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Augmented Reality and Indoor Positioning in Context of Smart Industry: A Review

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Abstract
Presently, digitalization is causing continuous transformation of industrial processes. However, it does pose challenges like spatially contextualizing data from industrial processes. There are various methods for calculating and delivering real-time location data. Indoor positioning systems (IPS) are one such method, used to locate objects and people within buildings. They have the potential to improve digital industrial processes, but they are currently underutilized. In addition, augmented reality (AR) is a critical technology in today's digital industrial transformation. This article aims to investigate the use of IPS and AR in manufacturing, the methodologies and technologies employed, the issues and limitations encountered, and identify future research opportunities. This study concludes that, while there have been many studies on IPS and navigation AR, there has been a dearth of research efforts in combining the two. Furthermore, because controlled environments may not expose users to the practical issues they may face, more research in a real-world manufacturing environment is required to produce more reliable and sustainable results.

Keywords
Industrial Augmented Reality, Indoor Positioning Systems, Smart Manufacturing, Smart Factory.

Introduction

Novel market requirements and emerging technologies are driving the shift to a "smart industry" (Ghobakhloo & Iranmanesh, 2021). In recent years, industries, especially process industries, have made sustainability and efficiency gains (Bai et al., 2020). Smart Industry requires constant data streams from networked operations and production systems to learn and adapt (Shi et al., 2020). Conventional digitization technologies use sensors, models, simulations, and automated process control. Particularly in the manufacturing sector (Zhou, 2013). Digital transformation of production, called "Industry 4.0" or "smart production", is reconfiguring modern manufacturing. Integrating intelligent machine tools into flexible production systems and developing new software for simulating, monitoring, and controlling production processes will require major industry changes Florescu & Barabas, 2020).

Digitalization of production changes how products are designed, manufactured, managed, and serviced. This affects factory operations, processes, energy base, and supply chain management (Ezell, 2018). Traceability and visibility are key to improving shop-floor performance because they aid in control, planning, and scheduling (Samir et al., 2019). A big challenge in industrial digitalization is spatially contextualizing information relevant to industrial processes like production or manufacturing so it can be analyzed and assessed in its real spatial context. In industrial manufacturing, the operational attributes of production machinery and product parameters must be assessed in a real-time and spatial context to take appropriate measures.

Several key technologies are supporting the digital transformation of manufacturing, and industrial augmented reality (IAR) is emerging as a way to enable Industry 4.0 or Factory 4.0 concepts (Masood & Egger, 2019a). Augmented reality (AR) adds virtual components to or replaces some aspects of reality, while IAR uses AR to support industrial processes (Van Krevelen & Poelman, 2010). Mixed real-

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ity (MR) is a step beyond AR and combines virtual and physical reality systems. MR allows users to interact with physical and virtual worlds. While (AR) improves a user's sense of reality, MR can blur reality's boundaries (Azuma, 1997).

AR superimposes computer-generated graphics on the real world, and spatial digitalization tracks device location (Furht, 2006). Location sensors and AR can create interactive manufacturing apps. Position tracking can increase production efficiency with accurate data (Brewer et al., 1999). Location-based AR can improve 3D visualization and provide contextual information. AR integration hasn't reached factories. Despite its benefits, manufacturing rarely uses augmented reality (Masood & Egger, 2019d). IPS and AR improve 3D visualization, provide context, and create a natural interface. IPS finds objects and people in buildings. Augmented reality and indoor positioning can enhance manufacturing. AR-based indoor positioning is rare in manufacturing (Park et al., 2020).

Previous research has identified general requirements for industrial AR solutions (Quandt et al., 2018) and indoor positioning systems (Carrasco et al., 2018b). An AR and IP solution must meet all requirements in both domains. Current solutions and ongoing research seem to have gaps. An exploratory review of the literature shows that most research has been applied, tested, and evaluated in a laboratory, not a factory. Research topics included maintenance and assembly. There has been little research on spatially enabled augmented reality applications in Smart Manufacturing.

This study reviews the application areas of indoor positioning systems for AR systems in manufacturing, the techniques and technical means used, the problems addressed, and research opportunities in this direction. The authors try to determine if there is a gap between actual requirements and available solutions and then identify research directions to bridge these gaps. The authors conducted a Systematic Literature Review (SLR) to accomplish the goal. SLR ensures the study's reusability, scalability, and objectivity (dos Santos et al., 2013). This approach is especially relevant given AR and IP's rapid growth. For this SLR, a step-by-step approach is used. The selected articles were reviewed to identify a) AR and IPS application areas in manufacturing, b) technical means used, and c) problem areas addressed. Each study's limitations and opportunities were reviewed. Based on the above, research gaps for AR and/or IP-enabled AR solutions in Smart Manufacturing were evaluated by analyzing specific requirements and available solutions. Finally, future research directions are discussed to help bridge the gaps.

Related previous works

Recent surveys and review articles focus on Industrial AR trends, challenges, and future scope. Table 1 lists some of the studies reviewed for this article. This section highlights previous surveys' contributions and under-researched areas. In a study, the authors reviewed state-of-the-art AR assembly systems before exploring a wide range of assembly applications (Wang et al., 2016a). This review states that one of the most important tasks in AR-supported assembly is to create a real-time tracking system for industrial scenarios, which challenge most existing techniques. The authors suggest advanced tracking methods, special registration approaches, and effective calibration methods to eliminate accuracy and latency. But this article focuses only on assembly system applications. Also, a study reviewed Augmented Reality Smart Glasses (ARSG) in a Smart factory and suggested an evaluation process (Syberfeldt et al., 2017a). The authors conclude Smart Glasses are not ready for industrial use. The work provides a broad product review, but positioning or tracking is only mentioned under sensors and controls comparison parameters. Another study focuses on mobile augmented reality (MAR) application fields, user interfaces, overall experience metrics, system components, object tracking and registration, network connectivity, data management, system performance, and sustainability issues (Chatzopoulos et al., 2017). Tracking and registration for MAR applications and device network connectivity are important, say the authors. Sensor-based and vision-based tracking are described. This article reviews MAR in general, not particularly industrial applications.

AR/VR is welcomed in manufacturing, and these solutions have been tested in real-world industrial settings, according to another review (Damiani et al., 2018). Tracking, positioning, and registration are key technologies for improving A/V reality in industrial systems. Fernández del Amo et al. (2018) review AR-related maintenance knowledge transfer. This article identifies geographic location data as important for context-awareness and tracking as a challenge for 'automatic' authoring in maintenance applications. However, this review only covers maintenance applications (Fernández del Amo et al., 2018).

Zhou et al. review smart manufacturing visualization technologies in the same year (Zhou et al., 2019). This article presents a detailed review of industrial data visualization, but it pays little attention to 3D visualizations that require tracking and positioning. Fraga-Lamas et al. (2018) describe IAR fundamen-

Table 1
Related previous works

S. no‘	Reference	Review topic
1	Wang et al., 2016b	An overview of AR-based assembly systems published between 1990 and 2015.
2	Syberfeldt et al., 2017b	Describes how to evaluate AR Smart Glasses, including what parameters to consider and their recommended minimum values.
3	Chatzopoulos et al., 2017	Basics of Mobile Augmented Reality (MAR), application fields, and examples are presented.
4	Damiani et al., 2018	Investigation of the present state of AR and VR, as well as how both could be used in industrial systems.
5	Fernández del Amo et al., 2018	AR maintenance applications based on their technological readiness are categorized and the potential of AR for user knowledge capture is revealed.
6	Zhou et al., 2019	A literature review on smart manufacturing visualization technologies
7	Fraga-Lamas et al., 2018	Description of the fundamentals of IAR followed by a thorough analysis of the most recent IAR systems for industrial and shipbuilding applications.
8	Masood & Egger, 2019b	The state of the art, current challenges, and forthcoming directions of manufacturing-related AR research.
9	Bottani & Vignali, 2019a	A review of the scientific literature on the use of AR technology in the industry.
10	de Souza Cardoso et al., 2020a	The applicability and utility of AR in real-world industrial processes.
11	Rokhsaritalemi et al., 2020	Review of the extensive research towards developing a robust system for Mixed Reality (MR) applications.
12	Gattullo et al., 2020	A classification system for visual assets based on the content exhibited, how it delivers the information, and the purpose for which it is utilized.
13	Morar et al., 2020	Computer vision-based indoor localization field is thoroughly discussed, including application areas, commercial solutions, existing benchmarks, and additional reviews.
14	Siegele et al., 2020	Review of non-vision-based indoor localization technologies and usability evaluation for augmented reality applications.

tals and analyze recent IAR systems for industrial and shipbuilding applications. IAR software development has many options, but IAR hardware is lacking for Industry 4.0 shipyard deployment. While this paper emphasizes accurate, rapid, and robust registration and tracking for developing AR approaches, the scope is limited to shipbuilding (Fraga-Lamas et al., 2018).

Another study presents the state of manufacturing-related AR research, current challenges, and future directions (Masood & Egger, 2019b). This review shows that the context of AR research is expanding, especially in addressing implementation challenges. In the same year, the research highlighted AR's potential in many industrial processes, including maintenance assembly, remote assistance, training/learning, facility management or inspection, and product design (Bottani & Vignali, 2019b). The authors acknowledge that tracking technologies are vital for locating users in industrial settings, but this topic is barely covered in the evaluated publications. Both articles recognize tracking as an essential component of IAR, but don't analyze spatial positioning for AR applications.

A recent study suggested AR research trends for developers and researchers and as a reference point for businesses (de Souza Cardoso et al., 2020a). Another study, "A Review on Mixed Reality: Current Trends, Challenges, and Prospects" (Rokhsaritalemi et al., 2020), reviewed research on developing a robust system for Mixed Reality (MR) applications. This study reviews MR development phases and models with simulation tools, systems, architectural types, and practical challenges for MR users. In contrast, another study highlights localization methods that provide orientation information, as this is becoming more important in indoor localization applications (Morar et al., 2020).

Another review examines the use of Extended Reality (XR) in industrial training. XR includes AR, VR, MR, and everything in between. The article discusses XR's use in maintenance training and assembly. They also discussed XR's use in other vocational fields and the manufacturing industry (Doolani et al., 2020). Existing restrictions on building and deploying XR apps are also discussed. Even though most previous surveys recognize tracking technology as an essential part of IAR, none have combined Industrial AR and Indoor Positioning Systems. Prior reviews downplayed the need for tracking technology to detect a user's location in an industrial setting. The reviews of industrial data visualization paid little attention to 3D, spatial visualizations, which are important for tracking and positioning.With this context established by prior related research, the following research questions for this review paper were formulated:

RQ1. What are the primary applications of AR and IP in the context of industrial processes?

As stated in the previous section, augmented reality for industrial processes can be used in design, assembly, maintenance, and training. Our study also integrates indoor positioning and AR. Through the first question's results, the authors aim to determine which AR and IP application areas have been tested and evaluated in the manufacturing industry, as well as where there is future potential.

RQ2. What are the different available techniques of Indoor Positioning for AR applications?

This question classifies IAR applications by their spatial needs and identifies indoor positioning techniques. The technical tools used and issue areas addressed are reviewed. In this section, IAR applications are categorized by their indoor positioning and navigation strategies.

RQ3. What are the advantages of incorporating IP and AR into manufacturing processes?

Concerning the previously identified application areas and respective techniques from the two previous questions, the results of this question should highlight the benefits of implementing IP and AR in manufacturing processes.

RQ4. What are the present impediments to the manufacturing sector's adoption of IP for IAR?

This question examines IP and AR application adoption in the manufacturing industry. This section considers industrial implementation issues in an organizational and user-centric context, along with technological limits, to gauge the technology's maturity. The authors plan to identify future research opportunities to eliminate barriers after identifying them.

Materials and methods

Exploratory research was conducted before finalizing the study design. Previous works related to the concerned field (mentioned in the previous section) were studied in depth. A protocol for the research was structured after screening the titles and abstracts of the associated articles found. The databases to be screened as well as the key concepts for query were part of the search strategy. The articles found were chosen using inclusion and exclusion criteria. The authors extracted data from the resulting full texts.

Selection process

Flow chart illustrating the articles selection process as per the PRISMA-P guidelines as shown in Figure 1.

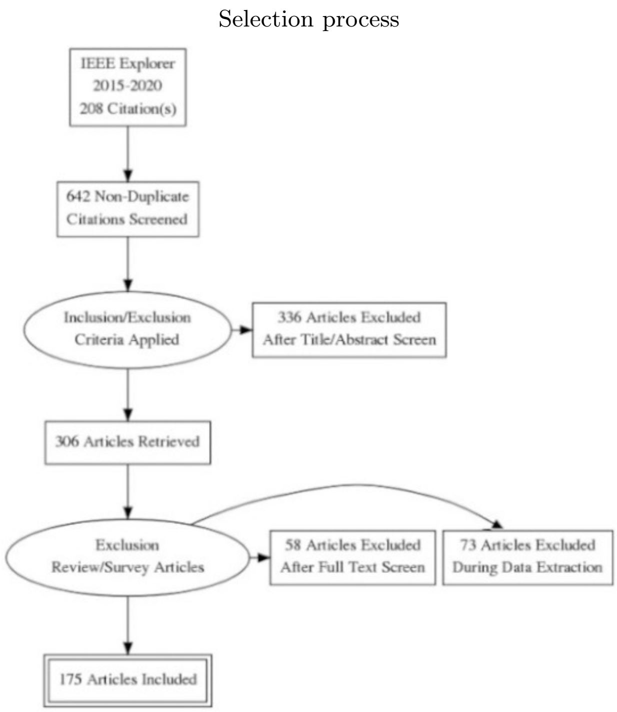

Fig. 1. Articles selection process

Search strategy

The review was carried out using the following electronic databases: IEEE Explorer, Science Direct, SCOPUS, Springer Link, and ACM. The research refers to the Preferred reporting item for systematic reviews and meta-analyses: The PRISMA statement (Moher et al., 2009). 14 different search strings were used for search queries on each of the above databases as shown in Table 2.

Table 2
List of search strings

1	"Industrial Augmented Reality" AND "Positioning" AND "Manufacturing"
2	"Industrial Augmented Reality" AND "Positioning" AND "Production"
3	"Industrial Augmented Reality" AND "Positioning" AND "Assembly"
4	"Industrial Augmented Reality" AND "Positioning" AND "Shop floor"
5	"Industrial Augmented Reality" AND "Manufacturing" AND "Tracking"
6	"Industrial Augmented Reality" AND "Production" AND "Tracking"
7	"Industrial Augmented Reality" AND "Assembly" AND "Tracking"
8	"Industrial Augmented Reality" AND Positioning" AND "Training"
9	"Mixed Reality" AND "Manufacturing" AND "Tracking"
10	"Industrial Augmented Reality" AND "Maintenance" AND "Positioning"
11	"Augmented Reality" AND "Positioning" AND "Manufacturing"
12	"Augmented Reality" AND "Navigation" AND "Manufacturing"
13	"Augmented Reality" AND ("Positioning" OR "Tracking" OR "Navigation") AND Manufacturing
14	"Spatial Augmented Reality" AND "Manufacturing"

Inclusion criteria

Both journal articles and conference papers were included. Included are articles discussing new or established applications or frameworks for AR methods, as well as pertinent information: application areas of AR and IP in a manufacturing environment, the technical means used, and exact problem areas addressed. Additionally, articles using Mixed Reality and IP were included. Articles in English referring to the concerned topic were included. The date range selected for including the articles was 2015–2021.

Exclusion criteria

All articles with virtual reality systems applications were discarded. Similarly, articles that did not comply with the precise concept of augmented reality as defined in the introduction section were omitted. Moreover, articles that did not mention the technical means and clear methodology were discarded. Patents and publications not defined as articles were discarded, as well.

Phenomenon of interest

Based on the research questions formulated earlier in this study, the following phenomena of interest were identified from the selected articles:

Application areas of IAR and IP in the manufacturing sector.

- Spatial requirements for these applications.
- Available techniques for implementation of IAR and AP in the industrial domain.
- Performance benefits of these IAR-IP applications.
- Impediments in the adoption of IP for IAR in the manufacturing sector.
- Each article was mapped in a tabular form populating fields based on the above phenomena of interest to derive results for answering the research questions.

RQ1 – Primary applications classified into: Maintenance, Assembly, Design, Training, and Repair.

RQ2 – Techniques for IP: Wireless technologies such as GSM, WLAN, Bluetooth, Infrared, UWB, and RFID Techniques for AR tracking: Marker-based & Markerless Spatial functions like 2D/3D spatial data, Components localization information, Navigation guidance.

RQ3 – Indicated Benefits classified as: Safety, Performance improvement, design improvement, Error reduction, improved communication, better training, faster execution, and others.

RQ4 – Cited challenges and impediments.

Results

Augmented reality (AR) is a major Industry 4.0 enabling technology (Davies, 2015). It's key to smart production (Uva et al., 2018a). AR-based design, AR-assisted maintenance systems, AR-based CNC simulation, and AR in assembly design and operations planning are areas where AR is more effective than other technologies (Nee & Ong, 2013). Industrial AR allows workers to overlay digital information on their physical working environment, reducing cognitive strain and resolving divided attention concerns (Masood & Egger, 2019c). AR can be utilized in assembly, as an online guidance system for operators, or in training. Other applications include maintenance (Abramovici et al., 2017; Martinetti et al., 2017) and assembly (Gavish et al., 2015). The efficiency of maintenance procedures depends on providing precise information to the correct user at the right time. AR's visualization capabilities enhance this information-intensive activity for maintenance staff (Lee et al., 2008). AR is a precise and intriguing solution that supports cloud-based remote maintenance services (Mourtzis et al., 2017) AR can improve maintenance practices by providing machine status and step-by-step instructions. A recent study shows AR-based assembly systems to assist manual workers, using a head-mounted display and video camera (Liu & Wang, 2017). In another recent work, authors describe an automated system for remote support of assembly stations with workers using AR (Mourtzis et al., 2017). The application collects the workstation schedule and automatically generates assembly orders based on product specs and design information.

While current research shows that AR is important and widely acknowledged, it is also clear that its implementation for industrial purposes remains difficult. Many laboratory investigations show that AR-supported tasks are more efficient in terms of eliminated errors and reduced task times, however, this efficiency depends on the activity's nature and complexity (Bosch et al., 2017; Sanna et al., 2015). A previous study shows that hardware and software concerns, user acceptance, performance and concentration, integration and security challenges, position tracking dependability, cost issues, etc. are involved in implementing AR in the industrial process (Masood & Egger, 2019b). Most empirical research has been conducted in labs, therefore industrial situations may provide unique obstacles.

Despite AR's rapid evolution and expanding scope, its use cases and content remain problematic. Technical mismatch across AR devices is a major issue. Developing a full AR app on a smartphone is different. The latter situation has had several difficulties that make the complete experience not very user-friendly and rather repetitious as a result of its increased operation. Popular AR apps use bulky head-mounted displays (HMDs) with a limited depth of field and poor ergonomics (Van Krevelen & Poelman, 2010). Long-term use in industry is difficult. HMD alternatives include smartphones. Handheld gadgets, on the other hand, restrict the use of hands for other processes, making them unsuitable for manual tasks.

Augmented reality has progressed beyond traditional eyewear or hand-held displays by utilizing massive spatially aligned optical devices such as mirror beam combiners, transparent screens, or holograms, as well as video projectors. This is Spatial Augmented Reality (SAR). SAR displays overcome the technological and ergonomic limitations of traditional AR systems (Bimber & Raskar, 2005). SAR can address the above ergonomic problems and is relevant for a smart manufacturing environment because it does not require wearables or other head-mounted or hand-held devices (Mengoni et al., 2018). In recent years, SAR has been used in manufacturing operations, particularly in assembly and maintenance applications. Uva et al. (2018b) evaluates SAR's use in smart manufacturing. This study shows that SAR technology improves operator performance over paper manuals. An experiment on a motorcycle engine showed that SAR-based instructions increased operator performance compared to a paper handbook. Some of SAR's disadvantages are higher latency, surface-based distortions, limited projector FOV, etc. (Kruijff et al., 2010).

Several AR systems are being studied for industrial use. AR has great potential in manufacturing, including product design, maintenance, training, and assembly. As an answer to the first research question, the next section reviews each of these application areas and identifies the limits and opportunities of existing AR solutions.

RQ1. What are the application areas for AR and IPS in the context of the Smart Industry?

Only articles using AR and IPS in Smart Industry applications were evaluated for this question. Consequently, 120 papers were analyzed. Maintenance, assembly, repair, training, and design are major applications. Figure 2 shows that 53 studies, or 44%, were in assembly-related applications. AR technology is used for assembly and disassembly guiding and training, which involves superimposing text, images, and animations on the physical assembly world (Chen et al., 2015). Knowledge of the real world, such as object and operator positions and postures, is also essential for an efficient assembly process. Chen et al. (2015) proposed a method to display 3D assembly and disassembly guiding information on the appropriate screen region from a comfortable viewpoint. Asset tracking

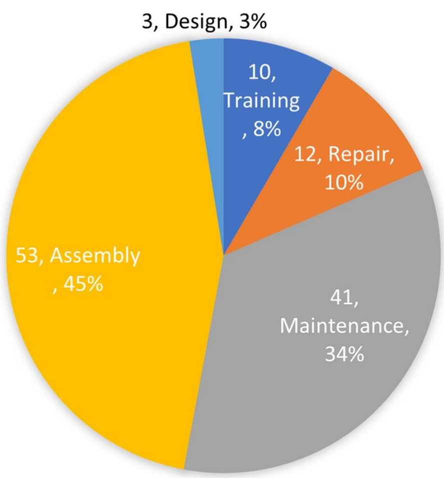

Fig. 2. Distribution of studies, application-wise

and AGV navigation are the most common industrial applications of IPS, but a recent trend is the creation of digital twins of manual manufacturing operations. Researchers developed a method for recording and transferring data from a manufacturing process to a 3D extended digital twin model in 2020 (Židek et al., 2020). A digital twin is a digital counterpart (virtual model) of a sensor, actuator, production unit, or plant. It includes 3D models organized into assemblies, data monitoring and synchronization, and offline simulation. RFID is used to precisely localize parts in production, and AR devices can be easily integrated into assisted assembly operations (Židek et al., 2020).

With 41 studies reviewed, industrial maintenance is another popular application area. Maintenance is vital to the manufacturing industry because it affects product quality, productivity, and production performance. As the Smart Factory evolves, manufacturers strive to improve maintenance. Several studies show that AR is one of the most impactful advances in this direction. Maintenance processes can account for a large portion of the lifetime cost of machinery, according to (Lamberti et al., 2014). The use of AR for preventive maintenance, predictive maintenance, remote maintenance, monitoring, and on-site to off-site communication between technicians and experts are popular research topics.

AR-supported remote maintenance can reduce maintenance time and cost by enabling cooperation between technicians and experts (Mourtzis et al., 2017). This study uses a HMD and a cloud-based system-oriented service for AR implementation, validated by a robotics SME case study. In another study, the authors proposed using AR for condition-based preventive maintenance, supported by a shop-floor monitoring service that calculates machine tools' remaining operating time between failures. AR-enabled predictive maintenance helps production and maintenance engineers monitor machine conditions and predict failures (Mourtzis et al., 2020). The integration of multiple digital formats and capabilities into a single functional process is another benefit of using AR in manufacturing and training. Hořejší (2015) proposes a system that uses a web camera to shoot a referential workplace with a worker. The assembly table has a distinctive marker. The software can move data based on a physical marker. The proposed software adds virtual 3D model instructions to webcam image data. The final image is on the worker's monitor. Repair and design are other applications, but little work has been done there. Augmented reality, which fuses 3D virtual objects with the real environment, has many benefits.

RQ2. What are the different available techniques of Indoor Positioning for AR applications?

This section classifies IAR applications by their spatial requirements and determines the different indoor positioning techniques for AR applications by evaluating the technical means used and the exact problem addressed in the reviewed articles. This section classifies IAR applications by location, tracking, and navigation.

GSM, WLAN, Bluetooth, Infrared, UWB, and RFID are used for indoor positioning. In 2020, a study looked at indoor localization for monitoring quality, safety, and efficiency. This article discusses data cleaning, preprocessing, and analysis for a real-time locating system project (Rácz-Szabó et al., 2020). Each indoor positioning system has its function and technical foundation (Syberfeldt et al., 2016b). None of these technologies are manufactured. As mentioned, AR superimposes computer-generated visuals on the user's real-world perspective to create a virtual-real-world hybrid. With AR, an IPS expands the user's view of localization information to complete tasks. The tracking technique, which identifies a person or object in an environment, determines the accuracy of AR apps. Real-time tracking and computation are needed to synchronize the physical and virtual worlds for an interactive and intuitive user experience.

AR tracking involves location information, so we considered AR Tracking, Indoor Tracking, and Indoor Positioning systems for AR in the manufacturing industry. Persons and things can be tracked indoors. Indoor positioning systems accomplish this. So, for this question, we looked at articles about AR tracking, indoor positioning (and/or navigation) systems, or indoor tracking in the context of manufacturing. So, 175 papers qualified for review in this category.

AR applications depend on the tracking mechanism, which locates a user or object in an environment (Arora & Parkar, 2017). Tracking calculates a camera's real-time location and orientation. AR tracking techniques are sensor-based and vision-based. Sensor-Based Tracking tracks the camera's position using sensors. Sensor-actuated tracking includes optical, magnetic, acoustic, and inertial. Vision-based tracking uses computer vision techniques to calculate the camera's viewpoint and the real-world object. Marker-based and marker-less vision-triggered tracking are subdivided (Rabbi & Ullah, 2013).

Table 3 summarizes recent indoor positioning articles in industrial systems, as well as application and problem areas.

In marker-based tracking, the marker to be recognized is previously stored in the database. Mark-

Table 3
List of search strings

S. no.	Reference	Indoor Positioning technology	Tracking technique	Information provided by the IPS	Application area
1	Carrasco et al., 2018a	Bluetooth, Wi-Fi	Proximity	Operator Location in the machine floor regarding machines	Manufacturing
2	Huang et al., 2017	RFID, UWB	Proximity & Triangulation	Location of various manufacturing objects like raw materials, tools, WIPs, equipment, workers	Manufacturing
3	Lu et al., 2017	RFID	Proximity & Triangulation	Location of automated guided vehicles (AGVs) used to transport raw materials, work-in-progress, and manufactured products	Manufacturing (Logistics)
4	Kumar et al., 2021	RFID, BLE	Proximity	Location of Raw materials and Finished products within the production management flow	Manufacturing
5	Chen et al., 2018	BLE, WLAN/WiFi	Proximity	Location of employees, machines, and other products in the factory	Manufacturing
6	Du et al., 2019	Visible light positioning (VLP)/ light-fidelity (Li-Fi)	Vision Analysis	Indoor position and tracking information of AGVs and other important assets in a smart factory	Manufacturing
7	Rátosi & Simon, 2018	VLC	Vision Analysis	Real-time estimation of item location and orientation in the manufacturing	Logistics
8	Awolusi et al., 2016	RFID	Triangulation	The distance and coordinated location of personnel at any instant	Industry (General)
9	Arkan & Van Landeghem, 2013	RFID	Triangulation	Location information of shop floor items and actions	Manufacturing
10	Guo et al., 2015	RFID	Proximity	Information on the physical location of workstations that include operators, machines, and a buffer area	Manufacturing
11	Lee et al., 2021	UWB	Triangulation	Location information of mobile equipment or workers, and statically located objects such as fixed facilities in a factory and also dangerous areas and obstacles	Manufacturing
12	Ghadge et al., 2020	RFID	Fingerprinting	Location and tracking information of metal parts in the factory	Manufacturing (Assembly)

ers can be images or image descriptions. A camera and AR software are used to detect virtual object markers. These markers have a real-time translation and rotation module (Martinez & Laukkanen, 2015). Mobile augmented reality uses marker-based tracking with a built-in camera. Sensor tracking is difficult in high-velocity environments. In such cases, markerless tracking loses track, so marker-based tracking must be used. Marker-based applications are widespread. This involves placing physical markers. AR markers triangulate an object's position. Natural marker or markerless systems don't need real-world objects to define virtual object positions.

In the articles reviewed, almost all used vision-based tracking. Vision-based tracking uses markers or none. In Figure 3, shows marker-based tracking has a 77% share. Marker-based tracking uses fidu-

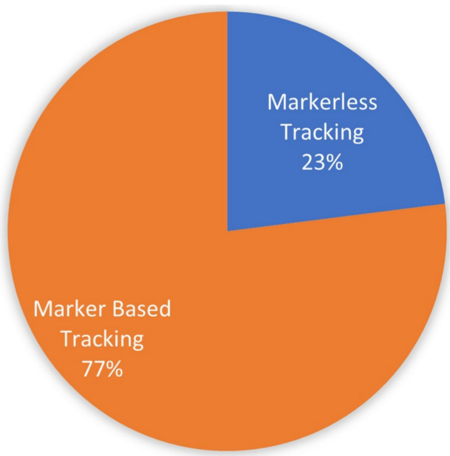

Fig. 3. Classification of studies based on tracking techniques

cial markers to extract, detect, and match camera features. Markers include QR codes, barcodes, and 2D images. Hahn et al. (2015) proposed an AR-based training system for PCB assembly using smart glass and custom software. Four markers show the user where to retrieve and install components.

Markerless AR retrieves content by scanning the environment without labels. Some studies used natural features as optical tracking markers due to their shape or color (Fiorentino et al., 2014; Koch et al., 2014). 23% of articles use marker-less tracking. Only 20 studies had indoor positioning and industrial AR. A study combined AR and RFID for warehouse item visualization (Ginters & Martin-Gutierrez, 2013). This study shows that combining AR and RFID can help identify warehouse components accurately. RFID scanners read component codes and render 3D models.

In another work, the authors offer SlidAR, a three-dimensional positioning approach for AR systems based on Simultaneous Localization and Mapping (SLAM). This allowed exact 3D positioning of virtual items in the real world, which Handheld AR (HoldAR) can't do. SlidAR positions virtual objects in mid-air without depth cues. HoldAR required more device movement and provided less feedback than SlidAR (Polvi et al., 2016a). The authors propose a self-actuated projector platform supported by UWB that enables precise, mobile, and user-friendly augmented reality projection applications (Elsharkawy et al., 2021). UWB wireless network provides moderate 3D tracking accuracy. There are several articles on Indoor positioning for the industry, but few on Indoor positioning and AR. Table 4 provides examples. Marker-based tracking systems are preferred

Table 4
Examples of AR and IPS applications in the industrial context

Reference	Ar Device	Ar Tracker	Indoor positioning system	Spatial function
Flatt et al., 2015	Context-aware AR-based device	Markerless	Camera-based localization system	2D position information i.e. XY coordinates along with identity, timestamp, location, user groups, mapped into the context mode
Kuo et al., 2013	Head Marker Tracking Augmented Reality (HMTAR) system	Marker-based	Infrared (IR) camera-based positioning	Positioning information of 3D virtual objects
Liu et al., 2017	AR visual interface		The AR solution is based on geomagnetic location and the transformation of space coordinates to the north.	Collects and stores information about POIs within the building and allows for the inclusion of any type of attachment, such as speech clips, text clips, or audio clips
Maly et al., 2016	Smart Glasses	Marker-based		Detect the positions of the robot and uses leading line visualization for the navigation to invisible points
Dosaya et al., 2020	Hand-Held Device	Markerless	Infrared (IR) Camera-based	Indoor Navigation guidance along with obstacle information
Mircheski & Rizov, 2018	Hand-Held Device / Head Mounted Display	Marker-based	RFID	Location information of components of interest and value for reuse in the disassembly process
Urbas et al., 2019	Head-mounted display	Markerless	Bluetooth	Enables tracking of the physical object based on its form. The 3D CAD model makes model-based tracking feasible.
Codina et al., 2019	Smart Glasses		Bluetooth	In the event of a rescue mission, the emergency elements in the three-dimensional building are mapped
Danielsson et al., 2018	AR Glasses	Marker-based	RFID	Assembly Operators are tracked
Zhang et al., 2011	Head-Mounted Display	Marker-based	RFID	Identification of the assembly activities and retrieving or generating 3D and 2D point location data

over marker-less alternatives due to their accuracy and ease of deployment. Position tracking is essential in AR, but a full-fledged IPS with a network of sensors adds many benefits, as shown in Table 4. Few studies integrate IPS and AR, so there's room for more research.

RQ3. How can the above-listed applications/solutions be categorized based on their performance and benefits?

In this research question, we review the performance of IAR and IP applications by cost, accuracy, robustness, usability, etc. This survey evaluated the articles' performance and benefits. Most studies don't state a direct or obvious smart industry benefit. An analysis of the suggested application and solutions deduced eight key benefits, and the articles were classified accordingly. As expected, IP and AR improved location positioning and communication in a smart factory. Other benefits include improved production process performance, improved accuracy in implementing tasks, faster execution of manufacturing subtasks, and better decision-making support through IP and IAR. Other benefits include better product design and fewer errors. Figure 4 shows stated and inferred survey benefits.

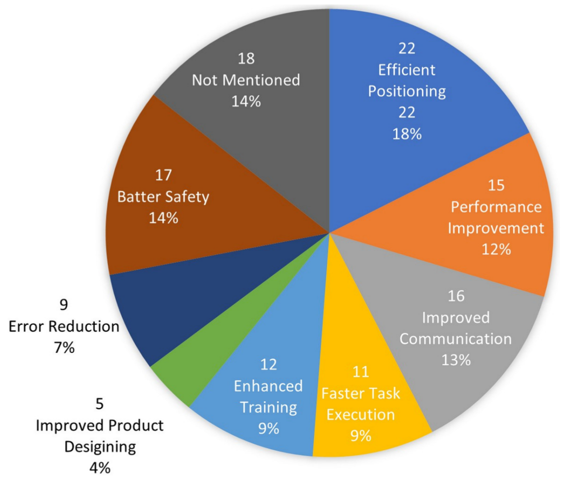

Fig. 4. Benefits of IP and AR in manufacturing processes

A 2017 study described a context-aware augmented reality application that helps maintenance workers communicate (Abramovici et al., 2017). Others suggested locating unseen objects and visualizing them with an HMD (Henderson & Feiner, 2011). Localization and visualization of the UWB transceiver in the HMD are accurate to 6 cm. When an industrial worker needs to handle visual mismatches or occlusions, manufacturing information can be provided intuitively and situationally based on estimated 3D spatial relation and depth perception, facilitating better communication (Kim et al., 2020). A 2019 study proposed image-based automated localization combined with AR to improve facility management visually (Baek et al., 2019). In another study, the authors suggest a cloud-based platform for condition-based maintenance operations, including a shop-floor monitoring service and an AR app (Mourtzis et al., 2017).

A study proposes SlidAR for SLAM-based HAR systems. SlidAR offered more subjective input, was faster, and required less device movement than a traditional device-centric method (Polvi et al., 2016b). Others propose a SAR-based design assessment approach that gives designers and users a flexible and intuitive evaluating environment (Park et al., 2015). Using AR and RFID together improves logistics item identification, while 3D visualization reduces errors (Ginters & Martin-Gutierrez, 2013). AR indoor navigation systems in a smart factory environment can improve navigation by reducing navigation errors and providing accurate positioning.

RQ4. What are the current impediments to the adoption of IP for IAR in the Smart Industry context?

50% of the studies indicate a challenge that may hinder the adoption of proposed applications or solutions. Indoor positioning, navigation, and AR in a factory environment are less developed and more complicated, according to studies. Large spaces with high ceilings, metal objects like machines, workbenches, etc., and moving objects cause a shifting environment in manufacturing (Syberfeldt et al., 2016a). Other researchers say noise and safety may affect AR voice command performance (Chalhoub & Ayer, 2018). Marker-less tracking methods like localization operators require a long setup time and are difficult to map. Also, these have virtual object instabilities and aren't mature enough to implement (Hou & Wang, 2013). According to studies, developing an AR application requires extensive knowledge and high implementation costs. When localization and indoor positioning systems are added, the complexity and costs increase many-fold (Kollatsch et al., 2014). Lack of information about new developments and the latest available solutions also hinders the adoption of these techniques (Syberfeldt et al., 2017b).

Discussion and conclusions

This paper adds indoor positioning to previous AR surveys. It examines how IP and AR are used in industry. This article examines current research directions and available solutions to analyze the gap. The study examines indoor positioning and industrial augmented reality application areas and technical means to identify limitations and research opportunities.

One major conclusion from this review is that, while there appear to be several studies on indoor positioning and navigation applications in the industrial environment, including separate studies of industrial AR, there is a lack of research efforts in solutions that combine these two for industrial applications. This is exemplified in some recent review articles dealing with IAR (de Souza Cardoso et al., 2020b; Jetter et al., 2018) and also separately dealing with IP in industrial applications (Carrasco et al., 2018a; Syberfeldt et al., 2016a). However, to our best knowledge, there exists no survey that deals with the integrated applications of AR and IP in industrial processes.

This review also shows that most research is applied, tested, and evaluated in a lab. This review found that 70% of IAR, IP, and combined studies were conducted in a laboratory. A 2019 paper on AR in manufacturing made similar observations (Bottani & Vignali, 2019a). More smart manufacturing research is needed to generate ecologically valid results, as lab settings rarely mimic real-world problems.

As shown in the results section, most studies focus on maintenance and assembly tasks; product design, repair, and training studies are rare. Industrial AR applications are difficult to implement because they are linked to complex processes. Adding a network of sensors for an indoor positioning system to an already complex process is perceived as more difficult than simply supporting the implementation (Masood & Egger, 2019b). IP and AR can improve inspection, logistics, and maintenance for operational versatility.

Developing IP and AR solutions for the industry presents technical challenges. Industrial indoor positioning has some barriers. Localization systems face many active and passive perturbations in industrial environments, especially shadowing and multipath effects from metallic objects (Syberfeldt et al., 2016a). Therefore, industrial localization technologies need further evaluation and validation. Adding indoor positioning systems to an industrial setup is expensive, adding hardware and infrastructure. Inaccurate indoor localization solutions for industrial AR also hinder implementation. Current solutions lack real-time, high-accuracy, cost-effective solutions that enable spatial contextualization of data.

AR implementation challenges are mostly operational. For AR to be widely adopted, the hardware must be industrial-grade (Masood & Egger, 2019b). Designed for gaming and consumer applications, the hardware lacked industrial robustness, reliability, and resilience. Studies show that most hardware platforms become uncomfortable over time (Egger & Masood, 2020). The software should be easily updated using standardized interfaces that integrate with industrial software. While progress has been made to overcome these obstacles on a larger industrial scale, more is needed before AR is widely implemented across all industries. Few solutions can be integrated directly into a smart factory. Therefore, cost-effective, reliable, robust, and usable solutions are needed to integrate spatially contextualized data into existing industrial processes.

Considering the above observations, we can conclude that while it may not be possible to propose or develop a universal IP and IAR solution that meets the diverse requirements of the manufacturing sector's numerous application areas, future research should be directed in certain specific directions. First, develop accurate and robust industrial positioning technology. Second, combined IP and AR/MR solutions need more research. Finally, more experiments should be conducted in factories rather than labs. Because manufacturing environments are more dynamic, evaluations must be done there. Only then can we anticipate the development of practical and implementable solutions.

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