AR for warehouses: a marker-based augmented system for navigation and inventory management

LEONARDO VEZZANI[1], FEDERICA MORO[2], FRANCESCO STRADA[1]
FEDERICO PIERI[2], ANDREA BOTTINO[1]

[1]Department of Control and Computer Engineering
Politecnico di Torino
Turin
ITALY

[2]Cluster Reply
Reply
Turin
ITALY

Abstract: This study investigates using augmented reality (AR) to assist warehouse operators. By employing head-mounted displays (HMDs), the AR application overlays relevant navigational information and inventory data directly onto the user's field of vision, enabling a hands-free interaction system that creates a more efficient workflow. Incorporating a marker-based AR architecture offers precise item localization and navigation support, addressing common issues such as time-consuming item checks and potential navigational errors while moving in the warehouse. Through the assistance of these processes, the AR system aims to enhance the efficiency and precision of warehouse operations. This research highlights the advantages and potential challenges of implementing AR solutions in industrial settings, emphasizing the need for innovative warehouse logistics and management approaches.

Key-Words: - AR, Warehouse, QR code, Wayfinding, Warehouse assistance, Head-Mounted Display

Received: March 9, 2024. Revised: July 11, 2024. Accepted: August 7, 2024. Published: September 25, 2024.

1 Introduction

In recent years, augmented reality (AR) has been increasingly used in industry to assist workers. Many companies are integrating AR tools to support their employees by providing quick access to information and guidance, improving the efficiency and accuracy of their tasks' execution. AR's versatility allows for application in areas such as assembly, maintenance, quality control, and workplace management, [1], [2]. One of the particular areas where AR has a significant impact is warehouse operations, where AR can significantly improve the performance of warehouse workers, especially when head-mounted displays (HMDs) are used by overlaying relevant data directly into the workers' field of vision. This hands-free access to data, navigation support and assistance in performing individual tasks ultimately increases productivity and effectiveness.

Managing warehouse shelves is a crucial yet time-consuming task for workers, involving careful inspection of box contents, quantity verification, and adherence to order forms to avoid errors and unnecessary waste, [3]. Typically, employees have to physically inspect shelves, take notes, and update computer systems, which can lead to delays and mistakes, [3]. To solve these problems, some papers have suggested using AR to streamline the workflow to reduce the distance between the worker and the computer, thus enabling a faster and more accurate process, [4], [5]. In these cases, AR is often implemented using markers to identify each item or shelf location, [4], creating a precise but complex system for tracking each item in the inventory. This approach requires extensive maintenance and may introduce potential error sources. Although these solutions are effective, they can be overly complex to implement and maintain in an active warehouse environment.

Another notable application of AR in warehouses, particularly in industrial environments, is assisting with wayfinding and navigation. AR can align navigation information with the physical world and effectively show the way to users, [6]. To achieve accurate navigation in indoor spaces where traditional geolocation technologies (e.g. GPS) are not precise enough to work properly, researchers have explored marker-based and markerless navigation aids.

Markerless AR navigation has been investigated for navigation in complex buildings, [7], in multi-floor environments, [8], and in challenging indoor conditions such as dark environment, [9]. However, markerless applications can be demanding and may not run smoothly on HMDs or require additional hardware to be carried by the user, [10]. For this reason, HMD applications often rely on markers for precise user positioning. Marker-based navigation approaches rely on QR codes or other markers that are added to the environment, [8], [11]. Some studies use natural markers such as signs, emergency exits, and furniture to aid navigation, [12], [13], [14]. Hybrid solutions combining markers and natural features have been developed to provide coherent navigation instructions aligned with the physical world, [15], [16], [17], although they are not yet optimized for HMDs.

Despite extensive research on AR navigation, few studies have focused on the use of HMDs to provide AR navigation instructions, [6], [10], [18]. The study by [10], tested four different solutions to support route planning and showed that AR navigation cues that blend into the physical environment are more effective in wayfinding than non-AR cues. However, they also require more computational power.

This paper introduces an innovative AR application designed for warehouse logistics, maintenance, and management, creating an AR tool that assists the operators in warehouse inspection and navigation. This application allows warehouse operators to work in the warehouse and interact with a computer while keeping their hands free at all times. Additionally, the AR app leverages the operator's positional information to provide wayfinding assistance through the warehouse and facilitate the interaction with the inventory data of the nearby shelving, preventing potential errors. Utilizing see-through AR HMDs and a minimal number of markers, this application provides logistics and navigation support for warehouse workers in a comprehensive solution, facilitating seamless transitions between different tasks.

2 Methods & Results

The complexity of warehouse environments and the high volume of goods handled daily require innovative solutions to increase productivity and reduce errors. This is where augmented reality can play a transformative role. The work described in this paper has emerged from Cluster Reply's[1] Augmented Warehouse initiative, which aims to develop innovative solutions to improve warehouse management and assist warehouse workers. The initiative focuses on addressing specific challenges, such as optimizing shelf management, improving navigation and reducing errors in inventory management by implementing a tool specifically designed for warehouse operators. The following methods were used to design and implement the AR applications developed as part of this initiative.

2.1 Requirements

The requirements for this project are divided into design requirements and functional requirements. The design requirements for this project are to develop a tool that is: (i) usable on HMDs; (ii) easy to maintain and update; and (iii) adaptable to different customer needs.

The functional requirements for this project address two main tasks that workers could most benefit from AR assistance: Storage Inspection and Wayfinding. By assisting operators in these tasks, we can enable quicker task execution, reduce fatigue, and prevent errors, thus significantly enhancing warehouse productivity and worker satisfaction.

Storage inspection requires the operator to access several pieces of information simultaneously to be most effective: location, stock, and pending tasks on a particular item are essential to optimize the worker's effort. For instance, the operator should be able to find a specific shelf among many in the warehouse quickly, know its content, including details such as size and quantity of items, and access its status in the system, such as how many items are on the shelf are to be shipped and where they are headed. Additionally, the worker is required to manage the shelf's content and update related data in real-time. Our application aims to create a tool that allows the user to accomplish all these tasks while staying in front of the shelving and accessing its information via a simple and easy-to-use AR interface to improve workflow efficiency.

Due to its size, navigating within a large warehouse can be another significant source of errors and waste of time, and even an expert operator may need help finding the desired location. For this reason, we decided to implement a wayfinding assistance tool for the workers. For effective wayfinding assistance, AR should provide clear instructions for workers to reach their destina-

[1] www.reply.com/cluster-reply/

tion within the warehouse, [8], [10]. By displaying a line through different corridors and areas, the operator is guided to their destination. This wayfinding tool optimizes movement time from one point to another and prevents mistakes, enhancing overall productivity.

2.2 Implementation

To implement an AR application that offers these features, we utilized the Unity Engine[2] version 2021.3.23f and the SDK MRTK 3.0 to build the application for various HMDs. Specifically, to prevent motion sickness in workers, we decided to rely on a see-through HMD (i.e., Hololens 2), as many users during preliminary tests felt pass-through HMDs uneasy in terms of offered field of view, distortion and latency.

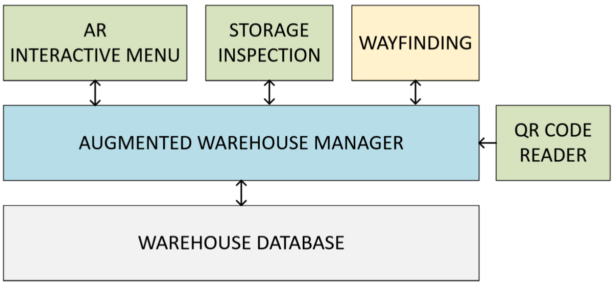

Figure 1: The application architecture

We adopted a marker-based solution to optimize tracking accuracy in large spaces, leveraging 2d barcodes (i.e., QR codes) to track the user's position within the warehouse. The application architecture is illustrated in Fig. 1. Each shelving in the warehouse is equipped with a single QR code that identifies it in the augmented application. The application employs a digital twin of the warehouse containing all the geometrical information of the building, as well as the position and identification values for each QR code placed in the warehouse. This digital twin is accessible by the Augmented Warehouse Manager (AWM) that creates a database of QR codes with their respective positions. When HMD's cameras detect a QR code in the physical space via the QR code manager, its value is compared with those in the AWM's database. If the value corresponds to one of the QR in the database, the positional data of the physical QR are used to align the digital twin's 3d mesh to the physical world by matching the virtual QR code's position with the once read by the QR code manager. Consequently, the application utilizes the ID and spatial data of the QR codes to determine the user's position in the warehouse and provide them with the relevant information.

Moreover, as long as the worker is within read-distance of a QR code, the system is capable of providing accurate navigational assistance to the user thanks to its wayfinding module, which will calculate the shortest path to the selected destination and guide the user to it using a virtual line drawn on the ground (Fig. 3). All the interactions between the user and the AWM rely on the AR interactive menu. This menu allows users to interact with the inventory item, input data, and manage the navigation.

As each QR code is attached to a shelving location, the AWM can use the value of each QR code to access the warehouse database and retrieve information about the stored items on the nearby shelves. This information is then passed to the storage inspection module, which displays it to the operator and enables them to interact with it using an intuitive menu. The menu is composed of two main parts: a selection grid is overlaid to the shelving, enabling the user to choose the desired location by pointing to the grid cell they desire. After the selection, an inspection menu pops up near the worker, facilitating content inspection and updates (Fig. 2). This includes the ability to view detailed information about the selected item, update its status, or perform any necessary actions related to the item. With this implementation, fewer QR codes are needed compared to other solutions found in the literature. For example, [4] marked each location on the shelves with a unique QR code that opens to more potential failure points and heavier computational requirements. Additionally, relying on a smaller set of QR codes results in a simpler and more streamlined maintenance process.

Figure 2: The storage inspection tool: in the foreground, the interaction menu; in the background, the shelves' selection grid

[2] www.unity.com

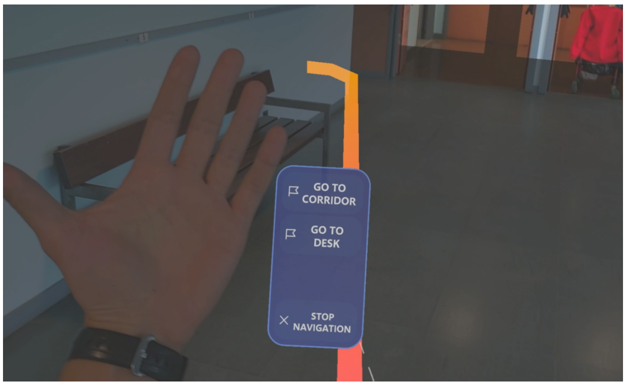

Figure 3: The wayfinding tool: in the foreground, the destination selection menu; in the background, the line indicating the way to the operator

2.3 Results

The implemented application meets all highlighted requirements. The reduced number of QR codes allows the application to run smoothly on a Hololens 2 with a stable frame rate. Using only one QR code per shelving reduces the computational demand for the tracking service and prevents potential conflicts between different QR codes while the user is near a shelving. Additionally, thanks to the ease of installation and removal of QR codes, the system can be quickly updated without requiring significant modifications to the application since it is only necessary to provide the AWM with the position of the added QR code and access to the corresponding information in the warehouse database. Furthermore, since the application relies on a digital twin that only requires geometrical information about the building and the QR code's position, it facilitates seamless replication of any physical warehouse updates in the digital twin, making the application adaptable to various client needs. Finally, since the application depends on the user's position to provide them with shelving data, it implicitly prevents the operator from selecting and operating on the wrong shelving, eliminating the possibility of selection errors during inspection.

3 Limitations & Future Works

Early testing of this application highlighted the need for warehouse operators to move across different floors while working. When using AR HMDs, the onboard sensors may have difficulty tracking the user's position when changing floors, especially when entering an elevator. Additionally, users may face issues viewing AR visual cues while using stairs or ramps. To tackle this challenge, we have chosen to pause the navigation when users encounter these architectural features and instead provide them with textual directions to move to the correct floor. Once they reach the new floor, users are required to scan the QR code conveniently placed in their arrival area to resume navigation. Moreover, another limitation that we encountered was that the user interface overlaid on the shelving should adapt to each shelving dimension as they may vary widely even within the same warehouse. To address this, future versions should implement a dynamic interface that adjusts its dimensions based on the shelving data provided by the AWM. This means that by updating the shelving data in the database, the corresponding interface should automatically adapt its dimensions accordingly.

This application constitutes the basis for new features that can assist warehouse operations in many tasks. One of the most interesting features is the possibility of assisting workers while conducting quality assurance tests or executing order picking. Providing operators with comprehensive instructions and verifying their correct execution could reduce the time needed for such operations and improve performance.

4 Conclusions

Our paper introduces an augmented reality (AR) application specifically created to improve the productivity and efficiency of warehouse workers. The application utilizes a marker-based approach, resulting in a lightweight and portable system that allows workers to manage inventory while navigating the warehouse seamlessly. Furthermore, the system offers real-time wayfinding assistance to optimize operations. This tool will enable workers to be more effective and optimize their work, resulting in more efficient time management and potentially fewer errors. Our marker-based solution is highly adaptable to various customer needs and warehouse environments. In the future, we plan to enhance the application by incorporating additional functionalities, such as control process features, to optimize warehouse operations further.

5 Acknowledgments

This publication is part of the project PNRR-NGEU which has received funding from the MUR-DM352/2022.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The concept and design of the study were jointly developed and approved by all authors. The application was designed and developed by LV and FM. LV, FS, and AB prepared the first draft of the manuscript. All authors commented on previous versions of the manuscript and read and approved the final manuscript.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

Conflicts of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.