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A review on the positive implications of augmented reality pick-by-vision in warehouse management systems

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Abstract: Augmented reality (AR) is a significant Fourth Industrial Revolution (IR4.0) technology that employs computer-generated display, sound, text, and effects to enhance the user's real-world experience via wearable devices. Order picking processes have had a substantial influence on overall operational efficiency in warehouse management systems (WMS). The conventional picking process is challenging to handle, which may result in deviations from the intended picking performance. Pick-by-vision, a new technological solution for order picking, is receiving growing attention and is now considered a significant WMS-supporting technology. This article explores the positive implications and prospects of utilizing AR pick-by-vision technology in the warehouse picking processes by performing a narrative review of the previous review articles. To demonstrate the focus of the main area, this study also presents the hierarchical classification structure of AR implementation in WMS and highlights the pick-by-vision method. The analysis provided important key findings by evaluating 23 articles (original articles and case studies) on AR pick-by-vision technology applications, which are significant to the prospective advantages of AR pick-by-vision deployment in warehouse operations. This study gathers knowledge and insight that can be used by both academics and professionals who are interested in optimizing this new advanced technology for future research.

1 Introduction

Since the emergence of the IR4.0, augmented reality (AR) has become one of the most prominent technologies in manufacturing and logistical operations. In a warehouse management system (WMS), AR can be implemented in fundamental processes including receiving, storing, inventory, order picking, shipping, and quality control to enhance warehousing operations, value-added services, and transportation. This technology improves the real-world experience of users by using computer-generated display, sound, text, and effects to help workers do regular tasks like order picking, assembly, and maintenance [1-3].

Order picking is the process of finding a specific item in storage based on a list, loading the items onto the right transportation, and delivering them to the place where the follow-up process will take place. Considered as the main and most labour-intensive task of warehouses, order picking is an important part of prompt assembly line production and is accomplished in many manufacturing industries [4]. Piece picking, cluster picking, zone picking, and wave picking are the four types of order picking [5-10].

Manual order picking is recognized as the most labor-intensive function in nearly every warehouse due to its simplicity and low cost. Manual order picking is instinctual for humans and is normally implemented on paper. However, the repetitive picking procedure, like reading and checking, consumes time and increases error rates owing to human error.

Enhancing order picking can be costly. For efficient picking process optimization, WMS administrators must match the suitable picking and automation techniques. Fortunately, the use of AR in WMS has lately been more noticeable in terms of enhancing order selection. This technology boosts WMS productivity by allowing for interactive 3D visualization, quick object tracking, inventory management, and automation [11].

To address the significance of AR in the order picking process to streamline the whole process of WMS, a summary of seven review articles is presented according to the ascending years of publication. The earliest review paper by De Koster et al. (2007) presented a detailed review of typical decision problems in the design and control of manual order picking processes. They focused on the optimal (internal) layout design, storage assignment methods, routing methods, order batching, and zoning. In their findings, picker-to-part systems (order pickers walk or drive along the aisles to pick items) have received less research attention compared to parts-to-picker systems [12]. Nonetheless, the study was still lacking in general design procedures and global optimization in order picking and neglected the effect of storage assignment.

A decade later, Haase & Beimborn (2017) reported the findings from a review study of 17 publications on pickers' acceptance of order picking support systems (OPSS). They discovered seven barriers to OPSS adoption, which comprise an overwhelmingly high subjective task load, loss of autonomy, loss of social interaction, negative influences from co-workers, high complexity in handling the technology, a lack of training, and a lack of maturity of the technology. OPSS provides significant value in terms of performance improvements. However, social effects among employees and different supporting situations must be considered when deploying such solutions and expecting warehouse workers to use OPSS. The limitation of this study is that OPSS adoption seems to be quite isolated so far. The suggestion is to integrate the technology with findings from related research fields in the future [13].

In 2020, Ilanković et al. performed a narrative review to describe the expected benefits and barriers of AR in warehouse operations. They also presented results based on the effect of information availability on order picking time. The study not only demonstrated the benefits of this picking method, but it also highlighted common issues that arise during order picking operations using AR technology, particularly one involving pickers' comfort [14]. However, this study has a limited review of selected studies, which do not comprehensively represent the exploration of recent knowledge about the usage of AR in the picking method and pickers' comfortability for pick-by-vision.

Egger & Masood (2020) conducted a thorough review to identify the current status, current challenges, and future directions of manufacturing related to AR and mixed reality (MR) research. They concentrated on shop floor management rather than picking processes, but the extracted items from the systematic literature review and citation network analysis are regarded as important views in AR in WMS perspective [15].

A recent study by Rejeb et al. (2021) provided a comprehensive review of the potential and challenges of AR smart glasses in logistics and supply chain management. They have selected 82 publications and performed a systematic literature review with four main clusters of potential benefits, including visualization, interaction, user convenience, and navigation [11]. The limitation that can be addressed in this study is that the keywords chosen appear to be insufficiently relevant to the publications chosen.

Another recent study by Winkelhaus et al. 2021 presented a conceptual design of order picking corresponding to IR4.0, which they called OP 4.0. Concurrently, they performed a systematic review to identify the various possible concepts in OP 4.0 and highlighted research opportunities within OP 4.0 at the intersection of social and technical aspects. Barriers found in this study include the research methodology, which relies on subjective decisions and does not apply a quantitative measurement. However, they had a strong opinion about defending the barriers. They believe that a qualitative, content-sensitive approach is necessary to extract the interactions of parameters instead of extracting the discussed topics solely [16].

The most current study by Rahman et al. (2022) provided a comprehensive review of AR technology in digital manufacturing applications. They investigated mixed reality image recognition, explored mixed reality object recognition, and demonstrated assembly and disassembly of 3D virtual models using Microsoft Hololens [17]. Their broad ideas in reviewing AR in a digital manufacturing context give valuable information on potential benefits and implications for future enhancement.

In conclusion, the gaps in existing review studies can be summarized into two key points. The first is that order picking has been the main area of focus and diligent attention in WMS, as it will enhance the entire operation's efficiency. The second is the need for keyword search clarity, as well as particularized documents in performing the review study. Overall, there is still a room for improvement in producing a comprehensive review that studies the state-of-the-art literature, discovers the missing potential benefits, investigates the challenges, and discusses the possible trends of order picking using AR in WMS. Therefore, to close the research gap, we pose the following research questions:

- What are the key findings concerning the prospective advantages of pick-by-vision in WMS?
- What positive implications have been overlooked in the literature?

To address these concerns, this paper will highlight recent works that have used AR in WMS, specifically pick-by-vision technology, which will be discussed in more detail in the next section.

The anticipated outcomes from this review are to give useful insights into the gist of the previous proposed methods, revealing potential, and future potential to provide a knowledge base overview of the technology for researchers and practitioners. The objectives of this paper are as follows:

1. To conduct a comprehensive review by identifying the positive implications of AR pick-by-vision implementation for WMS in related studies.
2. To discuss the key findings of prospective advantages and the missing ones based on the review findings.

The remainder of this paper is organized as follows. Section 2 presents a brief overview of the principle of pick-by-vision in warehouse picking operations. Section 3 outlines the methodology for performing the review study and presents the hierarchical classification structure of AR implementation in WMS. Next, we identify important key findings with positive implications by evaluating 23 articles on AR pick-by-vision technology applications in section 4. Then, we discuss the findings from the literature survey in section 5, which also reveals the missing key findings. Finally, the last section gives a conclusion and future work suggestions.

2 Overview of AR pick-by-vision

Pick-by-vision of AR is the visual aid of the order picking process using head-mounted displays or smart glasses. It is a paperless picking operation that requires processing orders with technologies that add visual layers to the reality perceived via them. Significantly, pick-by-vision has introduced an entirely new approach to managing warehouses with AR, allowing many organizations to simplify their accuracy and efficiency levels [18]. The process entails the preparation and processing of input data, the suggestion of an optimal picking route, the proposal of an AR navigation system, the selection of software and hardware resources, the incorporation of picking routes into process maps, and the actualization of the picking process [19].

Figure 1 depicts the interrelationship of the AR general system and the components of the AR pick-by-vision system. The fundamental parts of an AR system are the visualization technology, a sensor system, a tracking system, a processing unit, and the user interface [15]. On the left of Figure 1, represents the system diagram of components for AR pick-by-vision from the projection of visualization technology, which consists of the integrating module for the wearable device [20].

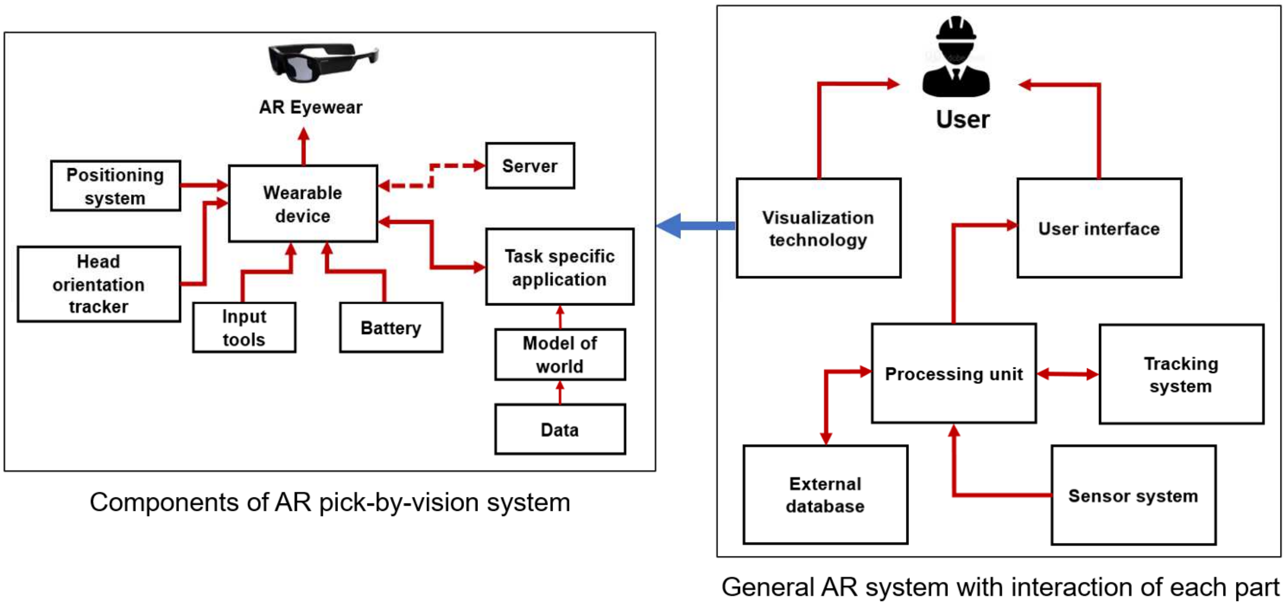

Figure 1 System diagram for general AR system and components of AR pick-by-vision system (based on [15,19])

To complete a pick-by-vision operation, a user or picker's operator must communicate by voice, sight, or gesture. Using virtual arrows, the AR device guides the user to the location of the things to be collected and subsequently displays the number of objects to be collected. The user can see virtual information about the items, such as their names, numbers, and locations. This operation will allow the user to quickly locate the products and accomplish the picking task. Once the operation was done, the AR system administrator would monitor operational management, order management, and commodity management of the warehouse.

Figure 2 shows the hierarchical classification structure of AR implementation in WMS and the highlighted pick-by-vision method to demonstrate the main area of this study. From the figure, there are five main types of AR technology in warehouse operations that encompass receiving, storing, order picking, shipping, and inventory [1,21].

In Figure 2, the picking orders can be categorized into seven types of picking techniques, including pick-by-paper, pick-by-light, pick-by-vision, pick-by-voice, pick-by-gesture, pick-by-scan, and cart-mounted display [7,22,23]. This study focuses on pick-by-vision where the terms for devices' names appear in the literature are head-mounted display (HMD) [24], head-worn display (HWD) [25], heads-up-display (HUD) [22,26], and smart glasses [22,27]. Among the most popular models in the market are Golden-i by Motorola, Hololens by Microsoft, HD4000 by Zebra, Vuzix Blade, and Oculus Quest 2, as shown at the bottom right of the figure. An example of a Hololens application in a warehouse is given in the bottom left [28].

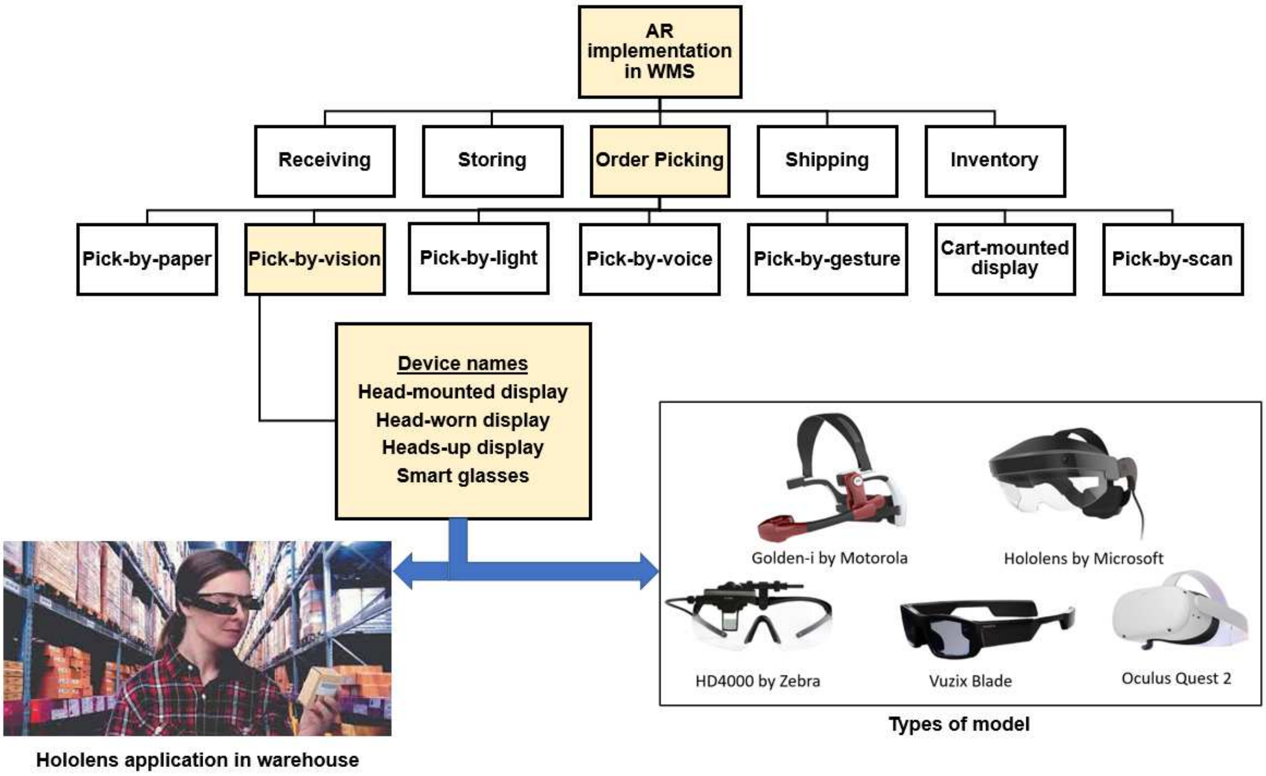

Figure 2 The hierarchical classification structure of AR implementation in WMS with highlighted pick-by-vision methods and application

3 Methodology

This section concentrates on reviewing the use of AR pick-by-vision technology in previous research in WMS. The snowballing technique (by tracking down references or citations in documents) and the use of scientific search engines (IEEE Xplore, Scopus, Science Direct, and Google Scholar) were used in the collection of related material from 2011-2021. Principal keywords in the list of the related works search include "augmented reality," "warehouse management system," "order picking," and "pick-by-vision". We retained 23 papers (17 research articles and 6 case studies) for full-text review after screening the titles and abstracts for relevance.

Based on the survey of previous review studies, seven positive implications which are associated with prospective advantages are discovered: productivity and operational efficiency; error reduction; hardware and software upgrades; distance reduction; worker motivation and training; security and operation planning; and ergonomic consideration. Table 1 represents the prospective advantages of AR pick-by-vision implementation in WMS from the selection of related studies.

In Table 1, the list is arranged in ascending order of the publication year. The author's name and year, target applications, and types of system or devices used are listed in columns 1-3. The next column lists the major findings of this study, which consists of seven implications items of prospective advantages for AR pick-by-vision implementation in WMS. These items are briefly discussed in the next sections.

4 Positive implications of AR pick-by-vision implementation in WMS

4.1 Productivity and operational efficiency

Order picking is one of the most costly operations since it might be challenging to get the appropriate products from the right section and in the right quantity. These challenges may be solved by using AR technology integrated with mobile devices to guide the worker through the picking process and lead them to the correct picking areas in the shortest possible duration of time. This eventually leads to higher productivity.

With automated capabilities that handle the processes, AR tools improve operational efficiency by enabling workers to work on many orders at once. The improved accuracy and effectiveness of warehouse operations lowers all additional expenses related to finding, picking orders, and tracking, saving a significant number of labour hours and corporate resources. Moreover, customers may anticipate their supplies to arrive substantially earlier and with less asset downtime as a consequence [1].

Table 1 Selected of relevant studies for AR pick-by-vision implementation in WMS

Authors, year	Target application	Proposed system	Prospective advantages of AR pick-by-vision implementation in WMS						
			Productivity & operational efficiency	Error reduction	Hardware/ software improvement	Distance reduction	Worker's motivation & training	Security & operation planning	Ergonomic consideration
Schwerdtfeger et al. 2011 [24]	Navigation and grasping aid.	HMD		✔					✔
Gharbi et al. 2014 [26]	Multi-agent system and optimization.	HUD & AR glasses	✔			✔			✔
Guo et al. 2014 [22]	Comparing the speed, accuracy, error types, workload, and preference.	HUD compared with CMD, pick-by-light, pick-by-paper	✔	✔					✔
Funk et al. 2015 [29]	Performing In-Situ projection for storage management and automatic detection	mobile camera-projector cart (OrderPickAR)	✔	✔		✔	✔		✔
Wu et al. 2015 [30]	Performing comparison to minimize error.	HUD compared with pick-by-light	✔	✔					
Diete et al. 2016 [31]	Sensor realibility in picking process.	AR glasses and wristband	✔		✔				✔
Sand et al. 2016 [32]	Supporting assembly workers in picking information and assembly data.	smARt.Assembly and AR glasses	✔	✔					✔
Hanson et al. 2017 [33]	Kit preparation for mixed-model assembly.	HMD compared with pick-by-paper	✔	✔					✔
Murauer et al. 2018 [34]	Evaluating scan mechanisms.	AR glasses and scan glove	✔	✔					✔
Puljiz et al. 2018 [23]	Implemetation in autonomous warehouse (navigation, assistance for picking and robot repair).	AR glasses and robot	✔					✔	✔
Bräuer & Mazarakis 2019 [35]	Investigating the effects of gamification in WMS.	AR glasses	✔				✔		✔
Elbert & Sarnow 2019 [36]	Cognitive ergonomics.	AR glasses and qualitative assessment							✔
Fang et al. 2019 [37]	Developing a scalable and long-term mobile AR solution.	AR glasses and marker-based global map	✔			✔			
Kim et al. 2019 [25]	Evaluating performance in simulated warehouse job.	HWD and User Interface design	✔	✔					✔
Krajcovic et al. 2019 [19]	Optimizing the movement of workers in the warehouse.	AR glasses	✔	✔		✔			
Matsumo et al. 2019 [38]	Investigating practical barriers.	HMD	✔			✔			
Nagda et al. 2019 [39]	Focusing on low-level machine-aided order picking.	HMD & web-based central (RASPICK)	✔						✔
Papcun et al. 2019 [40]	Possibilities of using AR and Humans-Robots Interaction.	AR glasses, AGV & Drone				✔		✔	
Fang & An 2020 [41]	Establishing adaptability and scalable wearable AR assistance system.	AR glasses and marker-based global map	✔	✔					✔
Plakas et al. 2020 [2]	Enhancing working environment and upgrading the work experience.	AR glasses & SMARTFLEX	✔				✔		
Plakas et al. 2020 [42]	Assessing the technical components and the overall viability	AR glasses & gamification module	✔				✔		✔
Colabella et al. 2021 [43]	Reviewing current case studies regarding the use of AR technology in supply chain operations.	HMD	✔	✔					✔
Tang & Liu 2021 [44]	Focusing on based interaction, voice-based interaction and gesture-based interaction.	AR glasses (Hololens 2)	✔				✔		

4.2 Error reduction

The conventional picking process is error-prone. AR implementation helps in guiding the worker through the warehouse to the desired item. Rework is eliminated by lowering the error rate. This enhances procedures by reducing turnaround time and increasing system accuracy. Additionally, automation completely automates item tracking while maintaining relevancy and accuracy based on real-time inventory data inputs, enhancing visibility and quality control of warehouse operations [1].

4.3 Hardware or software improvement

AR has a logical as well as a physical structure. The logical structure of the AR, which contains standards, rules, procedures, and protocols, describes its operation, whereas the physical structure comprises hardware and software [45]. The system complexity (like software applications), the weight of the devices, speeding up the processor's timing, and improving the picking system in recognising and monitoring activities (such as grasping and releasing of objects), are all aspects that can improve the hardware and software in AR pick-by-vision. Another element to consider is improving visual navigational information and vision quality on AR glasses [31].

4.4 Distance reduction

One of the major purposes of AR in the picking process is to navigate the workers around the warehouse so they may take the quickest path determined in the previous stage and to provide them with the necessary information to decrease picking errors. Additionally, reducing the amount of time to retrieve an item may be accomplished by presenting the precise location of the chosen collected items and improving the visual information by employing an efficient routing method. As a result, this will save time and improve the way the WMS works in the long run [19, 46].

4.5 Workers motivation and training

Aside from training new employees with less effort and saving time, warehouse managers may adopt AR to visually test proposed procedures, ensuring that companies are flexible and plan order placement with optimal space utilization. By familiarizing them with company processes, this will help in seamless onboarding and improve team cooperation. As a consequence, they may practice numerous times without disrupting or interfering with existing activities. Furthermore, workers may be supervised to raise their awareness and prevent mistakes in warehouse operations [2, 11].

4.6 Security and operation planning

For any organization to succeed, warehouse operations must be structured to achieve maximum efficiency. Standard warehouse operations require product inspection, allocation, assembling, packaging, and dispatching, as well as designing and testing the viability of a comprehensive warehousing strategy. By using AR technology, warehouse managers can now plan and test the WMS in an effective way. Besides being hands-free and safe for a human operator, AR also provides value-added services such as sharing insights and monitoring all activities to ensure precise service delivery. On top of that, the system may give safety feedback and information, as well as warn of impending danger [1].

4.7 Ergonomic consideration

The ergonomic design of AR technology is related to the perception of its ease of use. AR is considered to be durable, efficient, and easy to wear, which supports a hands-free interface compared to handheld scanners, which only allow one free hand to work. By employing this technology, virtual and real objects may be manipulated with both hands in the field of vision. Moreover, AR glasses are more practical and versatile than standard mobile devices and portable displays due to their features [11,15].

5 Result and discussion

Figure 3 represents the distribution of identified studies over the key findings, which were extracted from Table 1. The analysis from Figure 3 indicates that most research is giving more attention to productivity and operational efficiency, followed by ergonomic consideration and error reduction. About five to six studies focus on reducing distances and workers' motivation and training. Meanwhile, security and operation planning, and hardware or software improvement, receive very less attention from the researchers.

According to our review, the key findings of inventory optimization, new technology acceptance, demand forecasting, and external factor improvement in AR pick-by-vision have all been unexplored. Inventory optimization is the practise of having the right amount of inventory available to meet current and future demand. Achieving an ideal inventory level enables a company to not only fulfil demand projections but also reduce the expenses associated with common inventory issues such as backorders, overstocking, and stockouts. By enhancing stock workflows, AR may enhance the supply chain. Additionally, with this technology, workers may effectively scan multiple objects with a brief glance while the AR devices scan and record barcodes.

The acceptance of new technology indicates the success of implementation in terms of employing technology at various organizational levels as well as at the individual operator level [47]. Because it has the ability to relieve physical and psychological stress, technology acceptance has been generally acknowledged as an important driver for AR implementation [48,49]. External variables, on the other hand, are connected to improvements in certain scenarios, such as factory ambient illumination conditions, which may have a detrimental affect on AR pick-by-vision performance and usability. Readers may get an insight into how this aspect might assist in boosting labour productivity and optimizing workflows in warehouse operations by evaluating new technology acceptance and improving external factors.

Besides, we also suggested that future research should explore the integration between AR and artificial intelligence (AI) to overcome the model-mismatch paradigm by establishing a complete feedback loop between the user and the robot. This integration could provide a solid foundation for raising the efficiency of the robotic application as well as improving the human operator's situational awareness, safety, and acceptance of AI robots.

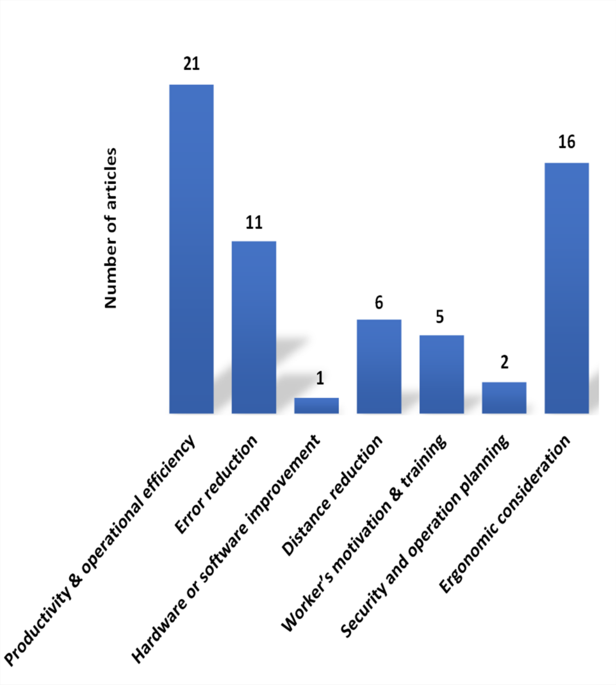

Figure 3 Distribution of identified studies over the key findings from Table 1

6 Conclusion

Over the last decade, the rate of advancement in AR pick-by-vision has been remarkable. In warehouse operations, the potential of AR pick-by-vision is undoubtedly immense, as it has the ability to transform ongoing operations and empower flexibility. For instance, AR pick-by-vision makes a substantial contribution to improving the overall efficiency of the warehouse operation. In fact, guided vision on mobile devices and AR smart glasses helps managers and employees optimize their workflows with a digital 3D warehouse guide.

This article dealt with review studies of AR pick-by-vision implementation in WMS to address the significance of AR in the order picking process. We found two gaps in the review studies, including the need for keyword search clarity as well as the need to review specific documents. Besides, a hierarchical classification structure of AR implementation in WMS was produced, which emphasizes the pick-by-vision method in order to demonstrate the focus of the main area of the study.

The main contributions of this study are based on a survey of the literature, which attempts to address the two research questions in the context of the positive implication of AR pick-by-vision. The analysis of 23 articles (original articles and case studies) on AR pick-by-vision technology applications contributed to key findings with positive implications that can be used by both academics and professionals, especially those interested in optimising this new advanced technology for future research. The findings of our study are one of the outcomes that could be valuable in initial efforts to add to the growing literature and theory of AR pick-by-vision technologies and their usefulness in WMS order picking operations. In addition, we also identify the key findings that have not been fully explored as well as the limitations that the researchers may need to overcome in order to improve their work.

In the future, we could suggest that upcoming research look at the limitations, challenges, and managerial implications of using AR pick-by-vision in WMS. Additionally, future research could also explore the integration between AR and artificial intelligence (AI) in order to develop a strong foundation for increasing the effectiveness of the robotic application and for enhancing the human operator's situational awareness, safety, and acceptance of AI robots.

To conclude, improving the picking process in a warehouse demands a continual effort on the part of system suppliers and researchers to discover and analyze the capabilities of every current AR technology. Above all, the best strategy involves concentrating on a particular methodology for the development of the AR pick-by-vision system and carrying out a case study to investigate the impacts, opportunities, and risks of the extended process of utilising AR pick-by-vision in warehouse operations in order to achieve an extensive result.

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