Sparse Order Picking in Warehouses Using Heads-up Displays

CS4605/CS7470-A Mobile & Ubiquitous Computing - Project 3: P2 Paper

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INTRODUCTION

Order picking is the process of finding and picking items and packages inside a warehouse, which accounts for up to 55% of the operational cost of a warehouse [1] mostly due to inefficient use of time. Further, travelling between different packages further accounts for more than a half of the order picking costs [1]. Despite variance in how densely packed orders are between different warehouses, most warehouses still use outdated system such as static maps and paper to pick orders [1]. Although it is effective, the usage of static maps and the paper-based method for order picking relies heavily on the picker's own memories and spatial understanding of the layout of the warehouse which makes this method error prone, especially in the situation of sparse order picking. More specifically, such method usually locates items using aisle and shelf numbers, which is not intuitive and is highly likely to require pickers to refer back and forth to the paper while holding it with one hand all the time along the picking process. Given the size of the present-day warehouse industry, and the impact of reducing its operational costs, a more performant order-picking system could optimize this large warehouse cost, saving employee time and company money. Augmented Reality headsets are a new and upcoming way of finding and picking orders inside a warehouse because they have the potential of enabling hands free and just-in-time delivery of picking information. By using heads-up-displays (HUDs), it is possible to provide real-time indoor navigation to users. Additionally, by carefully designing the interface, it is possible to spatially map a shelf into a 2D picture and indicate the order's position to the picker. The goal of this project is to implement and test a HUD system that can provide real-time navigation to the warehouse picker and determine whether live location and orientation data can decrease order picking time or increase accuracy in low-density picking environments.

RELATED WORK

Heads-up-display for order picking

Currently, most of the order picking is done manually, by hand, where a worker is given a paper list of items to collect and must follow the list to retrieve the correct type and quantity of each item [1]. Although fully automatic systems of order picking exist, they are extremely expensive and only have the dexterity to perform order picking on very limited use cases, which explains the pervasiveness of manual order picking [1]. Therefore, one purpose of this study is to evaluate the use of HMDs to improve manual order picking without costly modifications to current warehouse infrastructure.

Previous studies have shown the benefits of using heads-up displays and virtual or augmented reality to help users find and pick orders because they enable both hands-free and path optimal order picking [3]. HMDs have been shown to increase the speed of order picking by 37% compared to using paper [2], and show significant efficiency and accuracy advantages over audio representations [4]. HMDs have also been shown to reduce errors in order picking over methods such as pick by paper, and the errors that are made often have less severe impacts on warehouse processes [5]. HMDs have not only been found to improve performance over traditional methods such as paper, but also more "novel" methods such as stationary displays [6] and pick-by-light [8]. User of HMD interfaces also self-report very low frustration and physical demand ratings, indicating that HMDs provide little to no burden to the user [7]. Additionally, to the best of our knowledge, previous literature mainly focused on the dense order picking rather than sparse order picking that we mainly focused on in this project.

Navigation interface design

Multiple studies were conducted by Dr. Krum (Wearable Computers and Spatial Cognition [9]) to study spatial cognition with navigation. One of the first studies conducted by Krum was to study two different viewpoints, top-down (above) and perspective (below) shown in Figure 1, to analyze which view would help a user understand environment's structure better. The study found using a top-down approach is more efficient and less distracting than a perspective view that led to a greater error in environment recognition. Along with a top-down view, the spatial cognition aid should provide the user's path with trail markers to improve spatial learning.

Figure 1: top-down (left) and perspective (right) viewpoints from Wearable Computers and Spatial Cognition study [9]

Another study investigated which navigation controllers would result in the lowest navigation target times for HWD-based navigation, where two types of views were used which are egocentric navigation and exocentric navigation. The navigator of egocentric navigation maintains a static spatial orientation on the HMD to objects in the environment (‘‘route-based’’ navigation), and the one of exocentric navigation's spatial orientation on the display is fluid to the environment (‘‘map-like’’ navigation).

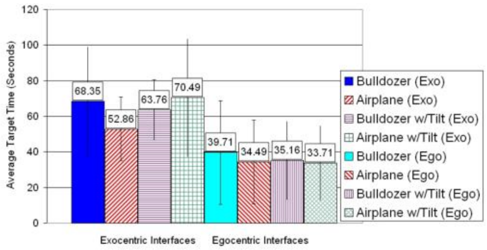

Figure 2: Average travel time to each target from Wearable Computers and Spatial Cognition study [9]

Therefore, based on the previous literature, we first utilized Krum’s findings by providing a top-down view with marking the user’s path to the user. Then mainly focused on comparing different navigation views with similar tasks instead of comparing different navigation controllers [2]. Besides, our study will not be utilizing a controller to navigate through an environment, but using the user’s real location and orientation.

IMPLEMENTATION

Our implementation has four major components: 1) set up the warehouse-like experiment environment on TSRB 2nd floor and select 20 different picking locations, 2) build our own Google Glass and Tablet applications to support new warehouse maps and real-time picking and path switching, 3) design the user study procedure and evaluation metrics, and 4) conduct a pilot study within our group, analyze the results, and present some preliminary findings.

Warehouse environment setting up

Since the goal of our project is to determine whether live egocentric navigation is beneficial and compare it with exocentric navigation, the user’s familiarity of experimental environment will have a huge impact on the experiment results. In other words, if the users are too familiar with the experiment environment, they probably would not need navigation systems to help them navigate in the environment which would skew results. Additionally, during the training sessions held before the user study designed to familiarize the user with the Google Glass based navigation system, participants may potentially memorize or become familiar with the experiment environment. Therefore, we needed a more complicated warehouse-like environment instead of using the original environment in room 243 of the TSRB, which only had 4 shelves with which the participants could easily remember after the training session. For the Project 2, we decided to use the north part of TSRB 2nd floor as our experiment environment and carefully selected 20 locations as order picking locations, as shown in Appendxi.Figure 1.

We then randomly generated 7 order picking paths with 10 picking locations for each picking path, as shown in Table 1. Specifically, 2 picking paths (F and G) combined with 3 previously designed picking paths in the room 243 serves as training picking paths and 5 picking paths (A – E) serves as testing paths. Here, we would like to emphasis that the reason for using 3 picking paths located in Lab 243 is to avoid exposing the experimental environment to the experimenter for a long time while still allowing the user to become familiar with the navigation system.

System modification

Our Google Glass based sparse order picking system contains two major components: 1) The Google Glass app that provides real-time indoor navigation and displays the location information to the user and 2) The location and rotation tracking app on the tablet that enables real-time location and rotation tracking of the user. These two components use Bluetooth to accomplish the communication and data transmission. We made three main modifications from project 1: 1) modified the system to fit new warehouse map, 2) modified the system to support real-time picking location switching in one picking path and 3) modified the book info view to only display the location number.

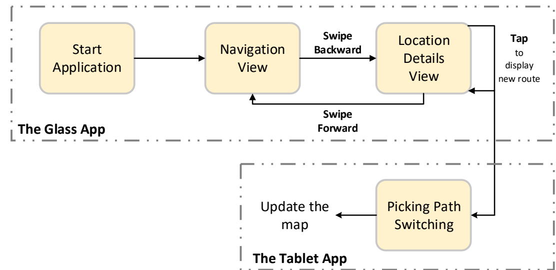

Figure 3: The workflow of Glass app and the real-time picking route switching logic.

After the modification, the workflow of our system is consisted of three main steps: 1) start application, 2) indoor navigation and 3) location details, as shown in Figure 3.

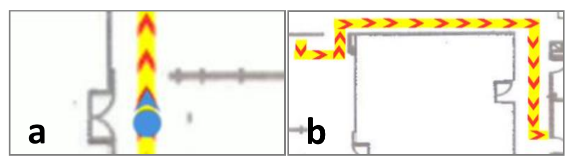

Figure 4: a. the 2D Top-down view of the warehouse with order picking path for live egocentric navigation. b. the 2D Top-down view of the warehouse with order picking path for static exocentric navigation

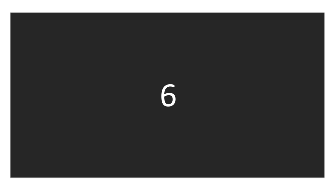

Figure 5: The location details view

The Glass app

The Glass app serves as an order picking tool that provides real-time indoor navigation and order picking information to the user. For the live egocentric navigation, a map that reflects the 2D top-down view of the warehouse will be displayed to the user, as shown in Figure 4.a. A blue pin-point with a direction arrow will be in the center of the display and show the current location and orientation of the user. A directional path from user’s current location to the destination will also be displayed on the map. As the user moves inside the warehouse, the blue point will update to indicate the current location and orientation of the user. For the static exocentric navigation, the map view will only show a 2D top-down view of the warehouse map that contains the start point, end point and a pre-planned route. It will not update with the user’s current location and head rotation, as shown in Figure 4.b. After user arrive at the destination, by swiping forward, a view that contains the destination number will be displayed to the user, as shown in Figure 5. Further, by tapping on the glass, the system will display the route to the next picking location on the navigation view and the corresponding location number on the location info view. We define the switching between the navigation view and the book info view as a picking loop, as shown in Figure 3. Therefore, by performing the picking loop multiple times, a user can successfully finish the sparse order picking task.

The Tablet app

Indoor localization is a well-known frontier problem that currently still has no solution. Therefore, due to the need of highly accurate indoor localization, we decided to use the "Wizard of Oz" method to solve the indoor location and rotation tracking problem. In other words, one research assistant tracks the user's location and rotation manually, and send the data to the user's Glass app for real-time navigation. The tracking app, shown in Appendix. Figure 2, runs on an Android device whose interface contains a Bluetooth communication panel, warehouse map and a joystick. The Bluetooth communication panel serves as the control panel for the data communication. The map and the joystick are for location tracking and rotation tracking, respectively.

Specifically, after the location tracking app receives the tap action performed by the Glass user, it will automatically change the map be displayed to a new map which contains the next picking route to help the research assistant understand the picker's behavior, as shown in Appendix. Figure 3.

PROPOSED USER STUDY PROCEDURE

For the user study, each participant will be asked to perform the sparse order picking task along with the identical picking path twice but using two different navigation methods. Further, by collecting the accuracy and duration for each picking route and subjective scores using NASA TLX in which the participant has to rate several scores related to their physical demanding, physical demanding, etc. Then we would like to perform a paired t-test on the data collected to determine whether the live egocentric navigation is more helpful and better than the static exocentric navigation. There are two major sessions in our designed user study procedure: 1) a training session and 2) a testing session. According to previous literature [11], the participants will get familiar enough with the prototype interface and interaction pattern after performing around 5 picking paths. Therefore, we split 10 paths each with 10 randomized routes into two sets of 5 - one for the training session and one for the testing session.

The Training Session

The purpose of training session is to help the participant get familiar enough with the working prototype and the user study procedure to be prepared well for the formal testing session. At the beginning of each training session, a research assistant will first explain the purpose and the process of the complete user study, and then illustrate the usage of prototype. During each training session, the participant has to finish the training picking path set twice using two different navigation methods respectively.

The Testing Session

During the testing session, each user has to finish the same testing picking path twice: once using the static exocentric-based method first and once using the live egocentric-based navigation first. The order in which the user performs the methods will be random. Then we will randomly generate two different sequences of 5 picking paths for egocentric-based method and the exocentric-based method respectively. Each participant will finish all the picking paths for one navigation method first then start the experiment on the other navigation method. To mimic the order picking process, at each destination, the participant has to choose the correct item according to the location info view, as shown in Appendix. Figure 5. During each picking path, a pair of research assistants will follow the participant. One will control the location and rotation tracker and the other will time the duration of each complete picking path, the duration on each individual picking route (from one location to another) and keep track of the errors. After each navigation method, the participant will also be asked to fill the NASA TLX form and the preference form for each condition. Afterwards, there will be a free discussion session to allow the participant give any additional comment about the user study. Finally, the Appendix. Figure 4 shows the flow of the designed user study procedure for each participant.

RESULT OF PILOT STUDY

To verify the system usability and also aiming to polish our proposed user study procedure, we first conducted a pilot study within our group. Because our group size is 4 and we always need a pair of research assistant during the user study, we had 2 available team members to be the participants. To avoid familiarity of the designed picking paths, we selected 3 picking paths out of the testing picking path set that were not designed by the 2 participants. Then, following the designed user study procedure, we recorded their errors, duration for the whole path, duration of each single picking route, their NASA TLX scores and preference scores.

For the picking speed, we first compared the mean duration of each navigation methods. The mean duration on each single route of exocentric navigation is 39.82 seconds per route and the mean duration of egocentric navigation is 34.76 seconds per route which is 5.06 seconds lower than the previous one. Then we conducted a one-tail paired t-test on these paired data under the alternative hypothesis that the exocentric mean is lower than the exocentric one, the result shows a significant different (p-value = 0.0019 < 0.01) between the speed of egocentric navigation and exocentric navigation, as shown in Table 1.

t-Test: Paired Two Sample for Means	*Exocentric*	*Egocentric*
Mean	39.81818182	34.75757576
Variance	388.3048951	219.3864802
Observations	66	66
Pearson Correlation	0.719974435	
Hypothesized Mean Difference	0	
df	65	
t Stat	3.003144305	
P(T<=t) one-tail	0.001895167	
t Critical one-tail	1.668635976	
P(T<=t) two-tail	0.003790334	
t Critical two-tail	1.997137908	

Table 1: The one-tail paired t-Test result

We also compared the error rate of each navigation methods. The average number of errors is about 1.16 per path for exocentric navigation and about 1 per path for egocentric navigation.

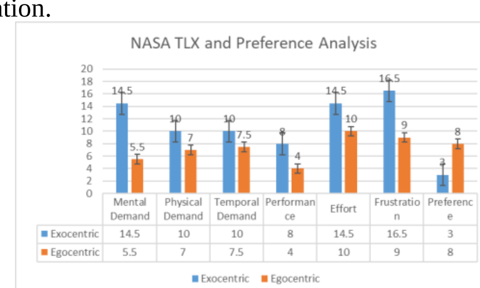

Figure 6: NASA TLX and Preference Analysis.

Due to the lack of sufficient participants, we didn't perform a paired t-Test on the NASA TLX scores and the preference score; instead, we only compared the mean of the NASA

TLX scores and the preference scores of these two different navigation methods. As shown in Figure 6, the exocentric navigation has higher scores for all the measured NASA TLX fields but has lower preference score.

DISCUSSION

In this section, we would like to discuss the quantitative and qualitative findings of our pilot study, and the lessons we learned about our system's usability and controllability from conducting the user study.

Quantitative Findings

First simply according to the paired t-test result, we can reject the null hypothesis that there is no difference between the mean durations of each navigation method with the alternative hypothesis that the mean duration of egocentric navigation is lower than the exocentric one. Also, the comparison between the NASA TLX scores, accuracy and preference scores all showed that the egocentric navigation can bring lower physical demanding and mental demanding which finally resulted in a higher accuracy. However, we admit this result may be not reliable enough as we had a really small number of participants, and all participants might be biased for they designed the prototyping system. However, the result may also show the potential trend that egocentric method will bring higher accuracy and better user experience to the user as we hypothesized.

Qualitative Findings

Based on our observation in the user study, we conclude that the whole process of performing a single order picking task can be divided into 3 main stages: 1) planning, 2) travelling and 3) picking. Further, based on the free discussion result and the observation, we find the main difference between using the egocentric navigation and the exocentric navigation lies in the first stage - planning. For the exocentric navigation, the user will usually spend around 3 to 5 seconds to understand the spatial mapping between the real environment and the virtual location on the map, then plan their travelling route. However, for the live egocentric navigation, it is pretty intuitive for the user to understand the spatial mapping and start the travelling stage much faster. As for the travelling stage and the picking stage, we didn't find too much difference, except for that the users of static exocentric navigation is more likely to head to a wrong destination and then realize that in the middle of their traveling stage or at the beginning of their picking stage which will lead to a beginning of a new planning stage.

A common observation among participants for the egocentric versus exocentric navigation was that it took a longer time and more mental effort to reorient themselves relative to their surroundings and the map path after picking each item. Not only did re-orientation prove to be more difficult using exocentric navigation, but also there was no sense of distance traveled using the static map as there was no location indicator. Because the scale of each map was different according to the length of the path, participants sometimes overshot/undershot the target location, and had to exert a considerable mental effort into determining their position relative to the map as they traveled.

Overall, compared to static exocentric navigation, live egocentric navigation seems to reduce picking time, result in less errors, and require less mental and physical demand of the user which could not only benefits the order pickers but also introduce potential benefits from the perspective of the warehouse operation cost, as well as other tasks which are similar to sparse order picking.

System's Usability and Controllability

One goal of our pilot study is to test our system's usability from the user's perspective and the controllability from the research assistant perspective. We found that: 1) Although sometimes, we need to unpair the two devices one or more times to establish the socket between the Glass app and the Tracker app, the Bluetooth communication is robust and fast enough for us to update the location and rotation information in real-time. 2) The controllability of our system is good but not very ideal. The control method is pretty straightforward that the research assistant can simply use his/her finger to control the location and user the virtual joystick to control the rotation. However, because we require the research assistant to track the location and rotation of the user simultaneously, sometimes this will cause a high physical demanding to the assistant. Moreover, because the research assistant can also lose the sense of spatial direction for some reason, it will also introduce high cognitive workload and mental-demanding to the assistant which could potentially affect the participant's performance. Therefore, making sure that the research assistant who controls the location and rotation of the user is familiar enough with the environment and the app is critical to perform a successful user study.

Duration of each User Study

After our pilot study, we found that it will usually take 5-8 minutes for a participant to finish a single picking path, which means that, with 20 total picking paths, the participant will spend at least around 100 minutes total for the user study, excluding the time for instruction, survey and other administrative process. Therefore, we estimate that for each single user, it probably will need at least 2 hours for finish the user study which might be too long for a user to keep his/her best mental and physical condition.

FUTURE WORK

Our pilot study has showed a pretty optimistic result about our hypothesis that the live egocentric navigation could bring faster speed, higher accuracy and lower cognitive workload to the user. Therefore, in the future, it's tempted to conduct a complete user study on this topic and publish the result which we believe would be both valuable to the HUD research community and the warehouse business community. However, as we mentioned above, many aspects of the working prototype and user study procedure need to be refined, such as the Bluetooth connection of the Google Glass and the time duration of the user study.

Additionally, during the pilot study, the static exocentric navigation will display a pre-planned route to the user. As we mentioned above, during the user's planning stage, they tend to spend around 5 seconds to not only understand the destination point, but also understand the pre-planned route itself. Therefore, it is also valuable to investigate whether only displaying the destination point and allow the users to plan the routes by themselves would make the static exocentric navigation more efficient.

CONCLUSIONS

In this project, we designed and implemented a Google Glass based sparse order picking system that can provide indoor navigation and order details to the user in real-time. We further tested the usability and controllability of our system. Then focusing on the question that whether knowing the location related to their surrounding could decrease order picking time or increase accuracy in low-density picking environments, we designed a user study procedure and conducted a pilot study within our group. The preliminary results show that the live egocentric navigation indeed can bring a faster speed, higher accuracy and lower cognitive workload to the user.

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[11] Augmented Reality Head Worn Display Positioning for Sparse Order Picking

APPENDIX

A	B	C	D	E	F	G
Start	Start	Start	Start	Start	Start	Start
17	19	16	13	18	5	15
10	18	8	10	2	11	4
11	4	13	7	13	18	1
1	11	14	19	4	17	19
8	5	6	17	19	14	12
18	20	5	9	7	9	16
3	15	7	8	9	1	10
19	9	12	4	6	7	8
20	17	10	12	14	10	3
14	2	1	3	17	16	17
Start	Start	Start	Start	Start	Start	Start

Table 1: Randomly generated picking paths

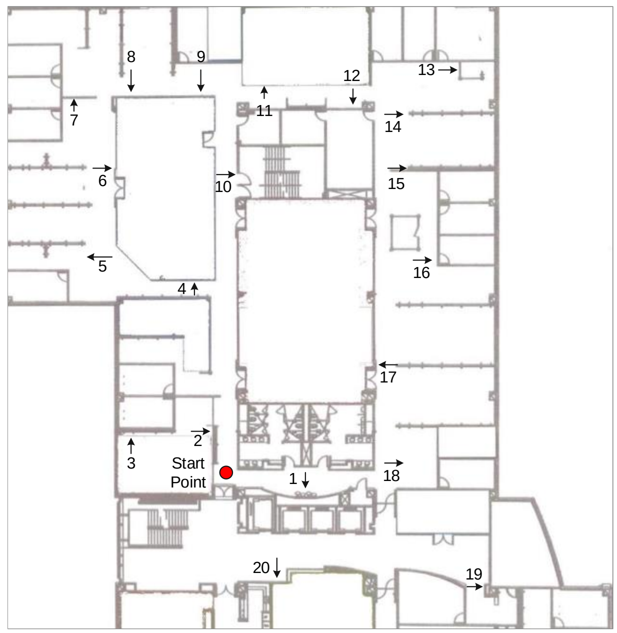

Figure 1: Selected picking locations

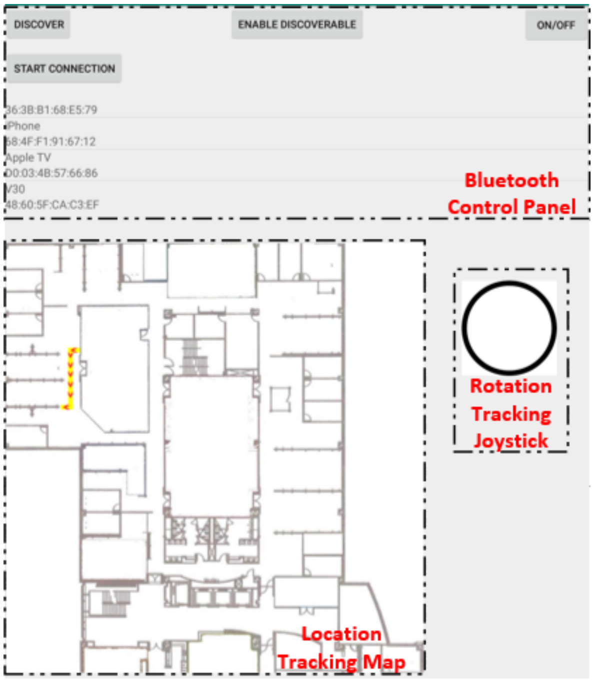

Figure 2: The interface of location and rotation tracking app

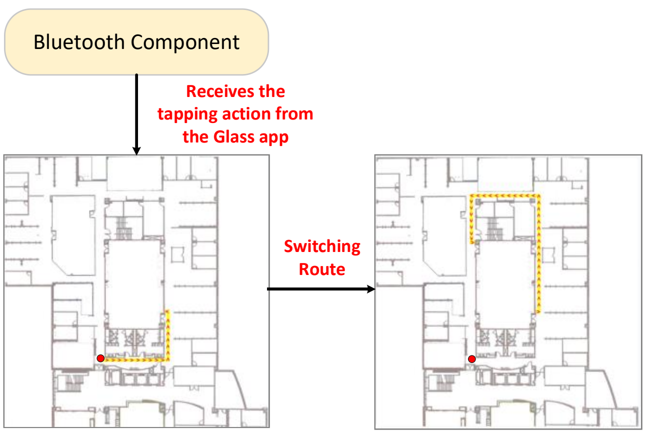

Figure 3: Switching the picking route

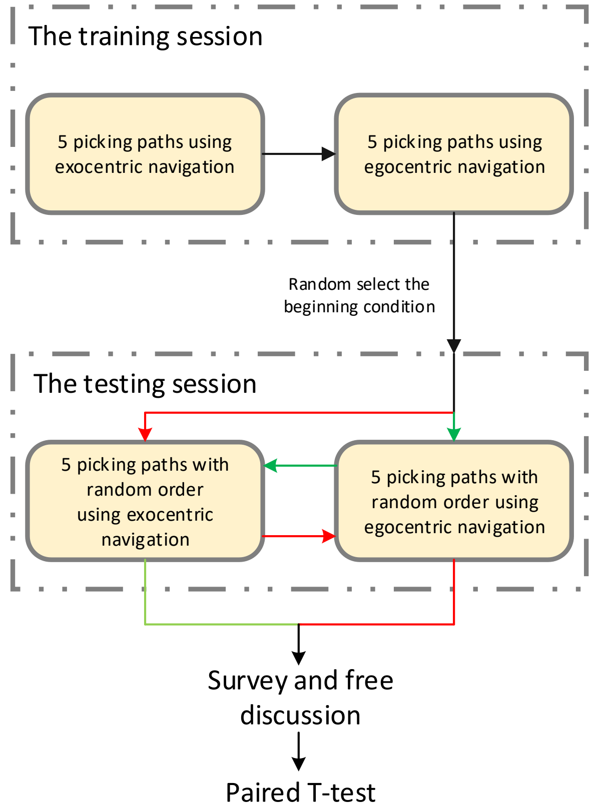

Figure 4: The flow of our designed user study procedure

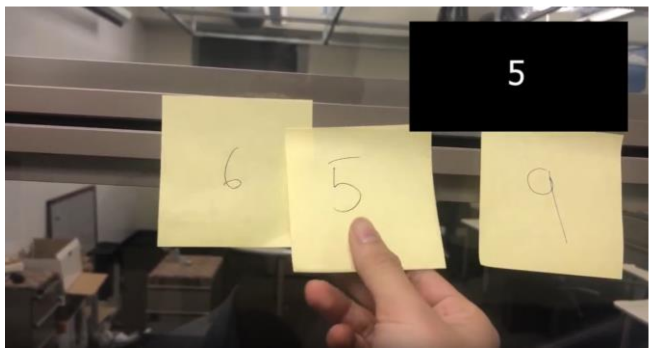

Figure 5: Multiple items to mimic the order picking process