



A Gaze-Based Unobstructive Information Selection by Context-Aware Moving UI in Mixed Reality

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Abstract. Mixed reality (MR) technology has been attracting attention in the automobile industry and logistics industry for work training and remote work support for newcomers. However, work support using MR technology has the problem that displaying too much information obstructs the user's field of vision and rather interferes with the work. Therefore, it is necessary to detect the user's intention and provide only the information that the user wants. In addition, the system should be able to detect naturally from the user's behavior without interrupting the work, which the user explicitly selects. To solve these problems, in this paper, we use the user's gaze to determine whether to display content by estimating whether or not they are looking at information. Another problem with gaze-based research in MR work support is that it is difficult to determine which space you are looking at in a space where virtual space and real space intersect. In order to overcome this problem, in this research, we grasp the user's behavior from the movement of the user's gaze, and we suggest a way to determine make the user interface (UI) the movement of the gaze that is unlikely to occur during that behavior to see if the user is looking at the UI. As a result of the experiment, we were able to promote the movement of gaze that is different from the characteristics of the movement of gaze during work with the proposed UI movement.

Keywords: Mixed reality · Eye tracking · Gaze interaction · Natural user interfaces · Interaction techniques

1 Introduction

Work support using Mixed Reality (MR) technology, which combines the virtual world and the real world, has been attracting attention. For example, Japan Airlines (JAL) in the airline industry has introduced MR technology for flight crew pilot training and mechanic maintenance training. In the automobile industry, Toyota Motor Corporation is using MR technology at its maintenance sites to display work procedures and other information by superimposing 3D images on

the relevant areas. Also, many researchers are conducting research and development in various situations such as the construction industry where workers can work while displaying columns, pipes, ducts, etc. in 3D on-site, and the logistics field using MR technology for navigation and remote support in warehouses.

However, work support using MR technology has the following problems. When information is presented in MR technology, it fills the user's field of view and prevents them from working. The information required by the user depends on the user and the user's situation. Narrowing the information to context awareness is possible, but limited. Therefore, It is necessary to know what the user is looking for (whether they want that information or not). You can make the user make an explicit choice, such as hitting the "delete" button or saying "close", but this causes interruption of the work, which is not good. Therefore, the system must be able to naturally detect whether the user is trying to view the information or not. In addition, although many context-aware user interfaces (UI) using gaze have been studied, gaze-based UI in MR has the problem that it is difficult to determine which space the user is looking at in a space where virtual space and real space intersect.

In this paper, we propose a gaze-based unobstructive information selection by context-aware moving UI in MR. This system moves the information presentation window (UI) and matches it with the movement of the user's line of sight to determine whether the user wants information (Fig. 1). A core idea of the proposed method is to determine whether the user is looking at the information or not by generating movements of the UI that generate eye movements that generate eye movements that are unlikely to occur in normal work. In our preliminary experiment, we measured the directions of the head and the gaze during three different indoor tasks and confirmed that there are tasks in which only the gaze moves, and tasks in which the head and gaze do not move in tandem. Based on this experiment, we designed and implemented a small moving UI for work with moving eyes and a large moving UI for work with moving heads.

As a result of experimenting with our system to five subjects to see if they were looking at the UI during three different tasks, we confirmed that their gaze and the movement of the UI matched when they were looking at the UI, but not when they were looking at the background. According to the user survey conducted after the experiment, most of the participants answered that the movement of the UI was easy to follow, but for all tasks, they said that the movement of the UI was slow and they spent a lot of time gazing at it.

In summary, the contributions of this paper are threefold,

- We provide the basics of the relationship between work content and gaze movement through preliminary experiment in three common indoor tasks.
- Based on preliminary experiments, we consider eye movements that are unlikely to occur during work, and present a gaze-based information selection system by context-aware moving UI.
- We evaluated the usability of the UI through the user survey. As a result, we confirmed that the proposed UI was easy to follow, but the speed of movement should be faster and the dwell time shorter.

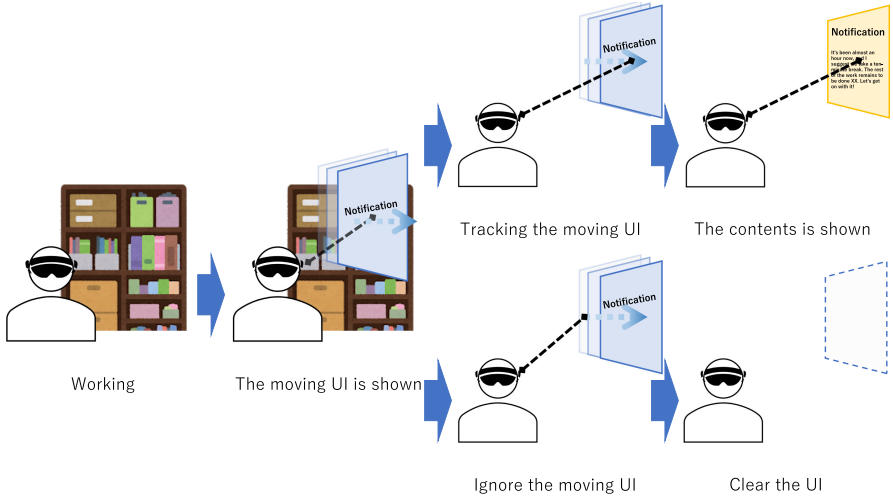


Fig. 1. Eye movement when looking at the moving UI and when not looking at it

2 Related Work

2.1 Activity Recognition Using Gaze

Andreas Bulling et al. devised 90 features based on the main eye movement features for recognizing human activity: saccades, fixations, and blinks [1]. In this study, they verified the method using five activity classes for eight participants in an office environment. Using a person-independent learning scheme, the average accuracy of all classes and participants was 76.1%, achieving a recall of 70.5%. The results showed that eye movement analysis is a rich and promising modality for activity recognition. Javier De Lope et al. proposed a system to recognize action behaviors performed in front of a computer using eye tracking information from low-resolution images captured by a conventional laptop webcam [2]. As a result of the experiment, it was concluded that it is possible to classify the behaviors performed in a typical office for multiple subjects having different physical characteristics such as skin, eye color, and face shape. Rafal Doniec et al. Based on a series of signals of accelerometer, gyroscope, and EMG acquired using smart glasses, a series of signals of accelerometer, gyroscope, and EMG acquired using smart glasses [9]. They predicted the appropriate activity class in about 85% of the cases. However, they concluded that there is insufficient research on the characteristics of specific classes of cognitive activity in this area, and that a more complex classification of activities associated with driving a car would help improve learning outcomes in driver training and testing centers. However, the methods developed in these studies were aimed at recognizing only those activities that are restricted to one specific location. So we extended the scope of our analysis to indoor tasks.

2.2 Gaze-Based Interaction

Head Orientation. Yuan Yuan Qian et al. compared eye-based selection with head-based selection in isolation to selection using both eye tracking and head tracking simultaneously [8]. They found that eye-only selection had the worst performance in terms of error rate, selection time, and throughput, while head-only selection significantly improved performance. Ludwig Sidenmark et al. proposed to exploit the synergistic motion of the eyes and head and used the Eye & Head gaze. The design principle of interaction has been clarified [10]. They demonstrated Eye & Head interaction in a virtual reality application and evaluated their technique against baselines in pointing and confirmation studies. The results showed that the Eye & Head technology enables new eye movements that provide more control and flexibility to the user in fast eye pointing and selection.

Dwell Time. Ken Pfeuffer et al. compared three techniques for menu selection: dwell time, gaze button, and cursor [7]. The results showed that user performance using dwell time was comparable to menu selection using a pointer and was less physically demanding. Mishael Fernandez et al. proposed a dwell time gaze input and feedback method [5]. In their method, visual feedback is presented to the user in the form of a filled wheel that, when fully filled, selects where the user is gazing. They compared three ways to respond to the user when they are staring away from the target. They found that the infinite and pause and resume GazeWheel were more error prone than the reset GazeWheel, but significantly faster when using a dwell time of 800–1000 ms.

Motion Match. Eduardo Velloso et al. analyzed motion correlation as an interaction principle for object selection by motion matching [3]. They found that pointing is more effective for fine-grained selection, which is common in desktop interfaces, and therefore not optimal in principle, but that when user motion is directly coupled with the device's motion feedback (i.e., not via a user-controlled input device) We have found motion correlation to be useful and compelling. Augusto Esteves et al. compared clickers and dwellers to implementations of motion matching [4]. Their experiments showed that clickers were the fastest and dwellers the most accurate, but they concluded that motion matching may provide a valuable compromise between these two poles.

As you can see, gaze-based interaction has been studied extensively, but experiments have been conducted with restricted behaviors, and not many have been analyzed for each type of behavior. In addition, in spaces where virtual space and real space intersect, such as MR, there is the question of which space is being looked at.

3 Methodology

In this section, we explain the proposed method for determining whether the user needs the information, the preliminary experiment to confirm whether the hypothesis that eye movements are related to behavior is correct, the system design based on the preliminary experiment, and the equipment used in the experiment.

3.1 Methodology Overview

This paper describes how to determine from the user's behavior whether the user needs or does not need the information presented in front of them while working. There has been a lot of research on UIs that make choices by matching the movement of the target with the movement of the eye [3,4], however, we do not know how to move the target in a way that is suitable for indoor work. Since eye movements are different for each task as shown by Andreas Bulling et al. and Javier De Lope et al. [1,2] our proposed method creates UI movements that are different from the eye movements during the task, and when the UI is actively moved and the user's eyes move in sync with the movement, we determine that the user needs the UI. Therefore, we conducted a preliminary experiment to investigate how gaze and behavior can be related. In the next section, we will explain the preliminary experiment.

3.2 Preliminary Experiment

Purpose. The purpose of conducting a pre-experiment is to find out if and how eye movements can be associated with the behavior. Andreas Bulling et al. used eye gaze for behavior recognition [1]. These studies were mainly conducted on desk work for behavior recognition. However, indoor work also includes standing and sitting tasks, which require more head movement. In this study, we measure head orientation and gaze movements for three indoor tasks, and confirm that head and gaze movements are related to behavior.

Experimental Setting.

Details. As a preliminary experiment, we measure head orientation and gaze direction using the HoloLens2 described in Sect. 3.3.1 for three behavior patterns. We measure head and eye directions for three behavioral patterns: “desk work” (reading text on a display), “eating” (eating alone at a desk), and “searching” (searching for a book on a bookshelf). The reason we chose these three behaviors is that desk work is one of the most common indoor tasks. We thought that searching for books from a bookshelf is similar to picking, which is a warehouse task. Also, since eating is not a time to stare at anything, in particular, we want to find out how the gaze of this behavior works.

Subjects. In this experiment, five students are asked to participate as subjects. We ask each student to perform each task for 5 to 10 min, and record their head orientation and eye movements during that time.

Data Contents. The data to be acquired in this experiment is unit vectors that indicate the direction of the user's head and gaze, with the frontal direction of the user on the z-axis, the vertically upward direction on the y-axis, and the rightward direction on the x-axis. For example, it is $(-1,0,0)$ if the user is facing

left, and (0,1,0) if the user is facing up. Note that the direction of the head and the direction of the gaze are independent of each other. In other words, if you move only your eyes to the right while keeping your head facing the front, the eye data will be (1,0,0) and the head direction will be (0,0,1), and if you move your head and gaze to the right at the same time, (gaze, head) = (1,0,0).

Results. The data of one subject obtained in the preliminary experiment is shown in Fig. 2 to Fig. 2. Here, the head orientation data has been subtracted from the gaze data to make it easier to understand the difference between head movement and gaze movement. In other words, the gaze here represents the orientation relative to the head orientation. The mean, variance, minimum, and maximum of the data for each task are also summarized in Table 1. From the desk work in Fig. 2 and Table 1, we found that the variance of gaze movement is large and the variance of head movement is small. In other words, the orientation of the head hardly changes during desk work, and only the gaze moves a lot. This means that when we read the text on the display in front of us, we do not move our head but only follow it with our eyes. In addition, since letters are generally read horizontally, eye movements are more active in the horizontal direction than in the vertical direction. From Fig. 2 and Table 1, we can see that most of the time during a meal, people are looking down. Also, most of the time, head movement and eye movement are linked. From the explorations in Fig. 2 and Table 1, in the task of searching for a book, the head orientation was more active in vertical movements and the gaze was more active in horizontal movements. It can be said that when looking for a book on a bookshelf, the orientation of the head determines which shelf the book is on, and the gaze determines where on the shelf the desired book is located.

3.3 System Design and Implementation

System Design

Overview. The system design of this research is outlined in the Fig. 3. The system design consists of four components: an Activity Recognition component that recognizes actions, a Contents management component that determines the contents to be displayed, a UI movement design component that determines the UI movement, and a Focus Status Detection component that determines whether the user is looking at the UI. By repeating these components, the system presents information that is appropriate for the user. The following is a detailed description of each component.

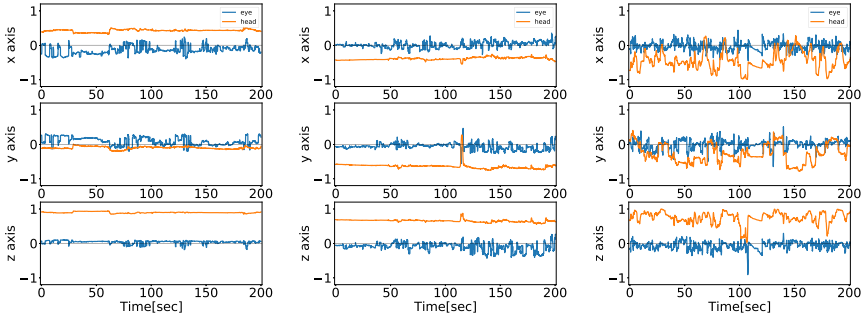


Fig. 2. Eye and head orientation movements using eye tracking and head tracking of HoloLens2: left) during desk work, center) while eating, right) when looking for a book on a bookshelf

Activity Recognition Component. As described in Sect. 3.2, head orientation and eye movement can be associated with behavior, so the current behavior can be inferred from each feature.

Contents Management Component. The Contents management component determines the information to be displayed according to the behavior estimated by the Activity Recognition Component.

UI Movement Design Component. The UI movement design component determines how to move the UI according to the behavior estimated by the Activity Recognition Component.

Focus Status Detection Component. The Focus Status Detection component compares eye movements with UI movements to determine if the user is looking at the UI. If the eye movement and the UI movement match, then the user is looking at the UI, and since the user is interested in this information, more detailed information is displayed. However, if the eye movement and the UI movement do not match, the user is not looking at the UI, and the UI is turned off.

3.4 Implementation

Hardware. This experiment is implemented using Microsoft's HoloLens2, a head-mounted mixed reality display that doubles the viewing angle and resolution of its predecessor, HoloLens1. The device is equipped with sensors such as eye tracking with two infrared cameras, head tracking with four visible light cameras, depth with a 1 MP time-of-flight (ToF) depth sensor, and hand tracking enhanced to five fingers. In this experiment, we use these eye tracking and head tracking features to determine whether the user was looking at the displayed content or the background.

Table 1. Description of eye and head movements for each task

Desk Work						
	Eye direction			Head direction		
	x	y	z	x	y	z
mean	0.300	-0.000	0.930	0.403	-0.099	0.906
std	0.140	0.147	0.054	0.065	0.049	0.026
min	-0.546	-0.644	0.667	-0.073	-0.721	0.652
max	0.740	0.259	0.999	0.554	0.066	0.988

Eating						
	Eye direction			Head direction		
	x	y	z	x	y	z
mean	-0.325	-0.679	0.552	-0.372	-0.571	0.683
std	0.156	0.256	0.197	0.101	0.220	0.106
min	-0.997	-0.993	-0.409	-0.928	-0.849	0.352
max	0.557	0.207	0.100	0.009	0.536	0.100

Search						
	Eye direction			Head direction		
	x	y	z	x	y	z
mean	-0.404	-0.366	0.695	-0.379	-0.356	0.744
std	0.293	0.294	0.220	0.268	0.251	0.200
min	-0.100	-0.942	-0.568	-0.996	-0.917	-0.777
max	0.818	0.596	0.999	0.998	0.413	0.100

Software. In this experiment, we prepare two patterns of notifications to be displayed: “Notice” and “Warning”. These two types of notifications are commonly used in various situations. Notifications are displayed in yellow, and warnings are displayed in red, colors that are easy to attract the eyes. Also, Based on the characteristics of the head and eye movements of the three work patterns in the preliminary experiment, we set the UI to make the following movements respectively.

– DeskWork

When Users was working at their desk, We found that their head hardly moved and only their eyes moved a lot. Therefore, we set the UI to move up and down in small movements within the visible range without moving the head (Fig. 4). The reason for the up and down movement is to distinguish it from the horizontal movement of the gaze when reading the text on the display. Also, since the distance between the display and the person is close, the UI is displayed closer and smaller than the display.

– Eating

We found that most of the time when Users eat, their head and gaze are looking down. So we created UI that goes upward so that the head looks upward (Fig. 4). Also, the size and distance of the displayed UI were set to the size and distance recommended by Microsoft [6].

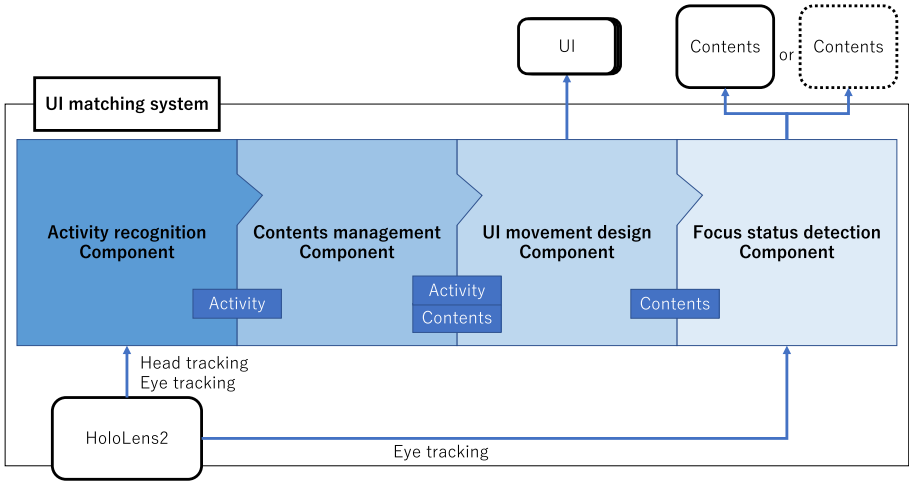


Fig. 3. System design overview: flow from activity recognition to content selection using gaze

– Search

The behavior of searching for a book on a bookshelf tended to be large up and down movements with the head and small horizontal movements with the eyes. So we move the UI horizontally to move the head sideways (Fig. 4). Also, unlike other tasks, the position of the body also changes, so we display it far and large.

Operation. We create a simple menu for experimentation to display the UI. There is a button to select the display method for each task, a start button to display the UI, and a reset button to turn off the display. When the start button is pressed, the UI will be displayed after a random time. Then, once the user looks at the UI, the UI will move in a predetermined way. If the user continues to follow the UI for a total of 5 s, it will display the details. If the user does not make eye contact with the UI after it starts moving, the UI will disappear after 15 s.

4 Experiments

This section describes an experiment using gaze and a moving UI to determine whether a user is looking at the UI, as well as the results and discussion of the experiment.

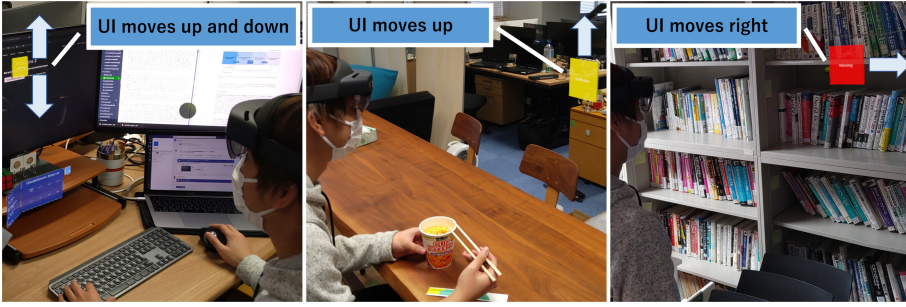


Fig. 4. UI movement: left) during desk work, center) while eating, right) when looking for a book. (Color figure online)

4.1 Experimental Design

Purpose. The purpose of this experiment is to investigate the ability to determine whether the user is looking at the UI by comparing the user’s eye movements with the UI movements we devised based on preliminary experiments.

Details. In this experiment, five students who participated in the preliminary experiment are asked to perform the task. As in the preliminary experiment, we have each student wear a HoloLens2 and perform three different tasks. We ask the users to specify in advance whether they want to look at the UI or not, and check whether they can distinguish between them based on their eye movements.

We also ask the users questions after the experiment to evaluate the usability of the UI. For each task, we ask the users to rate the following 7 questions on a 5-point scale: 1) is the UI movement appropriate, 2) is the speed of the UI movement appropriate, 3) to 5) is the position of the UI display appropriate (height, width, depth), 6) is the size of the UI appropriate, and 7) is the time spent staring at the UI appropriate.

4.2 Result

Evaluating Whether the User Is Looking at the UI and Making a Decision. We invited five subjects to participate in the experiment and collected data on eye movements with and without looking at the UI. Figure 5 to Fig. 7 show the eye movements of one subject for each task while looking at the UI and when not looking at it. From Fig. 5, we confirmed that the subject was able to control the user’s eye movements well when looking at the UI during desk work. Figure 6 shows that when looking at the UI during a meal, the user raises his face slightly in response to the movement of the UI. Finally, Fig. 7 shows that when looking for a book, the user is looking to the right according to the movement of the UI. From the above, when the user is looking at the UI, the gaze is locked on the UI and the movement corresponds to the movement of the UI.

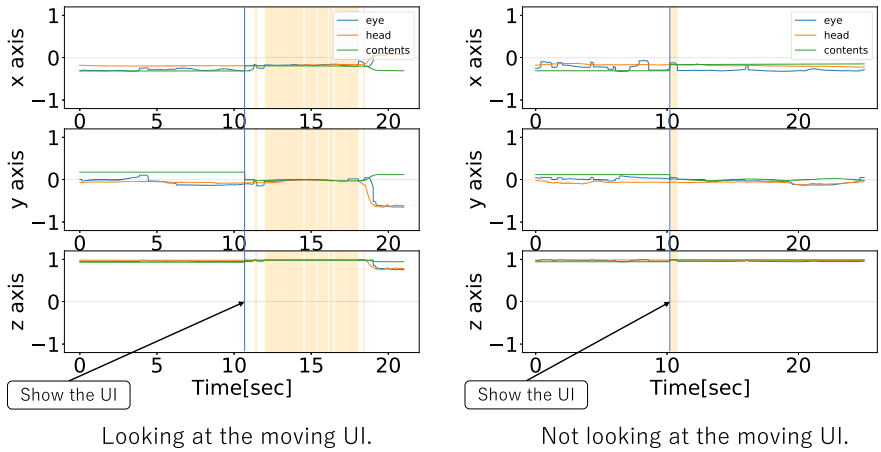


Fig. 5. Differences in eye movements during desk work: left) looking at the UI (yellow-painted area), right) not looking at the UI. (Color figure online)

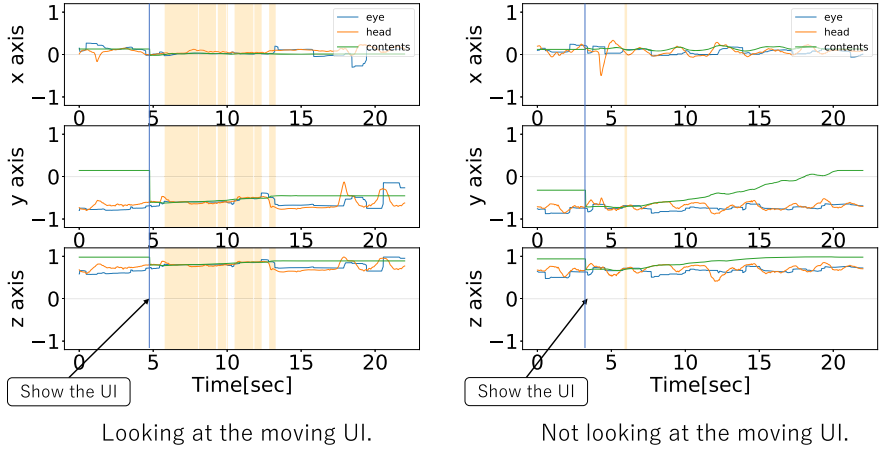


Fig. 6. Differences in eye movements during the meal: left) following the UI (yellow-painted area), right) not following the UI. (Color figure online)

User Survey. Table 2 is the result of the questionnaire about the usability of the UI conducted after the experiment. Table 2 is the average and variance values of the results of the five-point evaluation by five people. For desk work and search, all respondents answered that the movement and speed of the UI were easy to follow and slow, respectively, while for eating, the respondents were divided into those who answered that the UI was easy to follow but slow, and those who answered that the UI was fast and hard to follow. In all tasks, more respondents said they spent a long time staring.

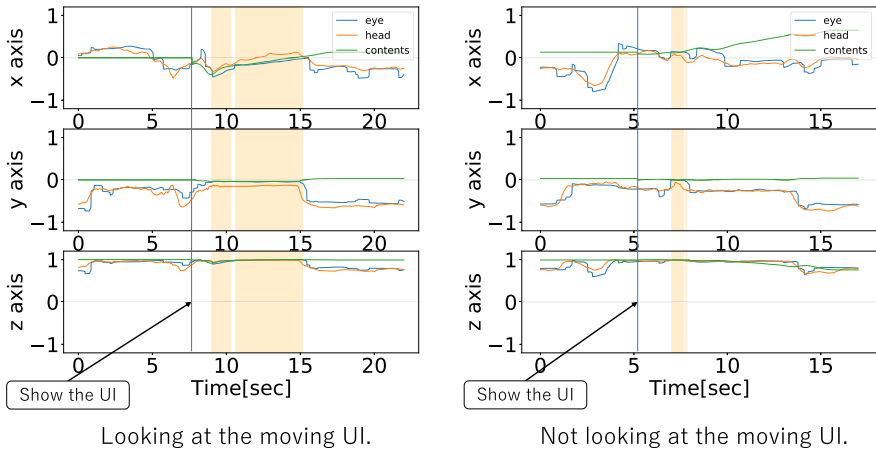


Fig. 7. Differences in eye movements while looking for a book: left) following the UI (yellow-colored area), right) not following the UI. (Color figure online)

Table 2. User survey on ease of following the UI

Question	DeskWork		Eating		Search	
	Ave.	Std.	Ave.	Std.	Ave.	Std.
How easy is the movement to follow? 1 easy - 5 difficult	1.6	0.547	2.6	1.341	1.8	1.788
How fast does the UI move? 1 fast to 5 slow	3.6	0.547	3.2	1.095	3.8	0.447
How high is the display position? 1 High - 5 Low	2.2	0.836	2.4	1.673	3.0	0.707
How about the side of the display position? 1 Left - 5 Right	2.6	0.894	3.0	1.224	3.4	0.894
How close is the depth of the display position?	3.2	1.095	3.2	1.095	3.4	0.894
How large is the UI? 1 large to 5 small	2.8	0.447	2.4	0.894	3.2	0.836
How short is the following time? 1 short - 5 long	4.0	0.707	3.4	0.894	3.8	0.447

4.3 Discussion

Accuracy of Gaze-Based Action Recognition. Preliminary experiments have shown that only gaze moves when working at a desk, that we look down most of the time when eating, and that our head moves vertically and our gaze moves horizontally significantly when looking for a book. We think it is possible to recognize behaviors in a limited number of tasks with data on gaze alone, but it is difficult to make judgments based on gaze alone when the scope is expanded to include indoor activities such as standing and sitting. However, by including the orientation of the head, we were able to obtain various behavioral characteristics, such as behaviors in which the head and eyes move in the same way, behaviors in which only the eyes move, and behaviors in which the head and eyes move separately.

Advantages of Moving the UI. By moving the UI, we were able to determine that the user is looking at the UI by encouraging eye movements that differ from the characteristics of eye movements during work. In addition, the determination of looking by moving the gaze is advantageous compared to other methods in that it does not depend on the size of the UI. Modalities such as gaze and hand tracking are in an “always on” state. Therefore, if the size is increased too much, it may cause malfunction. Therefore, the size needs to be adjusted.

Appropriateness of the Way the UI Works. In this experiment, we set up a simple motion that moves in a straight line. Therefore, users found it easy to follow the UI in most cases. However, simple motion is not always good, as we need to be able to robustly discard false positives as well as accurately follow the UI. In this experiment, we also set the speed of the UI to be slower and the gaze time to be longer for accuracy. However, according to the post-experiment questionnaire, most of the users answered that the speed was slow and the staring time was long. Since there is a trade-off between accuracy and speed of operation, we thought it would be necessary to adjust the speed depending on the situation.

In addition, the tasks performed in this experiment do not include actions that significantly change the background, such as walking actions. In such actions, the head direction and gaze are expected to fluctuate significantly. Therefore, it is necessary to consider the movement of the UI in consideration of the movement of the background.

5 Conclusion

In this paper, we investigated whether it is possible to determine whether the user is looking at the UI displayed in the virtual space or the background of the real space based on the user's head direction and eye movement by adding movement to the UI. In this study, five subjects were asked to perform three indoor tasks: working at a desk, eating, and searching for a book from a bookshelf. As a result, during desk work, the subjects' heads did not move, and only their gaze moved minutely. When they were eating, they looked down most of the time, and their head direction and eye movements were linked. When looking for a book, the head moved up and down, and the gaze moved left and right. From this experiment, it was found that the type of indoor task was associated with head orientation and gaze movement.

In addition, by taking into account the characteristics of eye movements for each activity, we proposed UI movements that can induce eye movements that do not appear in the activities. We implemented a UI that makes small up-and-down movements to the extent that the user does not have to move his or her head when working at a desk, climbs upward to turn the head upward when eating, and makes large sideways movements to move the head sideways when searching for a book. As a result of our experiments, we were able to determine

that the user was looking at the UI when the gaze and UI movement matched, and looking at the background when they did not.

However, after the experiment, we conducted a questionnaire survey on the viewability of the UI, and found that most of the users answered that the UI movement was easy to follow when they were working at a desk or looking for a book, while they were divided into two groups: easy to follow and hard to follow while eating. On the other hand, in all tasks, the respondents answered that the speed of UI movement was slow and that they spent a lot of time staring at it. In this experiment, we set the parameters to accurately capture what we are looking at, but in the future, we need to investigate various parameters to improve usability. Furthermore, although our approach is quite promising for hands-free task support, the tasks performed in this experiment are only a small part of indoor tasks. Therefore, we need to investigate the relationship between more behaviors and eye movements in order to know how to move the UI better.

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