An Augmented Reality Assisted Order Picking System using IoT

Mayank Kumar Nagda, Sankalp Sinha, Poovammal E

Abstract*: *It is widely recognized that order picking is the most complicated and time-consuming task in warehouse operations and often termed as the major bottleneck in warehouse workflow. Over the years the process of order picking has been extensively studied and many methods have been proposed to deal with its challenges. However, most of these solutions involve complex and expensive components with elaborate setups. In this paper, we propose RASPICK a modular, robust and cost-efficient order picking system that is scalable and can be used in warehouses of all sizes. The proposed system aims to reduce the cognitive load on the picker by providing crucial and relevant information for each item on the picking list. For a baseline, the proposed system is also compared to manual paper-based picking and shows significant improvements in average trip-time for lists of different sizes. The system combines the convenience of Augmented Reality with the power of the Internet of things to facilitate central control and management of pickers and attempts to address the low-level order picking bottlenecks.

Index Terms*: *Augmented Reality, Internet of Things, Order Picking, Warehouse Management

I. INTRODUCTION

Warehouses are an integral part of a company's supply chain and are central to logistics management in general. Warehouses in a crude sense can be described as temporary holding facilities. They are used to store raw materials and goods-under-process at the point of manufacturing, or finished goods close to the point of consumption. Warehouses in general, are much more than just simple storage facilities, they play a critical role in supporting a variety of value-added services like consolidation, reverse logistics, just-in-time manufacturing, customer support, etc. [2]. Warehouses are neither cheap to set up nor operate, a study by [3] showed that warehouse operations take up 20% of the total logistics budget of a company. Therefore, it is of utmost importance that companies streamline the daily workflow of a warehouse, to improve its efficiency and productivity. Thus, allowing companies to cut operational costs and improve their bottom lines.

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Generally, each warehouse has a central management system that is responsible for both managing the workflow of the warehouse and keeping track of the goods flowing in and out of the warehouse. The warehouse workflow can be divided into 4 major tasks as seen in Figure 1.

Firstly, the supplies to the warehouse which are either raw materials or finished products are sorted and cataloged into the inventory management system of the warehouse. The inventory management system then decides to store some goods in the long-term reserve storage, while the others go directly to replenish the stock on the warehouse floor also called the picking area. As customer orders roll in, the individual items that make up the order are retrieved from the picking area to fulfill that order, this is also referred to as order picking. All the orders are then accumulated and packaged for shipping to their respective destinations.

In the entire warehouse workflow as seen in Figure 1 most of the tasks like supply intake, accumulation, packaging, and shipping are highly optimized. Order picking, on the other hand, has been recognized as the single most costly and labor-intensive task in the entire warehouse workflow. It accounts for up to 60% of the net warehouse operating expense [6]. Optimizing order picking is of great importance as underperformance in order picking can lead to the reduced overall efficiency and increased operational costs of the warehouse. To optimize the task of order picking we first need to look at the different methods used for order picking. Based on the level of automation employed order picking methods can be broadly divided into 3 major categories namely, manual order picking, machine-aided order picking, and automated order picking.

Studies have extensively compared the different methods of order picking and found that machine aided order picking methods like voice assistance, cart-mounted displays, head-up displays, etc. outperform manual order picking methods on metrics like picking speed, picking accuracy and ease of use [6]. Fully automated order picking has increased accuracy, efficiency, and productivity as they remove the human element from the task of order picking. Although this comes at a cost as these systems require a large initial investment to set up and are also not suitable for warehouses in which the pattern or type of work may change from time to time. Moreover, they also need highly trained technicians to maintain and monitor these systems.

Our paper focuses on low-level machine-aided order picking. In low-level order picking the picker (human) goes to the correct aisle and locates the correct bin from which the item in its required quantity is picked.

Most of the warehouses around the world employ either manual or machine-aided low-level order picking methods. In this work, we propose RASPICK a modular and robust augmented reality (AR) assisted head-mounted device based on the raspberry pi platform powered by a web-based central management system.

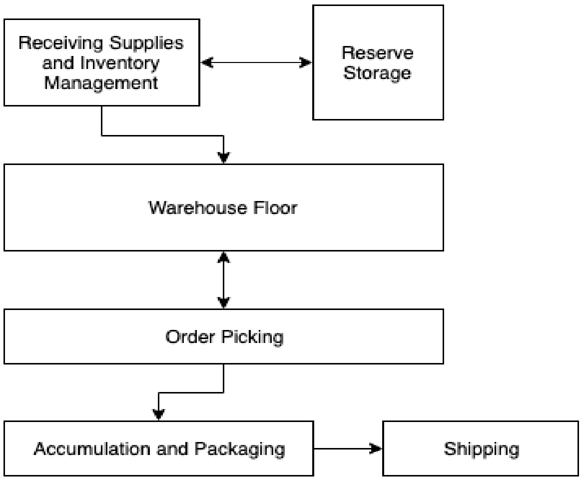

Figure 1 Warehouse Workflow

II. RELATED WORK

As order picking is a major bottleneck in warehouse workflow, it has received a lot of academic focus over the years. The process of order picking can be broken down into two independent but sequential subtasks. The first involves locating the correct aisle and bin on the warehouse floor by the picker. The second involves picking the right quantity of items from the bin.

Most of the early research focused on optimizing the first subtask. The performance of the first subtask depends on many factors such as storage policies, routing policies, layout and design of the warehouse, batching and zoning of orders, etc. Hence subsequently these areas have received a lot of focus. Storage policies as indicative from the name deal with the assignment of storage locations for items on the warehouse floor [8]. Mostly the storage policies are volume-based, this means that items that are picked most frequently are placed closer to the accumulation or drop off zone than others. A comparison of different volume-based storage policies like diagonal, within-aisle, across-aisle and perimeter are presented in [8] and show that within aisle is the best storage policy regardless of picker travel restrictions, picker list sizes, and demand skewness. Further, they demonstrate that perimeter and across aisle storage policies perform the worst regardless of routing policy or picker list size.

In [10] the authors showed that for certain arrangements of aisles in a warehouse the problem of locating the correct aisle and bin efficiently can be reduced to a solvable instance of the traveling salesman problem. This means that a careful arrangement of aisles and items can reduce the time taken to complete the first subtask of order picking. While other researchers focused on the routing policies that can be applied to make the first subtask more efficient. Routing policies refer to the path the picker takes to complete a single picking run efficiently, especially the order in which the items are picked. Many routing policies like the largest gap strategy, full traversal, midpoint, return, composite and optimal have been exhaustively compared in [8]. They show that the best routing policy for a picking run depends on many factors like picking list size, the skewness of demand and storage policies. Further demonstrating that optimal routing policies often produced routes that were counter-intuitive and confusing, thus are difficult to implement in a real-world warehouse. They argue that a trade-off exists between the raw efficiency of routing policies and their real-world ease of implementation.

Zoning and batching are both order management methods that are used to reduce the route travel time and average picking time for each order. In a large warehouse, having a single picking area leads to longer route travel time [2]. This is largely because, parts of the order could be located far from each other on the warehouse floor. This problem can be elegantly addressed with the use of zoning, in which the picking area is divided into zones and each zone is assigned a picker [2]. A customer order is broken into sub-orders for each zone, which is then fulfilled by the picker assigned to that zone. The different zoning techniques are exhaustively outlined and compared in [15], their study also goes on to show that zoning can significantly improve the efficiency of pickers. Another factor that directly effects picking efficiency is the size of the order.

When an order is large it is efficient to assign a single picker for the entire order. For orders with smaller sizes, it is far more efficient to bundle these small orders together and then assign them to a picker, this process is referred to as batching. Although as naive as batching may sound optimizing it is an NP-hard problem. Due to this nature of the problem, most of the optimization methods for batching are heuristic in nature. There are two types of heuristics methods namely, seed and time-saving. A comparative study of the two methods is presented in [1]. In the study, the two methods were compared on standard metrics like the ease of practical applicability, route travel time and the total number of batches formed. The study found that seed algorithms perform best with large capacity picking devices using the S-shaped routing policy. While time-saving algorithms best with small capacity picking devices employing the largest gap routing policy.

More recently the focus of the research has shifted to the second subtask which focuses on picking the required quantity of items from the correct bin and the related navigation of the picker in doing so [14]. In [11] the authors present an augmented reality assisted order picking system. Their order picking system consists of a head-up-display unit, that displays the relevant information regarding the order and a tracking system consisting of retro-reflective markers mounted on the heads-up-display unit. Using an array of infrared cameras, the picker's location is actively tracked in 3D space. Using this information, the system guides the picker to the correct bin using a Bezier curve-based Tunnel which is displayed on the head-up-display [14].
Further, it also shows the number of items that are to be picked from the bin.

In their study, they go on to compare their system with the traditional paper-list and pick-by-voice systems on the metric of picking-time and picking-error. Concluding, that their augmented reality assisted order picking system was faster than other methods of order picking. Their system also made seven times fewer picking errors than the paper-list method but the difference in picking error when compared to pick-by-voice methods wasn't found to be statistically significant. In [4] the authors develop a new approach to order picking by combining two existing approaches. They take the hands-free nature of pick-by-voice and combine it with the spatial aligned visual feedback of pick-by-light producing what they call an in-situ pick-by-vision system. Their system consists of a helmet-mounted Digital Light Processing (DLP) projector, which projects the relevant information on any surface in front of the picker and a motion-sensing input device that captures motion inputs from the picker. They evaluate the efficiency of their system by comparing it against pick-by-paper methods and found that their pick-by-vision solution marginally better than pick-by-paper methods in both picking time and picking error.

In [5] the authors assist the picker by the use of projected user interfaces. Their system consists of a set of projectors for each aisle and motion capturing sensors to sense if the picker has picked an item from a bin on the shelf. They create a 3D model of the layout of the warehouse and assign triggers to each shelf and bin. The system then uses the set of overhead projectors to guide the picker to the correct aisle and bin by projecting images on the sides of the shelves.

In [9] the authors propose an IoT based production logistics synchronization mechanism with dynamic control. They also implement this system in a real-world environment and compare the delivery rates before and after implementing the system in a large-scale paint manufacturer. Their findings show that IoT based systems have the potential to improve existing logistics in the area of large-scale production. In [7] the authors design a smart home automation system with surveillance capabilities that helps reduce human interactions and cognitive load in home management. Both [7] [9] show how IoT can help make processes more efficient by reducing human input and overall cognitive load.

III. RASPICK: THE PROPOSED AUGMENTED REALITY ASSISTED ORDER PICKING SYSTEM

As discussed in Section 2 order picking is widely considered as the major bottleneck in warehouse workflows. Pick-by-vision systems have proven to provide many advantages over their conventional counterparts [12] [13]. These systems show improved picking accuracy and reliability while also achieving a shorter picking time [12]. Most of these systems also reduce the variance of the picking error across picking runs of different lengths, but this improvement is not statistically significant as pointed out in [11] [4]. The major limitation of these systems is that they are expensive which restricts their use in smaller and medium warehouses.

The proposed RASPICK order picking system consists of a wearable head-mounted device and an advanced web-based warehouse management system which synchronizes with the head-mounted device through the use of IoT. RASPICK is a step towards a more affordable pick-by-vision system that can be used in warehouses of all sizes.

A. System Design and Hardware Components

RASPICK aims to be a cost-effective solution to order picking while being robust and modular. To better understand the design of the device it is essential to first look at the tasks the system is expected to perform. These tasks are as follows-

1. Communicating clearly with the picker at each step of the picking process.
2. Scan the item's object code (QR code) using the camera at the front of the device.
3. Processing the scanned information and sending the appropriate request to the online warehouse management system.
4. Receiving the response to the request sent and showing appropriate instructions to the picker.

The Block diagram of the proposed order picking system is shown in Figure 2. In diagram 102 shows the external attachable device module, that can be attached to any pair of glasses for scanning the object codes and displaying relevant information to the picker. While 104, 108 and 110 show the central database and the core logic of managing items.

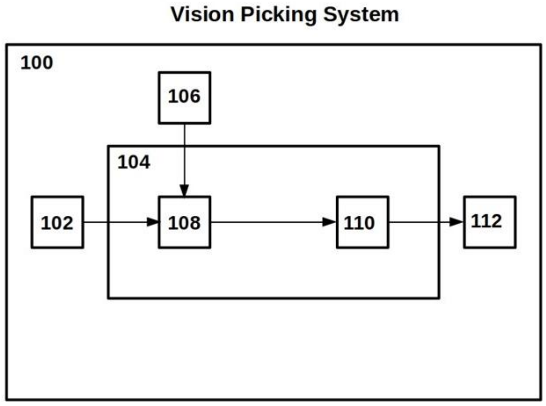

Figure 2 Block Diagram of RASPICK Order Picking System

The hardware components for the device were chosen based on the nature of the tasks that are expected to be performed by the device. The device is powered by a Raspberry Pi Zero W board which is connected to an 8 MP camera module that is used to scan the object code. A momentary capacitive touch sensor is connected to the Raspberry Pi using the GPIO pins present on the board to capture the touch of the picker. The information is displayed on a 128x64 OLED display. A plano-convex lens is used to create a virtual image of the OLED display roughly 30 cm away from the lens, this image is deviated by 90° and into the eye of the picker using a pentaprism. The entire system is powered by a portable battery in the form of a power-bank. Figure 3 shows the 3D model of the housing unit of the device.

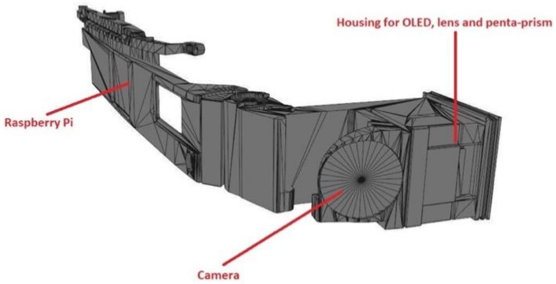

Figure 3 3D Model of the housing unit

Working of RASPICK

The RASPICK system consists of two components namely, the head-mounted device that uses augmented reality to assists the picker in picking up the correct item and web-based warehouse management system.

When the picker puts on the device and plugs in the power it boots up and connects to the nearest available Wi-Fi station. The web-based warehouse management system then assigns a set of items as an order to the picker, the information for which is downloaded onto the picker's device. This information consists of a list of items that are to be picked along with their required quantity. Each item and its required quantity are displayed to the picker directly. The picker then finds the corresponding aisle for the item using the letter assigned to it, which is displayed to the picker. Once the aisle is located the picker taps the touch sensor on the side of the device, the picker is then shown the bin number in which the item is stored. The picker locates the correct bin using this bin number. He then picks the required number of items from the bin and taps the touch sensor to scan the object code (QR code) associated with that item printed on the bin surface. The device then sends a request to the warehouse management system acknowledging that the item in its required quantity has been successfully picked. The information for the next item is shown to the picker and the process continues till the picking list is exhausted.

The head-mounted device for the picker uses custom language-independent codes that show the status of each action that the device performs. As symbols are easier to understand than words in a language, they help in reducing language dependency of the system. In Figure 4 going from left to right and top to bottom, 4(a) and 4(b) show that the device is ready and awaiting user touch input. While 4(c) and 4(d) tell the picker that the camera has been initialized and he should align the code to scan it. 4(e) and 4(f) inform the picker that a request is being sent to the central warehouse management system and whether the item is successfully picked. The system is lightweight, modular and can be attached to any pair of powered or unpowered glasses as can be seen in Figure 5.

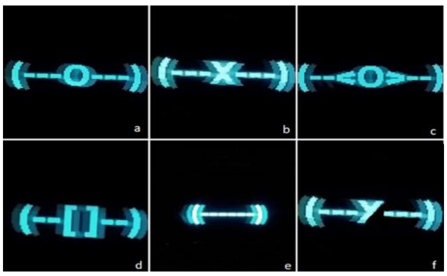

Figure 4 language-independent codes as seen by picker

Figure 5 The front and side view of the subject wearing the device

IV. EXPERIMENT SETUP AND RESULT

To test our proposed RASPICK system, we set up a demo warehouse which consists of 3 shelves and a deposit station. The 12' deep metal shelves have 3 racks and were arranged laterally on the warehouse floor to minimize their distance from the deposit station, a design widely used in modern warehouses of all sizes [2]. Each of the three shelves stores a particular category of products i.e. tools, stationary and packaged foods. Each item is stored on the shelf associated with its category and inside a bin that is specifically assigned for it. Each shelf is assigned a letter from a range of A-Z, while each bin in a shelf is assigned a number 1-30. Figure 6 shows the setup of the demo warehouse.

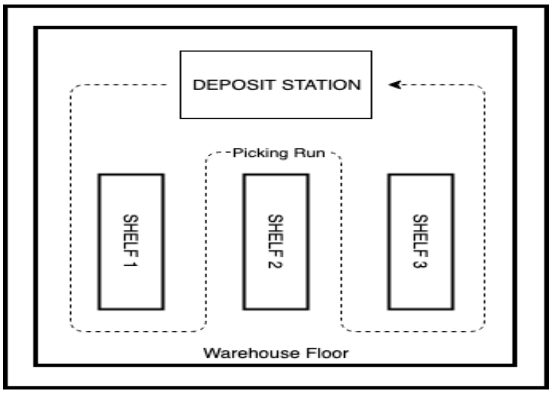

Figure 6 The Test Warehouse Setup

We compared the proposed RASPICK system against manual paper-based order picking, in which a picker is given a list of items to pick from the warehouse. Once he picks these items he has to manually check them out of the inventory at the deposit station with the help of a barcode scanner, the time taken to do so is called *scan time*. The total time the picker takes to pick and checkout the items of a list is referred to as the *trip time*. We use *average trip time* over three trips as our metric for comparison. We produce identical picking lists of 10 and 20 items each, consisting of the item and its required quantity for each picking run.

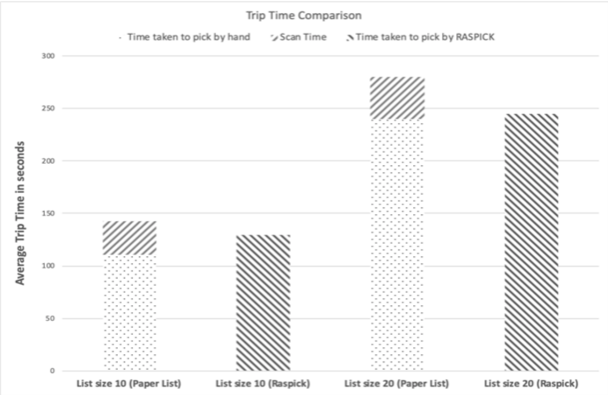

Figure 7 Comparison of Average Trip Times

In our demo warehouse setup, the proposed system showed promising results. The average trip times of both the methods are shown in Figure 7. It was observed that the average picking time of RASPICK is lower than conventional paper-based picking methods, mainly because picking and inventory checkout is one smooth motion due to the seamless integration of the virtual inventory management system with the RASPICK device using IoT. The RASPICK system showed an improvement of 9.16% and 12.55% in trip time for the 10 and 20 item lists respectively.

The major advantage of RASPICK system is that it allows both the hands of the picker to remain free. This means that the picker can focus on doing his job and not have to worry about carrying a large list in one hand. Further, unlike pick-by-voice order picking systems that lose their effectiveness in noisy environments, RASPICK relies on augmented reality to display relevant information directly to the picker, hence largely remaining unaffected by the conditions of the working environment. The system also reduces the overall cognitive load on the picker by handling all the tasks related to picking such as: keeping track of the picked items and showing which item is to be picked next etc., allowing the picker to be more efficient in his picking runs.

One of the major drawbacks of the system is that it cannot chart the most efficient picking sequence so that the picker spends the least time traveling in his picking runs. This task is still left to the picker who has to decide on the most efficient picking sequence for his runs. This drawback can be addressed with Wi-Fi triangulation techniques such as angle of arrival (AoA), received signal strength indication (RSSI), etc., to actively track the picker's location in the warehouse. The location data can then be used to generate the most efficient picking sequence for the picker which can be displayed directly to him.

V. CONCLUSION

In this paper, we presented RASPICK, a combination of a head-mounted display device and a web-based central warehouse management system that together support the process of order picking in warehouses. The head-mounted device that can be attached to any pair of ordinary glasses, utilizes augmented reality to display the information needed by the picker directly in his peripheral vision. Each device is constantly connected to the central management system of the warehouse through the internet. This makes each head-mounted device IoT enabled and provides the scope for efficient management and optimization of all the pickers. The device was tested in a controlled environment and performed as expected.

We also compared the proposed system with manual paper-based picking technique, to show that the system reduces cognitive load on the picker allowing him to focus on more important tasks like navigation and route selection. Thereby providing significant improvement in average trip times when compared to paper-based approach. The system also attempts to bridge the language barrier by the use of language-independent custom codes. These codes show the status of each action being performed by the device. RASPICK is designed for warehouses of all sizes, the system is scalable. For small warehouses, the system can employ only a handful of pickers while in larger warehouses many pickers can be spread across the warehouse floor each being centrally managed to improve the overall efficiency of the warehouse.

As future work, the authors plan to expand the system by the addition of Wi-Fi location-based services (LSB) that make use of methods like WI-FI signal triangulation, MAC addresses and signal strength to track the location of each picker. This will transfer the responsibility of calculating the best routing path to centralized computers further reducing the cognitive burden on the picker.

REFERENCES

1. De Koster, M.B.M., Van der Poort, E.S. and Wolters, M., 1999. Efficient orderbatching methods in warehouses. International Journal of Production Research, 37(7), pp.1479-1504.
2. De Koster, R., Le-Duc, T. and Roodbergen, K.J., 2007. Design and control of warehouse order picking: A literature review. European journal of operational research, 182(2), pp.481-501.
3. ELA/AT Kearney, 2004. Excellence in Logistics 2004. ELA, Brussels.
4. Funk, M., Mayer, S., Nistor, M. and Schmidt, A., 2016, June. Mobile in-situ pick-by-vision: Order picking support using a projector helmet. In Proceedings of the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments (p. 45). ACM.
5. Funk, M., Shirazi, A.S., Mayer, S., Lischke, L. and Schmidt, A., 2015, September. Pick from here!: an interactive mobile cart using in-situ projection for order picking. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (pp. 601-609). ACM.
6. Guo, A., Raghu, S., Xie, X., Ismail, S., Luo, X., Simoneau, J., Gilliland, S., Baumann, H., Southern, C. and Starner, T., 2014, September. A comparison of order picking assisted by head-up display (HUD), cart-mounted display (CMD), light, and paper pick list. In Proceedings of the 2014 ACM International Symposium on Wearable Computers (pp. 71-78). ACM.
7. Patchava, V., Kandala, H.B. and Babu, P.R., 2015, December. A smart home automation technique with raspberry pi using iot. In 2015 International Conference on Smart Sensors and Systems (IC-SSS) (pp. 1-4). IEEE.
8. Petersen, C.G. and Schmenner, R.W., 1999. An evaluation of routing and volume-based storage policies in an order picking operation. Decision Sciences, 30(2), pp.481-501.
9. Qu, T., Lei, S.P., Wang, Z.Z., Nie, D.X., Chen, X. and Huang, G.Q., 2016. IoT-based real-time production logistics synchronization system under smart cloud manufacturing. The International Journal of Advanced Manufacturing Technology, 84(1-4), pp.147-164.
10. Ratliff, H.D. and Rosenthal, A.S., 1983. Order-picking in a rectangular warehouse: a solvable case of the traveling salesman problem. Operations Research, 31(3), pp.507-521.
11. Reif, R. and Günthner, W.A., 2009. Pick-by-vision: augmented reality supported order picking. The Visual Computer, 25(5-7), pp.461-467.

12. Reif, R. and Walch, D., 2008. Augmented & Virtual Reality applications in the field of logistics. The Visual Computer, 24(11), pp.987-994.
13. Reif, R., Günthner, W.A., Schwerdtfeger, B. and Klinker, G., 2010, March. Evaluation of an augmented reality supported picking system under practical conditions. In Computer Graphics Forum (Vol. 29, No. 1, pp. 2-12). Oxford, UK: Blackwell Publishing Ltd.
14. Schwerdtfeger, B. and Klinker, G., 2008, September. Supporting order picking with augmented reality. In 2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality (pp. 91-94). IEEE.
15. Speaker, R.L., 1975. Bulk order picking. Industrial Engineering, 7(12), pp.14-18.

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