen, & Nee, 2012).

The crucial task of AR systems is blending actual and virtual objects, 3D registration, and real-time interactivity (Nee & Ong, 2013; Wang et al., 2019). In recent years, several strategies and solutions have been created to address tracking and registration issues in AR (Yuan et al. 2005; Yu et al. 2016). Based on these techniques, several well-known AR technology platforms have been developed to support the creation of various AR applications. Tracking and registration are the core enabling technologies for AR systems (Zhang, Ong, & Nee, 2008). Different sensing devices have been utilized for static and dynamic registration to track the users' heads and compute their viewpoints (Lee et al., 2011). Several sensors were introduced in this section. AR systems currently use three types of tracking and registration algorithms: marker-based tracking, natural feature-based tracking, and model-based tracking (Wenkai Li, Nee, & Ong, 2017). The application development system resources for manufacturing activities with AR assistance are shown in Fig. 3.

Fiducial markers are frequently used in AR applications for object tracking and identification. These markers are easily recognisable in a video stream because they include geometric features or distinctive patterns (Chauhan & Kayasth, 2014). Marker-based tracking provides a dependable and steady approach in a known environment (Fang et al., 2017; Weinert, Zabel, Ungemach, & Odendahl, 2008). With the right camera posture, different markers can be identified using feature detection and pattern recognition (Wang et al., 2015; Zhao, Ong, & Nee, 2016). AR Toolkit, a popular tracking tool in this field, can produce square markers with asymmetrical patterns. The virtual object is seamlessly placed on the marker once the target position has been determined. Design, robot programming, assembly, CNC machining, education, and other manufacturing applications have all employed AR Toolkit-based marker creation (Hsiao, Chen, & Huang, 2012; Kokkas & Vosniakos, 2019).

An open-source platform called ARTag was developed by using AR Toolkit (Park, 2011). ARTag comprises visual techniques and digital data image processing, which employs more in the AR application built. However, ARTag exceeds AR ToolKit in terms of tolerance and stability with changes in illumination. ARTag utilizes 2D barcode identifiers, so the necessity to load or train pattern information is not required. A toolkit for building web-based AR experiences is called FLAR ToolKit (Liu, Sohn, & Park, 2018). ARMES is a marker tracker that is offered for sale and is based on circular SDK markers. A computer vision-based library named BazAR is used to identify and match local features (Zhang et al., 2018). In this library, a key point-based approach has been developed. The authors framed the wide-baseline matching of essential features between the images captured and those in the model representations as a classification issue to significantly decrease on-line processing time (Choudhry & Premchand, 2021).

3. Architecture of AR system in manufacturing environment

AR system enhances the immersive and interactive experience between the users and devices by allowing users to move around the real environment and visualize the virtual models naturally. As a result, the AR system has become a potential tool to aid in mechanical production operations. Fig. 4 depicts the architecture of the AR-aided system for the manufacturing industry. The system consists of six modules, including production of manufacturing applications instruction, simulating entire manufacturing operations in the CAD platform, and real-world environment capture, tracking, rendering of virtual scenes, and real-time interaction.

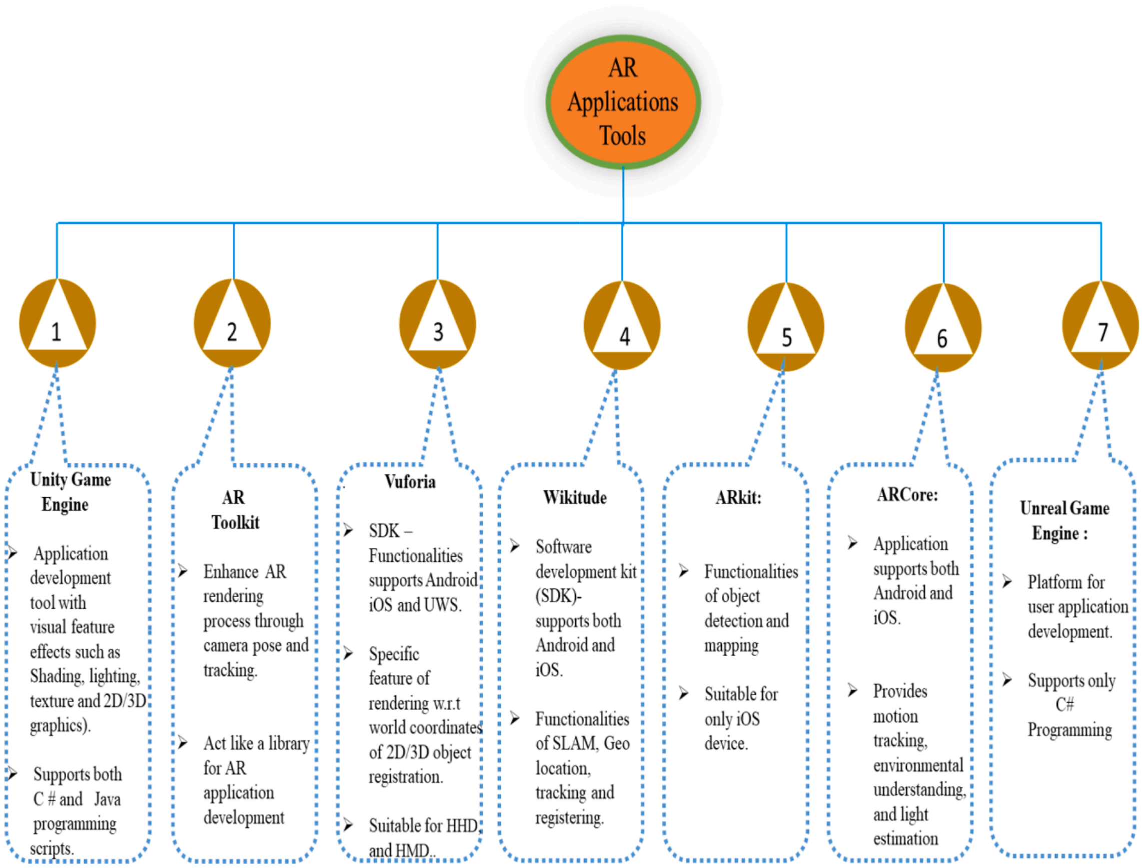


Fig. 3. Application Development Platform Tools for AR aid Manufacturing Activities.

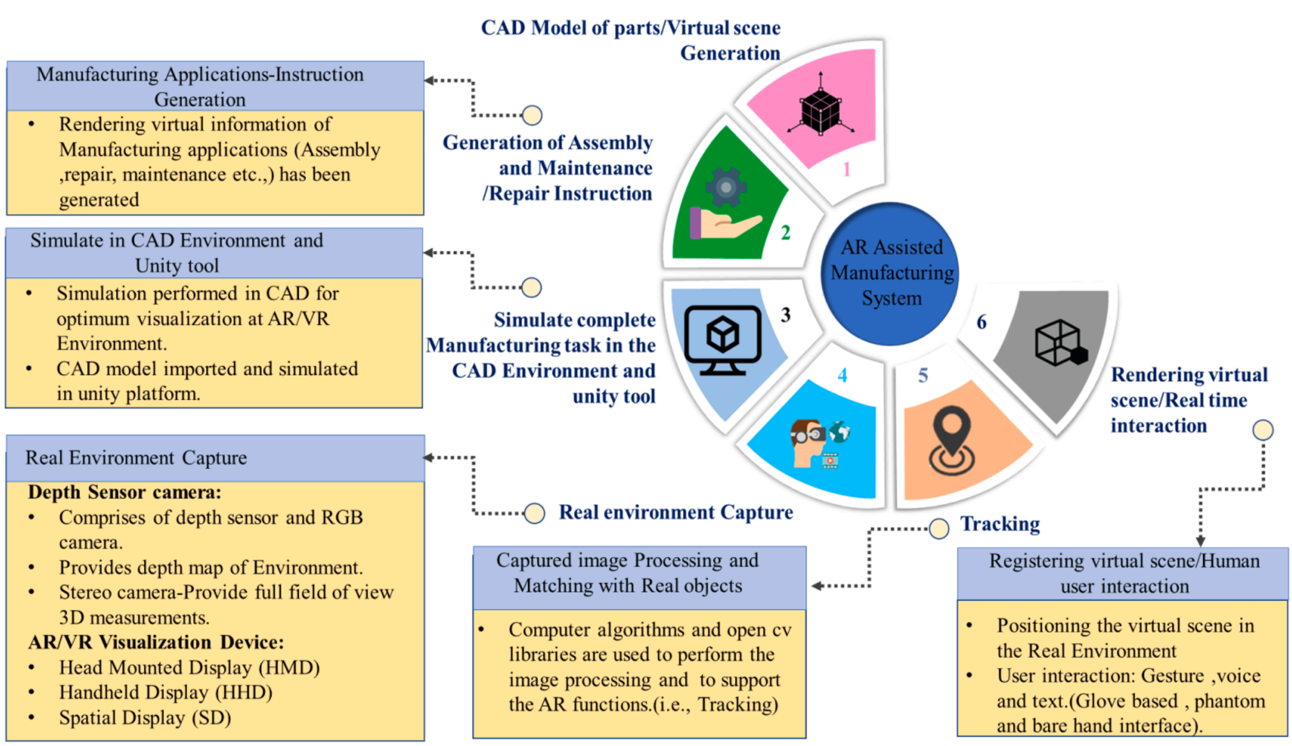


Fig. 4. Architecture of AR system in Manufacturing Environment.

4. Methodologies for object detection and mapping

This section reviews and discusses the methodologies that facilitate AR/VR manufacturing applications in an industrial setting. The techniques of AR/VR-supported manufacturing activities are shown in Fig. 4. One of the primary responsibilities for developing the AR/VR assisted manufacturing application is the generation of digital models. Using CAD software or a 3D reconstruction approach, geometric data from an existing physical component is collected and converted into digital form. Contrary to VR/AR games, the created 3D model needs to be precise in its geometric dimensions and functions to behave realistically in the virtual world. Consequently, AR/VR instructions were developed for various manufacturing tasks, including assembly, warehouse management, quality inspection, maintenance/repair, etc., (Ananthi, Rajavel, Sabarikannan, Srisaran, & Sridhar, 2021; Cirulis & Ginters, 2013; Kin, Ong, & Nee, 2014; Muñoz et al., 2019; Savla, Pandhare, Gulunjkar, Pandit, & Dhawale, 2022; Yan, Shan, Li, Yin, & Li, 2021). Then, both the Unity engine tool and CAD platform were used to simulate production activities. The following stage, object identification and tracking, is vital in the simulation of manufacturing processes helped by AR technology. In this step, the primary hurdles are identifying a specific object, superimposing the virtual information over the physical object, and monitoring the object (Antonelli & Astanin, 2015; Liu, Ong, & Nee, 2022; Siew et al., 2020). For object tracking and identification, these techniques rely on computer vision technology (Zhang, Ong, & Nee, 2011). Point cloud tracking, which uses 3D point clouds to follow the object in the real world, is an excellent technique for object tracking in AR technology (Drost, Ulrich, Navab, & Ilic, 2010; Kardos & Váncza, 2018; Radkowski, 2016).

The management of reference object point clouds, the extraction of cloud points from depth images, the initial overlapping, the matching, the minimizing of spatial distance, the pose estimation, and the overlaying are the six phases that build up point cloud tracking (Birdal & Ilic, 2015; Hinterstoisser, Lepetit, Rajkumar, & Konolige, 2016;). The object identification of physical parts using point cloud techniques is shown in Fig. 5.

Generation of point clouds from reference object (R_i): All physical objects in the production environment are generated as a CAD model, then translated into point clouds. These point clouds are reserved in the database and utilized to match the points of objects in the real environment (Birdal & Ilic, 2015; Drost et al., 2010; Stancelova, Sikudova, & Cernekova, 2021). The tracking database has been used to create and store all reference objects in advance. Generation of cloud points from depth image: The depth sensor's function is to create a point cloud of the parts and tools, which are located in the assembly environment. When a physical object is placed in the depth sensor's field of view, the visible surface of the object at various depths can be used to determine depth, which is then recorded as a point cloud (Drost et al., 2010; Qi, Su, Mo, & Guibas, 2017). Initial overlapping: The process of generation environment point clouds involves subjecting the input depth image from a depth sensor camera to map generation such as normal and vertex maps, which then result in the creation of the environment object cloud points (X_i). The initial overlap between the point clouds R_i and X_i has been done in the matching stage through translation and orientation.

Following the initial overlap of the entity, it can be followed through a process of ongoing matching of cloud point information. The reference object and the 3D point clouds for the chosen reference object are shown in Fig. 5. Spatial distance minimization is the process of reducing the distance between cloud points in space. When measuring the camera pose for AR technology, the spatial range of cloud points is indicated by a translation and rotation vector form. Camera pose prediction intends to render the virtual elements and correctly place or register the generated virtual scene over real-world physical objects.

5. AR for assembly guidance

The assembly of the components in an assembly system can be considered a flow process that generates the desired final product. Any product's assembly in the manufacturing industry consumes maximum time. Thus assembly workers have to be completely aware of the equipment to be used, the order of assembly activities, and the best ways to avoid collisions (Bahubalendruni, Biswal, & Deepak, 2017; Bahubalendruni, Gulivindala, Varupala, & Palavalasa, 2019; Murali, Deepak, & Raju, 2019). There is a vast amount of information on virtual assembly planning, but it cannot be used for instant reference on the shop floor (Bahubalendruni & Biswal, 2018; Bahubalendruni & Biswal, 2018;

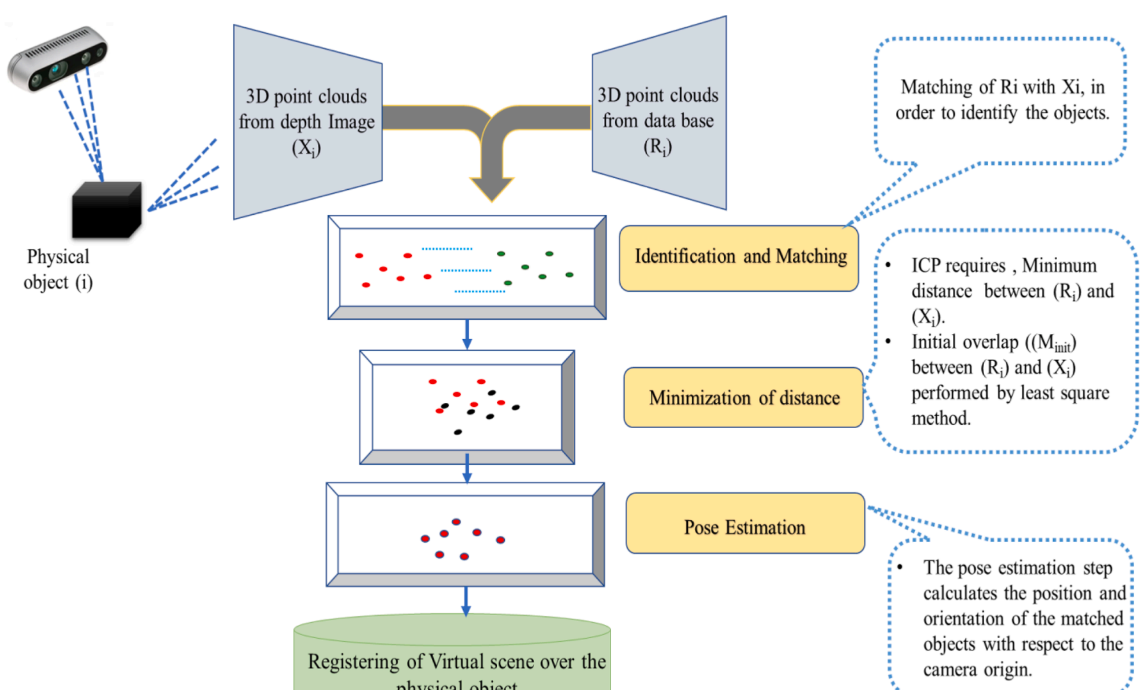


Fig. 5. Object Identification Based on Cloud Points Method.

Deepak, Bala Murali, Bahubalendruni, & Biswal, 2019; Bahubalendruni, Deepak, & Biswal, 2016). AR has made it possible to visualize the assembly process and task details for better task execution.

Many researchers focused their interest on the most recent advancements in visual representation, user cognition, interaction approach and ergonomics for AR-assisted assembly guidance and training (Brown et al., 2021; Hou, Wang, & Truijens, 2015; Wang, Ong, & Nee, 2016). These scientific breakthroughs thoroughly explain AR visualization technology in fostering industrial intelligence. In particular, the visualization in human–computer interaction offers a thorough research foundation for the creation of assembly guidance and training instructions and further highlights the design attributes of AR guidance techniques (Bahubalendruni, Biswal, Kumar, & Deepak, 2016; Khabbazi, Wikander, Onori, & Maffei, 2018). Moreover, AR instructions/guidance are a set of visual cues, and it is representing the objective of assembling a complete high-quality product with less time in the product assembly system (Da Xu, Wang, Bi, & Yu, 2013; Wang, Rong, & Xiang, 2014; Yu, Xu, Bi, & Wang, 2014). However, the system requires the user's perception, user's cognition, and prerequisite knowledge of particular functions in an industrial assembly system. Due to today's highly competitive industry, it is necessary to launch customized products on the market quickly (Cardoso & Zorzal, 2018; Demoly, Yan, Eynard, Rivest, & Gomes, 2011; Kuo, Chen, & Roberts, 2013). As part of the product development life cycle, stakeholders must exchange real-time information in the context of a collaborative industrial environment (Cohen et al., 2019; Mourtzis, Siatras, Angelopoulos, & Panopoulos, 2020).

Moreover, the assembly system provides the ability to complete complex assembly tasks to assembly line workers, ruling out the potential of using automated machines in place of humans to complete these activities (Wang & De Tian, 2016). In the context of a complex product assembly system, the description of assembly task details in physical mode is a critical factor in ensuring the result of assembly activities. The AR assembly system can be used to enable effective communication with users through AR guidelines in order to facilitate manual assembly tasks. At the same time, the purpose of assembly instructions has subtly evolved from only providing users with assembly knowledge to actively supplying them with heuristic visual cues to satisfy their cognitive demands. In reality, it is more efficient than standard operations and embodies the significance of communication and cooperation between AR and users to obtain an optimum assembly system.

The gap between digitization and manual tasks creates the maximum impact in the form of less ability to perceive and interpret the information (Sorko et al., 2020; Tan et al., 2021). However, AR is a promising technology for human–computer interaction, which incorporates assembly information into the cyber-physical universe as virtual objects that may coexist and communicate with actual assembly components, dramatically enhancing the users to interact with the physical world. It must be acknowledged that this technology has altered the users to interact with the physical world in the assembly industry (Wang Li, Wang, Liu, & Zhao, 2022; Yi et al., 2021). For instance, Fig. 6 depicts the assembly process of a bicycle with AR aided system in the assembly environment. This AR instruction allows the workers to execute any complex task by augmenting the virtual scene over the real environment object, which leads to completing the task without any flaws in the process.

However, the technological difficulties with an AR-based assembly system, motion sensing and registration could be crucial and difficult for the users. Since then, a lot of researchers have concentrated on and published work related to AR-based assembly activities. Molineros and Sharma proposed Assembly graphs as an advanced visualization technique for directing enhanced virtual data (Raghavan, Molineros, & Sharma, 1999). They offered several AR-based assembly systems that were focused on applying an AR assembly system to a real configuration environment in the industry. This could be accomplished by integrating design software tools such as CAD, PLM and PDM for assembly and maintenance/repair process in the manufacturing industry (Demoly et al., 2011). The use of AR-assisted educational tools for engineering assembly jobs was discussed by Hou, Wang, Bernold, & Love (2013). Researchers proposed a simple model of an AR-based assembly system that includes guidance, training, simulation, planning, and design for the assembly process. According to Makris et al., an assembly system using augmented reality (AR) technology could provide assembly workers visible instructions as they are working in the actual environment, as compared to using CAD software to create rendering models or

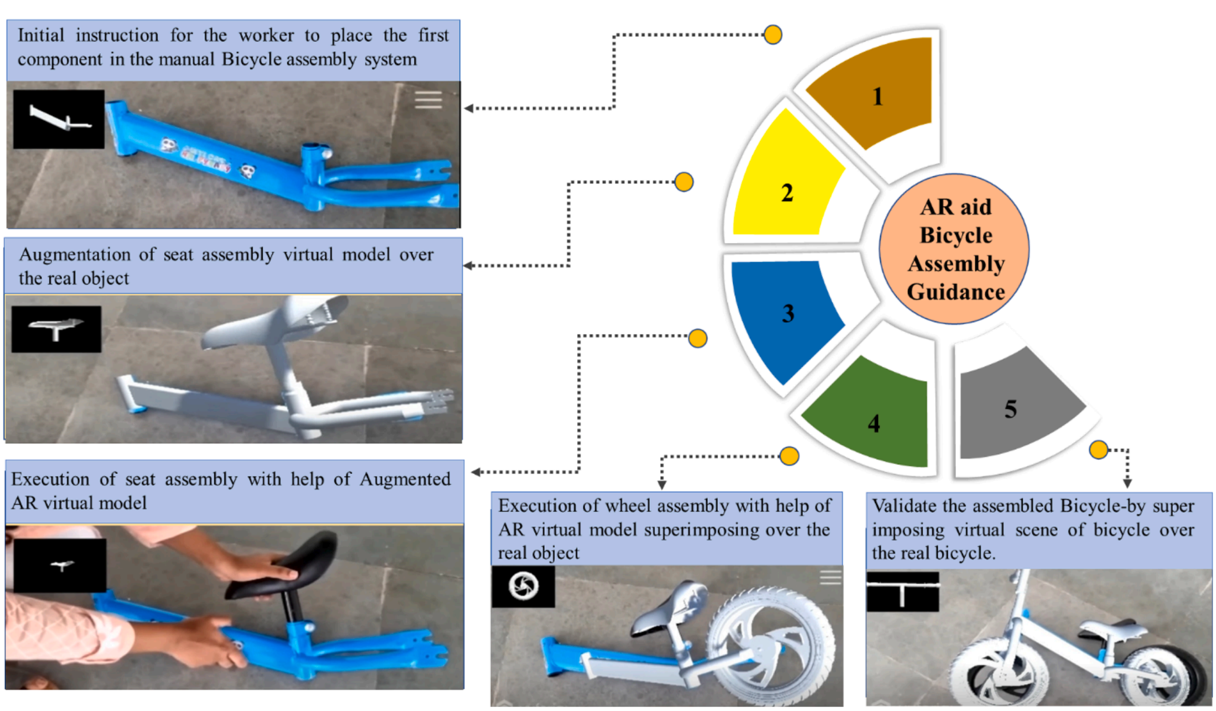


Fig. 6. Assembly of bicycle in AR Environment.

instructions (Lotsaris et al., 2020; Makris, Karagiannis, Koukas, & Matthaiakis, 2016; Makris, Pintzos, Rentzos, & Chryssolouris, 2013). Sukan et al. introduced the ParaFrustum interactive system, which allows users to see the target object from various angles in the surrounding environment and removes occlusions (Sukan, Elvezio, Oda, Feiner, & Tversky, 2014). A real-time occlusion managing approach in the assembly system, suggested by Wang et al., which eliminates occlusions in the assembly environment (Wang, Liu, & Zhong, 2005). Michela and Gino proposed an AR prototype to enable the worker during panel fitting tasks by providing direction instructions to fix alignment issues, including gap and flushness in the automobile body assembly process (Dalle Mura & Dini, 2021). Lai et al. introduced a method fusing AR and R-CNN techniques to assist assembly workers with tool recognition and task implementation in the assembly station (Lai, Tao, Leu, & Yin, 2020; Tao, Lai, & Leu, 2021; Zheng, Liu, An, Li, & Zhang, 2020). A strategy of implementing RFID technology in assembly task operations in an augmented reality (AR) environment was given by Zhang et al. with the goal of enabling employees to visualize just-in-time instruction rendering and navigate through intuitive instruction (Zhang, Ma, Li, & Yu, 2017). Boeing has investigated the AR assist assembly operation and assessed on the system's effectiveness (Barfield & Caudell, 2001). Chu and Ko suggested brand-new AR functions to support with manual assembly in an occluded system (Chu & Ko, 2021). The focus is on demonstrating the effectiveness of several AR aid information, including the assembly interface and assembly operator hand movements. The POC (proof-of-concept) approach was introduced by Andersen et al. to estimate the human position by matching the depth data with the reference environment object (Thøgersen et al., 2020). Numerous studies on AR assistance assembly processes have been carried out and studied using the conventional printed manual approach. Funk et al. developed the AR-based approach for the assembly process, where the real-time instruction is displayed to the worker through a depth camera and electronic projection display device (Funk et al., 2017). According to the experiment, the assembly process takes less time when adopting the proposed system than paper-based instructions and user feedback was acceptable. Janin et al. proposed an AR aid system for manual assembly tasks in aircraft mainframe, where the assembly instructions and annotations are projected over the object's surface in the presence of a physical environment and enable the workers to visualize the instructions through see-through HMD (Holloway, 1997). The outcomes of the proposed system were ineffective due to the operator's narrow range of view and the delay in the HMD's graphic display. Young and Smith addressed the effectiveness of AR aid assembly functions, where the instruction in the form 3D animation has been visualized to the assembly worker and enables the worker to complete the task in a short time without any flaws (Martin & Smith-Jackson, 2008). In contrast to paper-based instruction manuals, they asserted that exhibiting the part models in actual scenes improved the user's spatial reasoning. The users made fewer assembly mistakes, such as improper assembly sequences and element orientations, during the manual assembly of complicated goods with AR assistance. The majority of earlier research revealed that AR-assisted activities can address the current issues with paper-based assembly instructions, such as their cognitive task load, restricted flexibility, and susceptibility to misunderstanding.

The goal of this study is to determine how often the AR visualization technique is being used to direct workers while manually execute the assembly tasks. The study's findings demonstrate that the AR assistance method was superior to paper-based instruction for the assembly task. Additionally, the AR assistance methodology could be more effective at accomplishing challenging activities than traditional paper-based instructions.

6. AR for maintenance/repair

One of the most crucial and challenging tasks in the industrial sector is the maintenance system, where technicians must ensure the goal of optimum machine availability and reliability. In order to reach the highest productivity potential, the manufacturing industries are currently concentrating their research efforts on the significant aspect of optimal maintenance/repair systems (Aschenbrenner, Latoschik, & Schillingz, 2016; Sun, Osman, & Lang, 2021; Zhu, Ong, & Nee, 2013). Many of the exciting developments in industry 4.0 is AR, which expands a variety of ways to the maintenance and repair system and helps workers by providing both audio and visual instructions. In the traditional maintenance method, the workers frequently consult the manuals for instructions, taking extra time to complete the challenging duties.

An inventive machine servicing system is suggested by the researchers that uses immersive AR/VR technology to enable maintenance tasks (Runji, Lee, & Chu, 2022; Siew, Ong, & Nee, 2019; Sun et al., 2021). The suggested maintenance system's architecture and data interchange between the on-site technician and the industry's head mechanic is shown in Fig. 7. Three steps make up the proposed system: compilation of the failure report, diagnosis by the AR and creation of the maintenance instructions, and maintenance and evaluation. Registering the failure report is the initial stage in the system of architecture. Prior to scheduled maintenance or an unforeseen breakdown, the service report must be completed in the manufacturing sector (Ferrise, Caruso, & Bordegoni, 2013; Valentini, 2012).

In the traditional maintenance strategy, the onsite workers manually write up the report, which contains information about the possible issues, which remains the solution to be done in the form of text instruction (Kolla, Sanchez, & Plapper, 2021; Lundgren, Bokrantz, & Skoogh, 2021). However, the proposed solution enables the technician to generate a digitalized data report using the foremost communication protocols. The onsite technician could document machine failure in image, text, video, and audio format, and these failure reports might also be sent to the chief mechanic or other experts via the cloud platform. In this case, the cloud system makes it easier for experts and on-site technicians to communicate by enabling the interchange of failure reports to experts and AR instructions to on-site technicians.

Further, the experts will begin the major part of the service, which comprises identifying the source of the failure and creating AR instructions, after studying the failure report (Mourtzis, Zogopoulos, & Vlachou, 2017). Through the cloud system, the onsite technician could be informed of the failure's resolution (i.e., through an AR instruction). The remote maintenance/repair system with AR assistance is shown in Fig. 8.

As an illustration, industries that develop specialized machines and trade their goods globally in order to promote the technology. Some sectors, especially in developing economies, employ fewer skilled employees in the maintenance and repair sector. To address severe inevitable machine failures, experts must therefore fly there. This causes machines in production lines to sit idle for extended periods of time, which reduces output and raises repair costs. In this scenario, the manufacturers could instantly need to be in touch with the experts via smartphone to get guidance on where to fix the machine's problems. However, this way of instruction eliminates the requirement for physical appearance specialists for repair work and at the same time being competent for fixing the machine's complex maintenance tasks. This problem needs to be addressed in this situation in order to achieve the objectives of higher productivity and lower maintenance expenses. The manufacturing sector must be managed efficiently to avoid machine downtime in a competitive climate. Adopting AR technology for remote support in the realm of industrial repair and maintenance could help accomplish this goal.

Nowadays, AR technology allows remote specialists to guide local technicians by providing step-by-step instructions in real-time using the AR visualization device of HMD and HHD. When compared to the smartphone support technique, this adopted technology shortens the time required for remote assistance by 10 %. Fig. 9 illustrates the function of AR in each category of the maintenance system as well as the impact of AR on the maintenance system.

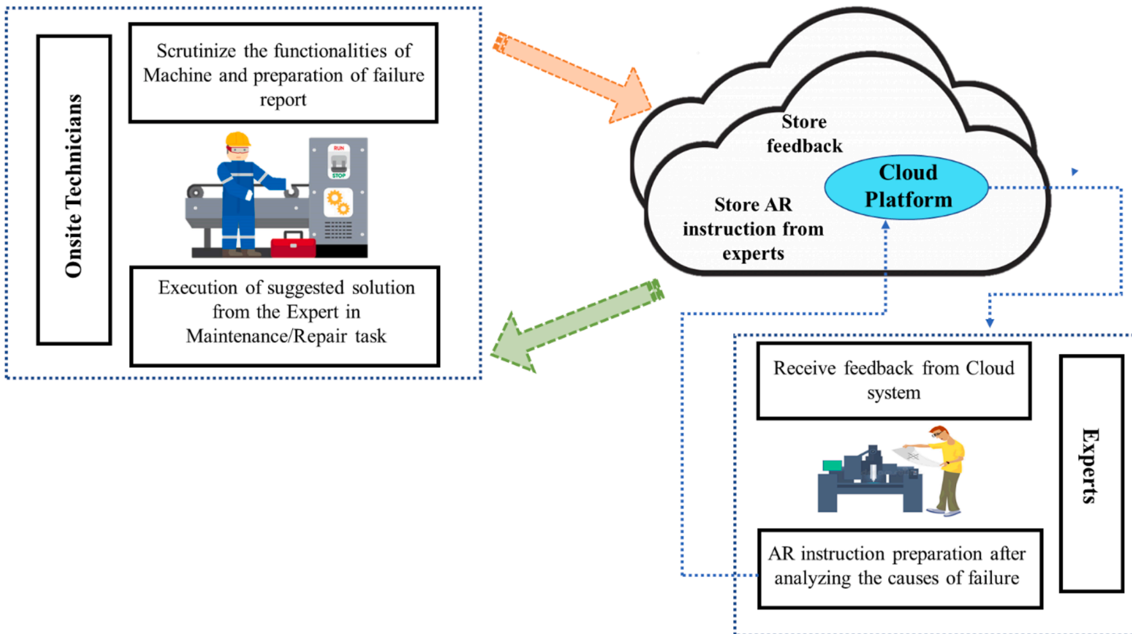


Fig. 7. The architecture of AR aid the Maintenance System.

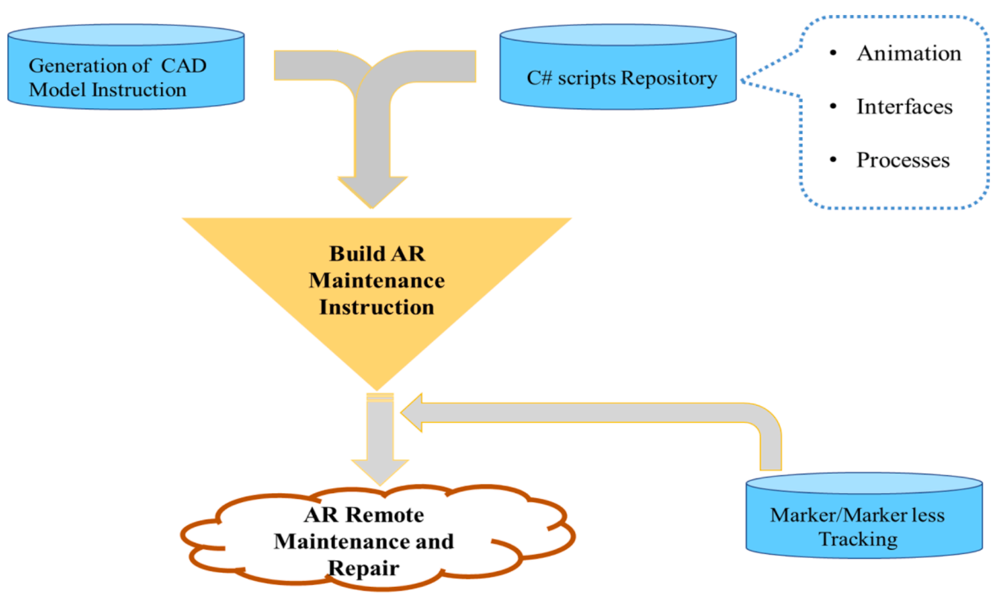


Fig. 8. AR aid Remote Maintenance/Repair System.

The manufacturing sectors, including BMW and Bosch, have more recently deployed this AR technology in their facilities to support challenging maintenance tasks (Werrlich, Nitsche, & Notni, 2017). Additionally, this technology offers effective synchronous and asynchronous information sharing between the experts and the on-site specialist.

The list of AR/VR tracking techniques and Visualization methods used for various manufacturing applications such as assembly and maintenance/repair from the cited literature is given in Table 1. Majority of industrial applications are focused on enhancing productivity, reduce training time and cost, quality assurance, error rate reduction, minimize the maintenance/repair time and cost and real-time assistance.

7. Challenges and Future research needs

Currently, the manufacturing industries are exploring the latest immersive technology of AR for the flexible manufacturing system, which enables the manufacturer to achieve the main goal of increased production in less time. However, many obstacles and problems need to be resolved despite the rising interest in AR and the significant quantity of research and development activities in manufacturing industries. Numerous researchers have evaluated on AR-based manufacturing industry applications in-depth through pertinent studies, highlighting the many difficulties that need to be solved before the sector completely adopts the technology (Kaviyaraj & Uma, 2021).

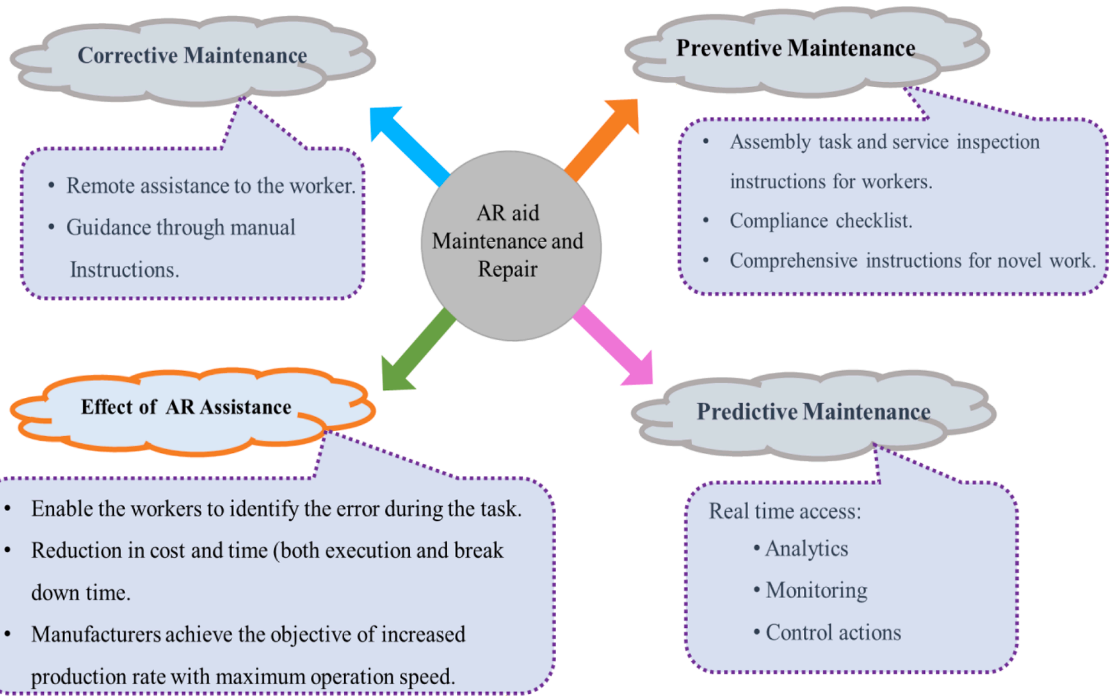


Fig. 9. Function of AR in various Maintenance Systems.

7.1. Challenges

The challenges and constraints of augmented reality (AR) are summarized in this section using a various range of aspects and the details were extracted from the critical reviews of AR on manufacturing systems. This concern includes technological, organizational, and environmental factors. The main obstacles to AR in the manufacturing industry are depicted in Fig. 10. The main technological issues include tracking & rendering (i.e., difficulties in sensors and sensing techniques for estimating human movement and environment experience), ergonomics and processing speed.

The primary techniques of AR enablers are tracking and registration systems. Without adequate tracking and registration, it is impossible to successfully combine object models that are virtual with those that are real. The user's posture has been tracked using a variety of sensing devices to determine their viewpoints, which is required for both static and dynamic registration of digital content to function. Advanced sensors and sensing technologies are needed for human position prediction methods and perception estimation.

The development of a real-time tracking system appropriate for industrial scenarios, where the researchers mostly concentrated on some of the critical challenges of real-time tracking with textured characteristics of various smooth surfaces, variation in lights and very tiny size in product dimensions. Many studies in real-time tracking have been carried out by experts, where most of the researchers adopted the marker-based tracking technique, which is the most often and popularly used tracking method in AR-based manufacturing activities (Seeliger, Netland, & Feuerriegel, 2022). Since the feasibility of accuracy, adaptability, and ease of usage makes the several researchers to enable to include the marker-based tracking technique in AR-assisted production systems. In this proposed tracking technique, A camera records a specified marker for this tracking, which is then recognized and tracked on each frame. This enables to calculate the marker's position and orientation in reference to the camera. Afterwards, a virtual model is rendered over the actual items using the estimated pose. Wang et al. explored on tracking tool models that used a colour-based marker and non-square visual markers so that users could manage articulated scanned real items consistently. The estimation of camera posture is incredibly accurate, since markers may be built with the best tracking patterns in marker-based systems (Pang, Nee, Ong, Yuan, & Youcef-Toumi, 2006). However, in some cases, these methods are problematic, particularly for small or irregular items on which marks cannot be affixed. Furthermore, when the marker is obscured by any actual environmental elements, the tracking mechanism may not work properly. According to the earlier reviewed studies, there is a research gap in AR-assisted manual assembly tasks with occluded components. In order to assemble occluded parts manually in an AR technique, it is necessary to establish the most helpful technologies and which facilitate the manual assembly involving components that are visibly concealed from the human operator in the workplace. Most experts concurred that such complicated assembly activities require advanced functionality, and it has to be developed to accomplish the critical task much easier. However, this method development has a high level of technical complexity and infrequently oversimplifies the usage circumstances. Hence, various comparative research has been carried out to assess the effectiveness of different display details, involving assembly interface, worker hand motions, and part to be assembled. The evaluation's findings indicate if and how much each piece of information speeds up assembly under occluded conditions. In order to design Gesture functionalities, they offer design assistance by detecting more useful data that enables assembling occluded elements (Han, Shao, Xu, & Shotton, 2013; Ng, Oon, Ong, & Nee, 2011;). The function of AR immersive technology facilitates the numerous manual task process in the manufacturing sector, where manual assembly and disassembly are typical shop floor tasks in which AR has successfully illustrated its values. The digital content instructions in the form of multimedia context utilized in the interactive real environment, which replaces the manual/paper assisted assembly guidance in the manufacturing industries. Hence, the proposed AR in marker-less tracking systems improves the efficiency and quality of the assembly system with less time and lighter workload of workers.

Marker-less tracking technique has been explored as a preferable replacement for the marker-based tracking technique in recent years. SLAM (Simultaneous Localization and Mapping) technology is a well-developed method for making a map in an unprepared environment while keeping track of its current location using extracted scene objects (Paulo Lima et al., 2017; Slater & Wilbur, 1997). The generated

Table 1
List of AR/VR tracking techniques and Visualization methods used for Assembly and Maintenance/Repair applications.

Research Group	Focus and contributions	Field of work	Tracking Method	Visualization device		Method of Visualization		
				HMD	HHD	SD	Optical	Video
Boeing (Barfield & Caudell, 2001)	Assistance to assembly task	Assembly in Aircraft	Marker based	X	–	–	X	–
Chang et al. (Chang, Nee, & Ong, 2020)	Enhance efficiency and productivity	Manual Assembly	Natural feature-based	X	–	–	X	–
Siew et al. (Siew, Ong, et al., 2019)	Enhance efficiency and safety	Maintenance instructions	Marker based	X	–	–	X	–
HIT Lab (Campbell, 1996)	Shorten training time and improve production efficiency	Training and assembly	Marker less tracking	X	–	–	X	–
VRAC (Radkowski & Oliver, 2014)	AR instruction for Complex assembly.	Manual assembly	Marker less tracking	X	–	–	X	–
Crystal Young, Rahul Rai (Young & Rai, 2021)	Reducing manual maintenance task time	Maintenance instructions	Marker and Model based	X	–	–	X	X
Novak-Marcincin's team (Novak-Marcincin, Barna, Janak, & Novakova-Marcincinova, 2013)	AR instruction for precise assembly context.	Precision assembly	Marker less tracking	X	–	–	X	–
Mario Lorenz et al. (Lorenz, Knopp, & Klimant, 2018)	Support system for Maintenance worker	Maintenance instructions	Projector based AR system	X	–	X	X	X
Raatz's team (Araiza-Illan, De San Bernabe, Hongchao, & Shin, 2019)	Increase efficiency and productivity	Manual assembly	Marker based	X	–	–	X	–
Sanna et al. (Sanna, Manuri, Lamberti, Paravati, & Pezzolla, 2015)	Shorten production time and improve efficiency	Maintenance and Assembly task	Marker based	–	X	–	–	X
Mika Hakkarainen et al. (Billinghurst et al., 2008)	Step by step guidance	Manual assembly	Marker based	–	X	–	X	–
Yan Pang et al. (Pang, Yuan, Nee, Ong, & Youcef-toumi, 2006).	Assembly feature design	Manual assembly	Marker less	X	–	–	X	X
Gabriel Evans et al. (Evans et al., 2017)	Step by step guidance	Assembly applications	Marker based	X	–	–	X	X
MAS Lab (Zheng et al., 2020)	AR instruction for product and process semantics	Automobile assembly	Marker less tracking	X	–	–	X	–
Alves et al.(Alves et al., 2019)	Assistance to assembly worker	Assembly and task validations	Marker based	X	–	X	X	X
Funk's (Funk et al., 2017)	Performance of AR instruction analyzed	Manual maintenance	Marker based	X	–	–	X	–
Stefan et al.(Werrlich et al., 2017)	Shorten training time and improve production efficiency	Assembly Training	Marker based	X	–	–	X	X
Thitirat (Siriborvornratanakul, 2018)	Increase productivity, decrease unnecessary workloads and enhance user experience	Manual assembly	Marker based	–	X	X	–	X
Patrick (Renner & Pfeiffer, 2017)	Step by step guidance	Assembly task	Marker based	X	–	–	X	X
Marco and Elizabeth (Sá & Churchill, 2013)	Shorten production time and improve efficiency	Assembly task and training	Marker based	–	X	–	–	X
Hanson's (Hanson, Falkenström, & Miettinen, 2017)	Assistance to assembly worker	Kit Assembly	Marker less tracking	X	–	–	X	–
Marco et al. (Schumann, Fuchs, Kollatsch, & Klimant, 2020)	Enhance Efficiency and flexibility of Design	Manual assembly	Marker and Marker less	X	–	–	X	–
Makris et al. (Makris et al., 2013)	AR instruction for effective transformation of assembly knowledge	Manual assembly	Marker based	X	–	–	X	–
Chang's (Chang et al., 2020)	AR instruction for micro assembly feature	Micro assembly	Marker based	X	–	–	X	–
A. Z. Abdul Halim (Halim, 2018)	Shorten production time and improve efficiency	Maintenance in automotive industry	Marker less tracking	X	–	X	X	X
Columbia CG & UI Lab (Schmalstieg et al., 2002)	Shorten production time and improve efficiency	Maintenance and Assembly of military task	Marker based	X	–	–	X	–

information from the real environment scene elements includes ceilings, wall-to-floor transitions and object edges, is used to estimate the object's position and orientation. SLAM system comprises of data sensing sensors (i.e., self-navigation technique) such as GPS, visual, Lidar and odometer, which enables to builds or update a map of an uncharted area while tracking the user's location inside that map (Della Corte, Bogoslavskyi, Stachniss, & Grisetti, 2018). Moreover, the proposed marker-less tracking techniques is the best replacement for the marker-based system by offering non-invasive techniques.

The prominent Microsoft Kinect falls into this category. It comprises of a depth sensor that measures image depth and employs that data to predict human posture based on a skeleton. Currently, the depth information is generated through a new depth camera such as Intel RealSense and Structure Sensor, which are readily available on the market to use (Zhang, 2012). Moreover, thanks to recent advances in deep learning, particularly artificial intelligence (AI), it is now possible to accurately predict the human location directly from a captured digital image of objects, where depth information is not necessary. However, the 3D structures updation for moving objects are not taken into account by SLAM methods, where the target working scene must remain static, else the system would have to restart for every frame of the collected video. Open Pose is another system and which is the first real-time multi-person technique, used to identify human posture from a single shot, and it was initially introduced in 2017. It can identify key locations on the hands, face and body of a person and it has a potential solution for human pose finding because it does not demand for special cameras. However, one of its limitations is that real-time person tracking is computationally expensive and demands top-tier GPUs.

Initially, most of the researchers are utilized the sensors-based tracking technique before the development of marker-based tracking, Sensor-based tracking was a trusted tracking technique that was frequently utilized in AR manufacturing and assembly (Pang et al.,

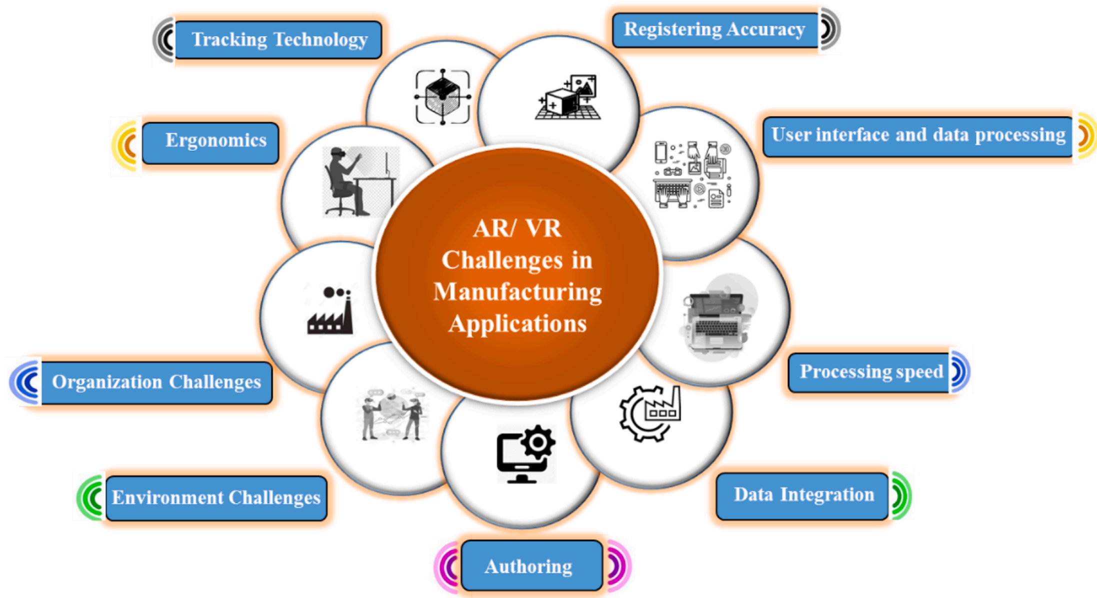


Fig. 10. Key challenges of AR in Manufacturing system.

2006; Yuan, Ong, & Nee, 2008). The tracking principle makes use of a variety of sensors, including inertial, magnetic, auditory, optical, and/or mechanical ones, whilst computer vision algorithms are used for vision-based tracking. In general, sensor-based trackers is necessary to have the significant factor of low latency and high precision, when it is often applied to the AR-assisted industry applications. For instance, optical sensors are expensive, heavy, and require lengthy calibration, yet they offer exceptional accuracy, adaptability, and low latency.

The registration method is another main objective of tracking in AR, which is used to simplify the registration of virtual models and/or manual user instructions with the appropriate position in the augmented environment. Accuracy and latency are the two fundamental issues in this field. The error brought on by misaligned sensors, incorrect sensory equipment, and/or imprecise tracking findings is referred to as “accuracy.” Zheng et al. suggested a closed-loop registration technique that directly applied the desired synthetic images (real and virtual) as the target to remove errors (Zheng et al., 2020). Yang et al. built a dedicated technique employing partially known metric data from the visible scene to obtain extrinsic calibration of RGB and depth camera rig (Bogoslavskyi & Stachniss, 2017; Ha, Cho, Rojas, & Yang, 2011; Yang, Yang, & Chu, 2014). Currently, implementing enhanced tracking systems, precise registration strategies, and efficient calibration methods is the key to solving the accuracy problem. The term “latency problem” describes alignment issues with virtual models brought on by the delay between an observer moving and the projection of the visual that corresponds to its new movement. Moreover, when user movements and head movements speed increases, then the severity of the issue also grows. The other miscellaneous challenges such as speed of processor, organizational impacts and ergonomic consideration, that have to be revealed critically for the best performance of AR in manufacturing applications.

The user experience and functionality of AR systems, specifically HMDs utilization issue are most challengeable one, as per Stoltz et al. and Porcelli et al. (Porcelli, Rapaccini, Espíndola, & Pereira, 2013; Stoltz et al., 2017). AR devices require a lot of processing power to perform real-time scenarios with extremely high-quality digital data and tracking techniques. Although Moore’s Law indicates that integrated circuit component densities double every-two years, this means that as time goes on, processing speeds for AR devices also grow. Cloud computing seems to be a viable choice, because it enables for effective usage of resources and content. Fernández et al stated that a strong network connection and security are necessary for smooth content distribution in AR systems (Fraga-Lamas et al., 2018). However, the present 5G internet network offers a cellular connection with low latency and high bandwidth that is adequate for AR to function.

In organization, security and privacy are related to user approval. For training and task/error tracking, the AR system has to monitor AR users and record their gestures, speech, and other behaviours (De Pace, Manuri, & Sanna, 2018). Researchers have examined AR in the workplace and found a number of issues in the industrial environment. A number of field studies states that, AR has a detrimental effect on performance because of software limitations, the comfort of HMD, privacy concerns, and high cognitive load. A user-acceptance is influenced by its ergonomic product design. The ergonomics in both software and hardware are includes camera angles, light sensitivity of AR algorithms, weight and FOV. Further, the long-term use of AR devices, especially HMDs, causes diplopic vision, weariness, issues with depth perception and discomfort in the visual field.

7.2. Future trends

Advances in AR technology are necessary for manufacturing applications in an industrial context, consequently research and development effort are needed. The picture depicts the research requirements for immersive AR/VR technologies in manufacturing applications, including enhancement of the virtual interface for reality, identifying worker behaviours, and enabling sharing and collaboration between multiple streams in an industrial context. Significant efforts have to be carried out to enhance immersive technology, which enables to increase the user’s realism experience in the virtual interface of an immersive environment. In other words, upgradation of the optical system with low tendency and high fidelity of the visual system interface, adoption of upgraded 3d auditory system, improved haptic multichannel devices, advances in locomotion interface (movement realism), upgradation of marker-less tracking technique, an optimum method to estimate human posture, adoption of well-developed interactive system and determination of optimal algorithm for tracking and registering.

The recognition of worker activity has been taken into consideration in manufacturing industries for assessing employee performance. The numerous research prospects for AR/VR immersive technologies in the existing production system are shown in Fig. 11.

In order to meet market demand, industries are currently required to manufacture new product variants. The sharing of product details with

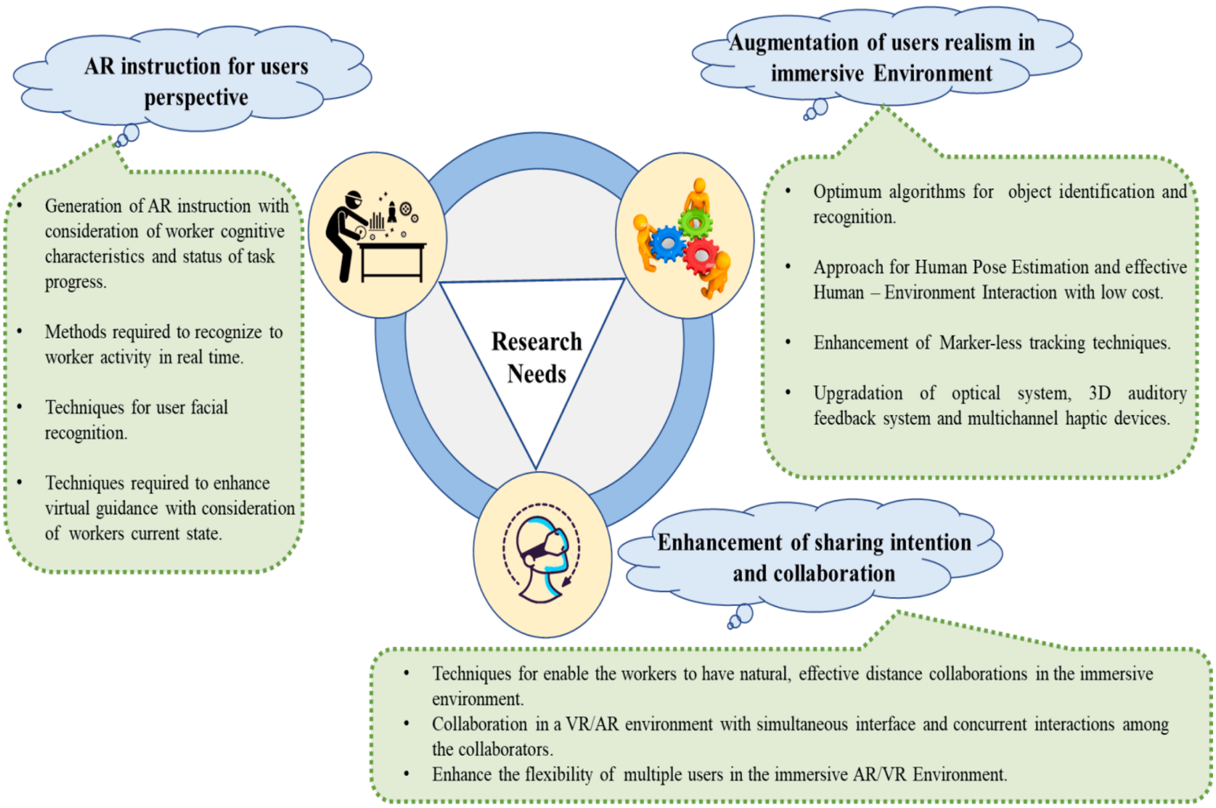


Fig. 11. Future trends of AR/VR technologies in the current industrial environment.

the many streams of various personnel in the industrial context has become more challenging for manufacturers. Several studies have to be carried out in the field of collaboration and sharing, which involves the following:

- Generation of AR instruction with consideration of user's cognitive status, cognitive characteristics and task activities.
- Enhance the adaptability of numerous users in the AR/VR immersive environment, which can connect precisely to a certain coordinate system and regularly update their content.
- Techniques to enable the users to work distant comfortably and productively in an AR/VR immersive environment.
- Construction of effective approaches for simultaneous collaborations and concurrent interfaces between stakeholders in an immersive system.

To enable many workers to share their relevant expertise and experience among the various workshops of sectors from various location, the discussed cloud-based collaboration strategy needs to be implemented.

8. Conclusion

This article provides a thorough analysis of AR/VR research and advancements in a wide variety of industrial applications such as assembly and maintenance/repair by addressing few difficulties and suggestions for further studies in advancements related to existing production systems. Terminologies and information pertaining to AR/VR systems for manufacturing activities have been addressed, and complications with the tracking and registration approach for human posture estimation and environmental perception have been thoroughly reviewed. The following fields of expertise need to be done in order to study worker behaviour in the industrial environment.

- The existing state of worker activity in the production process must be addressed in order to compute the operating time for assessment purposes. Hence, the recognition of worker activity in real time must be investigated.
- The techniques for identifying a worker's facial features and emotional state during the production process are required.
- An upgraded system is necessary to increase the effectiveness of interactions with the workers, and flexible virtual guidance approaches must be developed with consideration of existing worker conditions.

The possible use of this technology makes it easier for manufacturers to implement other modern industry 4.0 development technologies for their production processes in the industrial context, which includes IoT, cloud computing, and blockchain. The AR/VR immersive technologies are expected to play an important role in the upcoming decade, improving human–machine interaction through real-time instruction exchanges across the production system in the manufacturing industry.

CRediT authorship contribution statement

M.Eswaran: conceptualization, data curation, writing. **Anil Kumar Gulivindala:** Draft preparation, editing. **Anil Kumar Inkulu:** data curation, interpretation. **M.V.A. Raju Bahubalendruni:** Interpretation, Editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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