2022 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET) | 978-1-6654-6837-4/22/$31.00 ©2022 IEEE | DOI: 10.1109/IICAIET55139.2022.9936785

Pick-by-vision of Augmented Reality in Warehouse Picking Process Optimization – A Review

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***Abstract*—Augmented Reality (AR) is one of the most notable technologies in the Fourth Industrial Revolution (IR4.0), which uses the capabilities of computer-generated display, sound, text, and effects to improve the user's real-world experience through wearable equipment. Order picking operations in warehouse management systems (WMS) have a significant impact on overall operating efficiency. The conventional picking process is laborious to handle, which may result in deviations from predefined picking performance. Pick-by-vision, a new technology solution for order picking, is becoming increasingly popular and has been recognized as an essential technology supporting WMS nowadays. This article is a short review of AR pick-by-vision utilization to investigate the potential benefits and opportunities in optimizing warehouse picking operations. Besides presenting the basic concept of AR pick-by-vision, this study also produces a taxonomy layout of literature reviews for AR technology in WMS, to demonstrate the focus of the main area of the study. By reviewing 23 documents of AR pick-by-vision technology application, the analysis has produced important key findings, which are significant to the potential benefits of AR pick-by-vision implementation in optimizing the warehouse operation. The accumulation of knowledge and actionable insights in this study will benefit both academics and practitioners interested in this emerging smart technology for future research.**

Keywords— pick-by-vision, augmented reality, order picking, warehouse management system, potential benefits

I. Introduction

A. *Background of the Study*

The Fourth Industrial Revolution (IR4.0) marks a substantial technological revolution in warehouse management systems (WMS), which provides value to the whole operation and supply chain. In general, WMS is in charge of enforcing warehouse operations and keeping track of the details flowing in and out. WMS technology transformation entails improving the essential operations of receiving, storage, inventory, order picking, shipping, and quality control. Fig. 1 depicts the general warehouse workflow, which includes four key activities that must be optimised in terms of cost, time, space, and labor utilization [1]–[4].

B. *Order Picking in WMS*

Order picking is regarded as the most critical process among all warehouse operations, accounting for 55–65% of warehouse operations' expenses [5]–[8]. Order picking is the process of preparing an order that involves finding a certain item in storage according to a list, loading the items into the relevant carriage or transport vehicle, and delivering them to the specific place for the following processes. Additionally, it is considered the most important and labor-intensive activity in warehouses [9], [10]. Order picking is classified into four types: piece picking [11], cluster picking (also known as bulk or batch picking) [12]–[14], zone picking [15], and wave picking [16].

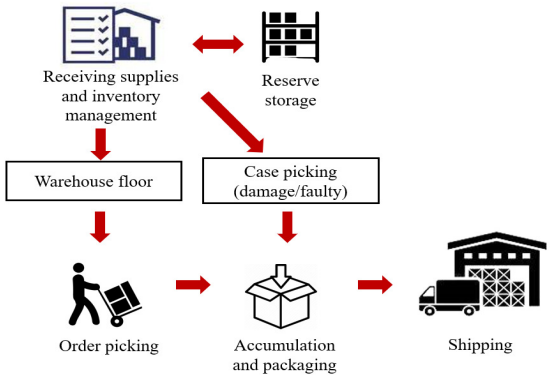

Fig. 1. General warehouse workflow

Conventionally, manual order picking, which normally uses paper, has always been instinctive for humans due to its simplicity, low cost, and relative flexibility in changing volumes of the picking process [8], [10], [17]. However, the repetitive picking process in reading and checking leads to significant time losses and higher error rates due to human error. This may result in deviations from predefined picking performance [18], [19].

Since order picking is the most expensive process in the warehouse, optimizing it can reduce operational costs and improve the overall WMS efficiency in terms of productivity, labor, overall processing times, and space usage [8]. A warehouse administrator must choose the appropriate picking and automation technology for optimal picking process optimization. Adopting augmented reality is one of the best options for that significant technology. In fact, AR implementation in WMS has lately been more notable in optimizing order picking because it offers interactive 3D visualization, fast object tracking, efficient inventory monitoring, and automation technology [20].

From summarizing the existing review studies by [5], [8], [20]–[22], the main area of focus that needs diligent attention in WMS to enhance the entire operation's efficiency is by researching current studies to identify the in-trend potential benefits and the unattended ones for improvement. Thus, the purpose of this paper is to review recent studies and analyse their findings in terms of potential benefits that could optimize order picking in WMS, specifically pick-by-vision technology.

The remainder of this paper is organized as follows. Section II presents a brief history of AR, the basic principle of pick-by-vision in warehouse picking operations, and the taxonomy layout of the literature review. This section also conducts a literature survey of the application area. Section III presents the results and discussion, which also reveal the mislaid potential benefits. Section IV stated the limitations and future work suggestions. Finally, the last section gives a summary of this study.

II. Pick-by-vision of AR in Picking Process

A. *A Brief History of Augmented Reality*

Augmented reality (AR) is a combination of real and virtual information that overlays digital information on top of the existing psychological reality. AR operates using a 3D environment and acts as an interactive display medium for human-object interactions in real-time. The first recorded appearance of AR was in 1961, when a cinematographer, Morton Heilig, designed a motorcycle simulator called Sensorama. The AR technology of Sensorama is a combination of visual, audio, and sonic sensations so that viewers are able to feel everything as if it were real [23].

AR gained more serious attention in the 1990s when it was used for military purposes. The U.S. Air Force's Armstrong Laboratory created the Virtual Fixtures system in 1992. It was the first AR system that worked and let users have immersive mixed reality experiences. Since then, AR has also been implemented in commercial industries such as education, communications, medicine, and entertainment [24]. In fact, the use of AR has extended to various industrial systems as technology progresses with the growth of the internet and smart technologies. Users are able to access information at any time and from any location, allowing for precise planning and high-quality execution of specified activities, which is crucial for offering better customer service.

Since the emergence of the IR4.0, AR has become one of the most prominent technologies in manufacturing and logistical operations. There are several categories in logistics where AR can be implemented: warehousing operations, transportation optimization, last-mile delivery, and enhanced value-added services. This technology enhances the user's real-world experience by using computer-generated display, sound, text, and effects to assist operators in routine tasks like assembly, order picking, and maintenance [1], [25], [26].

Fig. 2 shows the taxonomy layout of the literature review for AR technology in WMS. The highlighted block represents the focus of this study. Based on the figure, there are four main types of AR technology used in warehouse operations, which include receiving, storing, order picking, and shipping [1], [2].

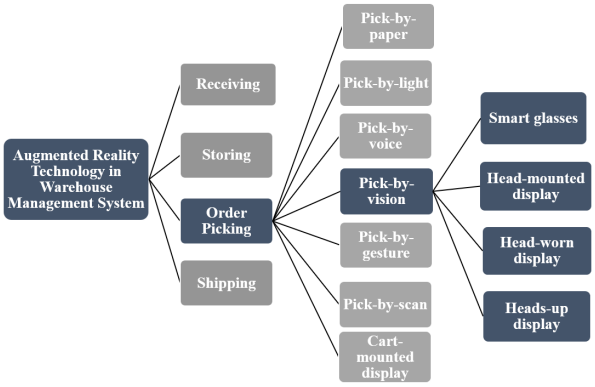

Fig. 2. Taxonomy layout of literature review for AR technology in WMS

This study focuses on picking orders, which can be classified into seven types of picking techniques: pick-by-paper, pick-by-light, pick-by-vision, pick-by-voice, pick-by-gesture, pick-by-scan, and cart-mounted display [13], [27], [28]. To narrow down the scope, this study selects pick-by-vision as the main subject. The pick-by-vision falls into four categories, consisting of head-mounted display (HMD) [29], head-worn display (HWD) [30], heads-up-display (HUD) [27], [31], and smart glasses [27], [32]. However, these terms might be used interchangeably. The next section will discuss the pick-by-vision in order picking in more detail.

B. *Basic Principle of AR Pick-by-vision*

Pick-by-vision is the visual support of the order picking process, employing head-mounted displays or smart glasses [33], [34]. It is an undocumented picking operation that involves processing orders with technologies that add visual elements to the reality seen through the device. The flowchart in Fig. 3 demonstrates the essential processes of AR implementation in order picking, which are applicable to any type of AR picking technique for WMS, including pick-by-vision. The process incorporates preparing and processing the input data, proposing the best picking route, providing an AR navigation system, selecting the software and hardware resources, transforming the picking routes into process maps in the AR software, and realizing the picking process [18].

A pick-by-vision task requires an operator to communicate through voice, gaze, or gesture. AR gadgets, such as smart glasses, use virtual arrows to guide the user to the item's pickup location before displaying the number of items that need to be picked up. The operator may view virtual information, such as the name, quantity, and location of the items, from the AR system [35].

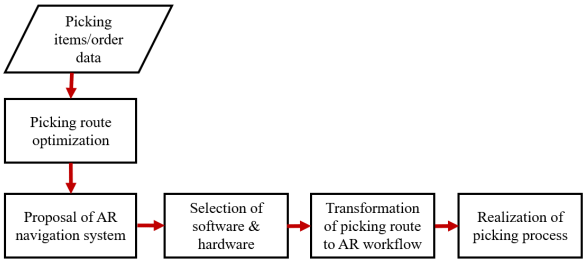

Fig. 3. Flow chart of AR implementation in order picking (based on [18])

Fig. 4 represents the system diagram of major components for AR pick-by-vision, which consists of the integrating module for the wearable device. The order will be assigned to the operator via the AR system terminal that is connected to the server. Accordingly, the terminal will calculate the optimal route through the arrow. This action will allow the operator to find the goods immediately and complete the picking task. Upon completing the process, the AR system administrator would monitor the operational management, order management, and commodity management.

III. Methodology – Review on Application Area

This section reviews various past research on order picking improvement in WMS using AR pick-by-vision technology. The collection of the related work was performed in the range of years 2011–2021, resorting to the scientific search engines IEEE Xplore, Scopus, Science Direct, Google Scholar and the snowballing technique (by tracking down references or citations in documents). The selection of related work contains primary keywords such as "augmented reality," "warehouse management system," "order picking," and "pick-by-vision".

Having screened the titles and abstracts for relevance, 23 articles were retained (17 research articles and 6 case studies) for full-text review, which is presented in Table I. The first to third columns displayed the authors, the year of publication (arranged in an ascending manner), and the study type. The next column of Table I shows the key findings, which consist of seven elements that describe the potential benefits of AR pick-by-vision implementation in WMS. The next subsection is a brief discussion of these elements.

A. Productivity Improvement and Operational Efficiency

Order picking is one of the costliest operations since selecting the appropriate item from the right section and in the correct amount is a challenging task. AR technology integrated with mobile devices is able to resolve these issues by helping the operator through the picking process, directing them to the right pick locations in the shortest period of time. This eventually leads to increased productivity.

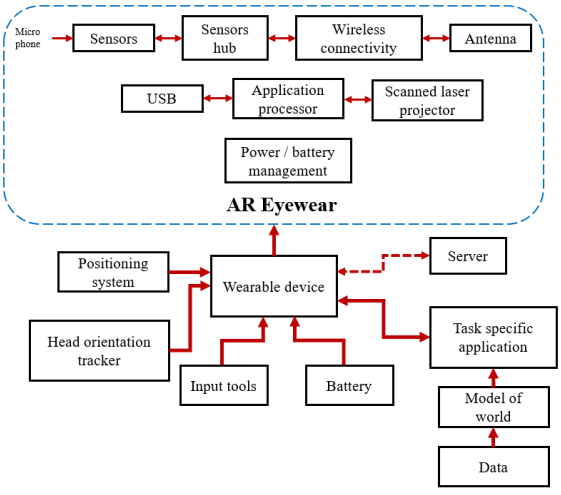

Fig. 4. System diagram of major components for AR pick-by-vision

In terms of operational efficiency, AR tools make it easier to work on numerous orders at once, with automated features that handle most of the processes. The increased accuracy and efficiency of warehouse operations reduces all of the extra costs associated with locating, order picking, and tracking, saving multiple labor hours and company resources. As a result, customers can expect their supplies to come much faster and with less downtime for their assets [1].

B. Error Reduction

Warehouse picking is always prone to errors. With AR, the operator is guided along the warehouse to reach the right item. By decreasing the error rate, re-work is not necessary. This improves processes by decreasing time and improving system accuracy. Furthermore, AR technology totally automates item tracking while maintaining accuracy and relevancy through real-time inventory data streams, improving visibility and quality control of warehouse operations [1].

C. Employee Training, Monitoring, and Motivation

Aside from training new staff with less effort and saving time, warehouse administrators may employ AR to visually test proposed procedures, ensuring that companies remain flexible and plan order placement with optimal space utilization. This will aid in seamless onboarding and improve team collaboration by familiarizing them with corporate processes. As a result, this interactive type of training allows them to practise countless times without disrupting or interfering with ongoing procedures. Besides, employees can also be monitored in order to increase their awareness and prevent errors in warehouse operations [25], [36].

D. Warehouse Planning and Security

For any company to succeed, warehouse operations must be structured to attain optimum efficiency. Normal warehouse operations need product inspection, allocation, assembly, packing, dispatching, planning strategy, and verification of feasibility. By using AR technology, warehouse administrators can now plan and test these operations. AR also provides value-added services such as sharing insights and monitoring all activities to ensure precise service delivery. At the same time, AR can be safer for a human operator because it is hands-free. The system may give safety feedback and information, as well as warn of impending danger [1].

E. Users' Comfortability and Satisfaction

The benefits of AR technology are associated with the perception of its simplicity and convenience. They are viewed as powerful, efficient, and comfortable to wear, which complements their hands-free interface. By using AR pick-by-vision, virtual and real objects can be manipulated using both hands, which are displayed in the line of sight. AR eyewears are more convenient and adaptable than conventional mobile devices and portable displays due to their functionality and features [36].

F. Hardware or Software Improvement

Similar to every system architecture, AR has both a logical and a physical structure. The AR's functioning is described by its logical structure, which includes standards, codes, procedures, and protocols, whereas the physical struc-

TABLE I. IDENTIFIED STUDIES OF AR PICK-BY-VISION IN WMS WITH FINDINGS OF POTENTIAL BENEFITS

Authors [reference]	Year	Study type	Findings of potential benefits						
			Productivity improvement & operational efficiency	*Error reduction*	*Hardware/ software improvement*	*Strategic location & distance reduction*	*Employee training, monitoring & motivation*	*Warehouse planning & security*	*Users' comfortability and satisfaction*
Schwerdtfeger et al. [29]	2011	CS		/					/
Gharbi et al. [31]	2014	RA	/			/			/
Guo et al. [27]	2014	CS	/	/					/
Funk et al. [37]	2015	RA	/	/		/	/		/
Wu et al. [38]	2015	CS	/	/					
Diete et al. [39]	2016	RA	/		/				/
Sand et al. [40]	2016	RA	/	/					/
Hanson et al. [41]	2017	RA	/	/					/
Murauer et al. [42]	2018	CS	/	/					/
Puljiz et al. [28]	2018	RA	/					/	/
Bräuer & Mazarakis [43]	2019	RA	/				/		/
Elbert & Sarnow [44]	2019	RA							/
Fang et al. [19]	2019	RA	/			/			
Kim et al. [30]	2019	CS	/	/					/
Krajcovic et al. [18]	2019	RA	/	/		/			
Matsumo et al. [45]	2019	RA	/			/			
Nagda et al. [46]	2019	RA	/						/
Papcun et al. [47]	2019	RA				/		/	
Fang & An [10]	2020	RA	/	/					/
Plakas et al. [48]	2020	RA	/				/		
Plakas et al. [25]	2020	CS	/				/		/
Colabella et al. [49]	2021	CS	/	/					/
Tang & Liu [35]	2021	RA	/				/		

CS = Case study
RA = Research article

ture is comprised of the hardware and software [50]. Aspects that can improve the hardware and software in AR pick-by-vision are the system complexity like software applications, weight of the devices, speeding up the processor's timing, and enhancing the picking system in recognizing and monitoring activities like grasping and releasing of objects. Another consideration is to improve the visual navigational information and vision clarity on AR glasses [39].

G. *Strategic Location and Distance Reduction*

Besides reducing picking errors, one of the main functions of AR in the picking process is to guide the operators through the warehouse to follow the fastest route [18]. Furthermore, by improving the visual information with an efficient routing technique and displaying the actual position of the selected object to be gathered, the item retrieval time may be reduced [48]. Thus, this will eventually save time and improve the overall WMS operation performance.

IV. RESULT AND DISCUSSION

The outcome from Fig. 5 (which was extracted from Table I) demonstrates that 87% of the studies are able to prove productivity improvement and operational efficiency. About 70% of studies are capable of improving users' comfortability and satisfaction; 48% reduce errors; 26% emphasize strategic location and distance; and 22% improve employee training, monitoring, and motivation. Meanwhile, 9% analyze warehouse planning and security, and only 4% of studies demonstrate hardware or software improvement.

The analysis of the review leads to the conclusion that the current trend of potential benefit among researchers is more focus on productivity improvement and operational efficiency, and user comfortability and satisfaction. On the other hand, warehouse planning and security, and hardware or software improvement, lead to very little attention by the researchers. Although pick-by-vision has been extensively researched for WMS, its applications in demand forecasting remain unexplored.

This study also discovered that the potential benefit of AR pick-by-vision in inventory optimization, new technology acceptance, and external factor improvement has all been unattended. Inventory optimization is the process of having the appropriate quantity of inventory available to fulfil demand, both now and in the future. Reaching an optimal inventory level allows companies to not only meet

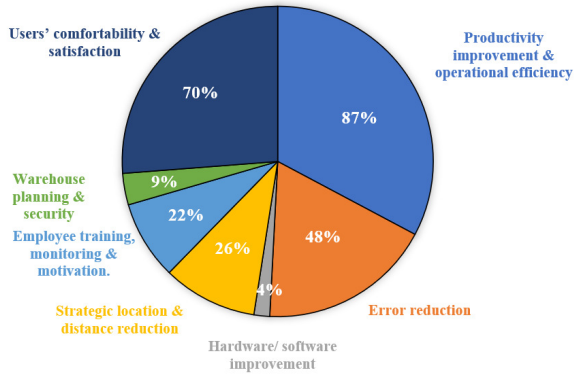

Fig. 5. Distribution of identitified studies over potential benefit elements

demand forecasts but also lower the costs of frequent inventory concerns like backorders, overstocking, and stockouts. AR can optimize the supply chain by improving stock workflows. With this technology, operators may effectively glare at multiple items while the AR devices scan and record barcodes.

New technology acceptance describes the success of implementation in terms of using a technology at different organizational levels and at the individual operator level [51]. Technology acceptance has been widely recognized as a key factor for AR adoption because it has the potential to reduce physical and psychological stress [52], [53]. The external factors, on the other hand, are related to improvement in certain situations, such as factory ambient lighting conditions, that might have a negative impact on AR pick-by-vision performance and usability. By considering new technology acceptance and external factors' improvement, readers could have insight into how this element could help to increase work efficiency and optimize workflows in warehouse operations.

V. Limitations and Future Suggestions

Several limitations exist in this study. First is the absence of the term "ergonomic" in the list of benefit elements. Ergonomic terms are associated with the reliability and comfortability of the design, or with convenience in the workplace. This includes health and safety issues, visual fatigue, headaches, dizziness, device heaviness, discomfort, and the factor of distractions [36]. However, this term is implicitly associated with users' comfortability and satisfaction, and might be related to warehouse planning and security as mentioned in Table I.

The second is that the study did not give much attention to technical improvement. There are technical challenges that can be improved in the AR pick-by-vision system, which are related to hardware and software issues, such as insufficient computational power, short battery lifetime [54], vision clarity [29], and algorithm complexity [55].

The third limitation is that the study has very few reviews of case studies. A comprehensive comparison with existing solutions and well-documented case studies will help in assessing the impact of AR integration even better.

Therefore, besides overcoming the limitations of this study, future research should explore hybrid technologies such as hybrid RFID, hybrid automated guided vehicles (AGV), or hybrid sensors, and additionally pay more attention to global positioning system (GPS) signal strength to advance the existing AR pick-by-vision system. The integration of AR and artificial intelligence (AI) should also be considered since it has the potential to overcome the model-mismatch scenario by providing a complete feedback loop between the user and the robot.

VI. Summary

The picking process, with the support of AR, contributes significantly to optimizing the overall efficiency of the warehousing operation. This article dealt with review studies of AR pick-by-vision in optimizing the WMS. The findings of this study are one of the initial efforts to contribute to the growing literature and theory of AR pick-by-vision technologies and their usefulness in the order picking operation of WMS.

To conclude, optimizing the picking process in a warehouse requires continuous effort from the system providers and researchers to explore and analyse the possibilities of every up-to-date AR technology. System providers and researchers must continue to collaborate closely with end users to identify appropriate scenarios of study cases for the initially developed system to demonstrate real benefits over less expensive options. Most importantly, the best practise is to just focus on a specific methodology and perform a case study to investigate the impacts, opportunities, and risks of the long-term process of AR pick-by-vision in warehouse operations for a comprehensive outcome.

Acknowledgment

This work is supported by Tenaga National Berhad (TNB) Seeding Fund No. U-TS-RD-21-24 and UNITEN R&D Sdn. Bhd.

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