Visual Effects of Turning Point and Travel Direction for Outdoor Navigation using Head-Mounted Display

Yuji Makimura[1], Aya Shiraiwa[1],
Masashi Nishiyama[1,2], and Yoshio Iwai[1,2]

[1] Graduate School of Sustainability Science, Tottori University
[2] Graduate School of Engineering, Tottori University
[3] Cross-informatics Research Center, Tottori University
101 Minami 4-chome, Koyama-cho, Tottori, 680-8550 Japan
`nishiyama@tottori-u.ac.jp`

Abstract. We investigate the visual effects of superimposing turning points and travel directions within the user's field of view in a navigation system using a subjective assessment procedure. Existing methods were developed without conducting subjective assessments of the effects of superimposing the turning points and travel directions on the user's display while walking outdoors. We therefore designed a questionnaire-based subjective assessment of the use of these navigation methods. We developed an outdoor navigation system using a recently launched optical see-through head-mounted display (HMD) product that was compact and lightweight. We demonstrated that the subjective scores in terms of understanding of the turning points and the travel directions were significantly increased by the visual effects of superimposing these cues on the display. We confirmed that the HMD helps to increase user likeability of use of the navigation system while walking outdoors.

Keywords: Visual effect, Navigation, Superimposed image, Turning point, Travel direction

1 Introduction

There is considerable demand for an outdoor navigation method that can guide users intuitively while they walk. Conventional navigation methods [1] guide users by providing a route on a map to allow the user to reach their destination smoothly. Before the user walks, he or she sets the destination at the starting point and selects the route that is suggested by the navigation method. While walking, the user checks for the required turning points on the map and searches for landmarks in the real world. Figure 1 illustrates the typical process of this type of navigation method. If the user understands and can determine the turning points in the real world, he or she can then determine the required travel direction. Otherwise, the user must laboriously repeat the navigation process

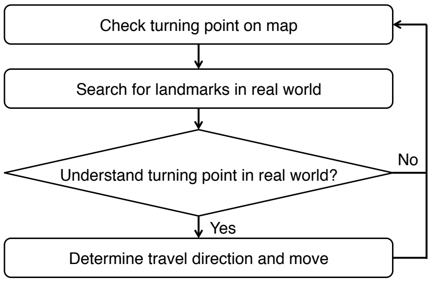

Fig. 1. Overview of conventional navigation method.

until he or she correctly understands both the turning points and the travel directions. Note here that a turning point is a location at which the user changes the travel direction to start the next stage of the journey, and the travel direction is a unit vector that is directed from the current position to the next turning point. A navigation method that leads to frequent repetition of the navigation process cannot guide the user intuitively. Ease of understanding of both the turning points and the travel directions for the user is therefore very important. Many researchers [2, 3] have attempted to design suitable navigation methods.

To reduce repetition in the navigation process, the existing methods [4, 5] often generate either a rough map or a written announcement. These existing methods can thus become a burden because they require the user to read the map or the announcement at least once. To eliminate the repetition from this process, existing methods [6, 7, 8, 9, 10, 11] generally overlay the navigational information on real world images. Narzt et al. [6] overlaid routes on images that were acquired from a camera equipped in a mobile device. Mulloni et al. [7, 8, 9] developed hand-held indoor navigation systems using mobile phones. Oliveira et al. [10] overlaid the travel directions on images using a process based on recognition of markers using a mobile device. For their car navigation application, Narzt et al. [11] overlaid the route when using a head-up display for the car's driver. We believe that users can understand the routes intuitively, including the turning points and the travel directions. However, holding up a mobile device or using a head-up display while walking can prove to be very inconvenient for the user.

In this work, we discuss a method to superimpose the turning points and the travel directions directly using an optical see-through head-mounted display (HMD). As described in [12, 13, 14, 15], an HMD helps the user to have intuitive understanding of the navigation process. In indoor navigation studies using HMDs, Rehman et al. [16] superimposed the travel directions, while Gerstweiler et al. [17] superimposed the route on the HMD. However, the existing methods assumed the case of indoor use. In addition, the existing methods did not assess whether or not the user understood the turning points and the travel directions intuitively. Recently, compact and lightweight commercial optical see-through HMDs have been launched. We are now able to test outdoor navigation with these HMDs using subjective assessment processes.

Fig. 2. This study investigated whether or not the visual effects of superimposing turning points and travel directions within the user's field of view help the user's understanding of the directions given while walking outdoors.

In this paper, we investigate the visual effects that are used in our method for outdoor navigation and demonstrate that they help the user to understand the turning points and the travel directions intuitively while walking by superimposing these directions directly into the real world using the HMD. Note that we consider the scenario in which the user is approaching a turning point while walking. Figure 2 illustrates the overview of the outdoor navigation process. We conducted a questionnaire-based subjective assessment of the navigation methods used with the HMD. The experimental results show that there was significant agreement among the participants about the visual effects of superimposing both the turning points and the travel directions. The rest of the paper is organized as follows. Section 2 describes the user study protocol, while Section 3 and Section 4 present the results of the subjective assessment. Our concluding remarks are given in Section 5.

2 Design of test for evaluation of the visual effects

2.1 Overview

We aimed to evaluate whether or not the visual effects of showing the turning point and the travel direction aid the user's understanding of these aspects. We therefore developed a navigation method that superimposed both the turning point and the travel direction in the user's field of vision using the HMD. We tested four possible methods, as follows:

M1 : The navigation method did not provide visual effects for the turning point or the travel direction.
M2 : The navigation method provided visual effects for the turning point only.
M3 : The navigation method provided visual effects for the travel direction only.
M4 : The navigation method provided visual effects for both the turning point and the travel direction.

We set a walking task for each participant using each navigation method. After walking, we used a questionnaire to ask each participant about the different navigation methods. We showed a printed map that included the starting point,

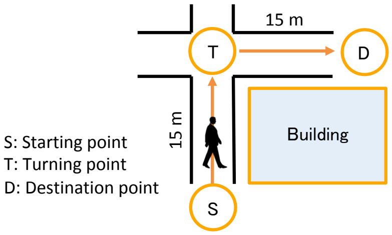

Fig. 3. Illustration showing the starting point, the turning point, and the destination point.

the turning point, and the destination point to each participant before they began walking. While the user walked, our navigation method provided the same voice guidance for each of methods M1 to M4 to inform the user of the timing of the turning point. The details of this evaluation are described below.

2.2 Walking task

We designed a walking task in which the participant moved from a starting point to a destination point. In the general case, there is a polarity for the turning points that are used for navigation. In our evaluation, we set the number of turning points to be one to simplify the navigation issue. We used a crossroads as the turning point. When standing at the starting point, the participant was able to see the turning point, but was unable to see the destination point, which was hidden behind a building. The distance from the starting point to the destination point was 30 m. We set the turning point to be 15 m forward from the starting point. Figure 3 shows the starting point, the turning point, and the destination point. We prepared two combinations of the starting point, the turning point, and the destination point. We used the combinations of these points at random for each assessment.

2.3 Representation of the turning point and the travel direction

We used a three-dimensional virtual object composed of an arrow to represent the turning point and/or the travel direction. The arrow object is frequently used in navigation systems, as described in [18]. Use of the arrow object was intended to ensure that the experimental conditions remained the same for each of methods M1 to M4.

Figure 4 shows examples of the superimposed arrow objects used for each navigation method. In this figure, the angle of view shown in the camera images is smaller than the actual angle of view of the participant. The arrow object had identical dimensions of 28 × 10 × 34 cm in each navigation system. We adjusted the height of the arrow object above the floor to suit each participant within the range of the vertical angle of view of the HMD. In method M2, we superimposed the arrow object at the three-dimensional location of the turning point to inform

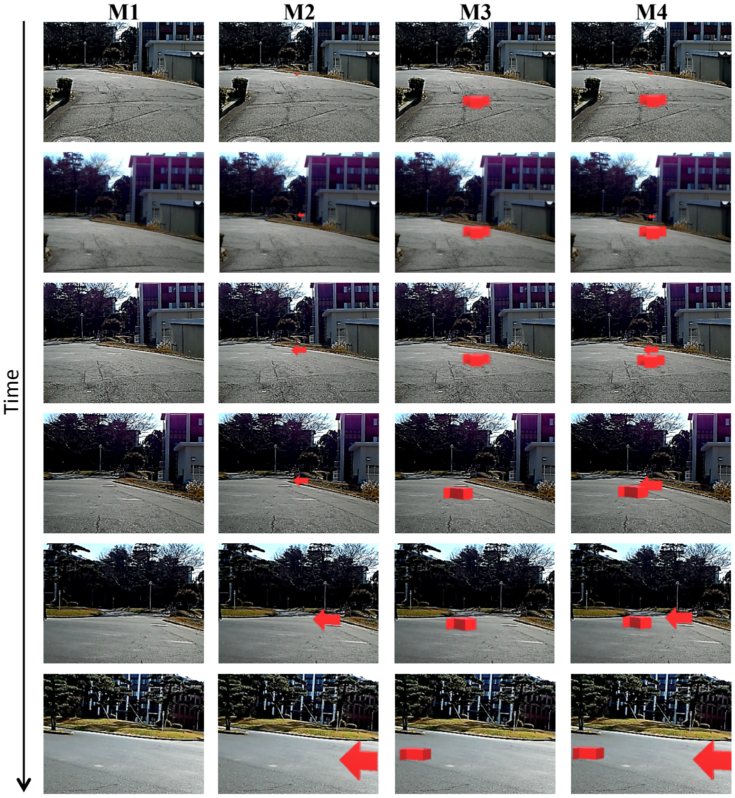

Fig. 4. Navigation methods M1 to M4 were compared to investigate the visual effects of superimposing the various combinations of the turning point and the travel direction. The participants walked wearing the HMD while using each navigation method. In this figure, we have overlaid the arrow objects on images that were acquired from a camera that was attached close to the eye level of the user.

the user of the turning direction. The navigation system varied the size of the arrow object based on the distance from the current position to the turning point. In method M3, we superimposed the arrow object to inform the user of the travel direction. We set the arrow object at a distance of 2 m in front of the user's current position. The navigation method changed the direction of the arrow when the user reached a distance of 1 m from the turning point. The arrow turns stepwise by 45 degrees rather than turning by 90 degrees around the turning point. We assumed that each walking human moves by 1 m over a period of 0.75 s, as described in [19]. In method M4, we superimposed arrow objects for both the turning point and the travel direction in the user's field of view by combining methods M2 and M3. Note that the arrows of methods M2 and M3 never crossed because the arrow in M3 turns stepwise around the turning point, as described above.

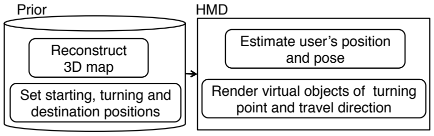

Fig. 5. Architecture of proposed navigation method using the HMD. We used an HMD (HoloLens Development Edition, Microsoft). Our method superimposed the arrow objects by rendering them on the display based on the position and the pose of the user.

Fig. 6. Participant wearing the HMD.

2.4 Optical see-through HMD

Using the HMD, we developed navigation methods to superimpose the arrow objects within the user's field of view. Figure 5 illustrates the architecture of our navigation method. We used an HMD (HoloLens Development Edition, Microsoft) that was equipped with an optical see-through display, an inertial measurement unit, cameras and a speaker. The HMD is capable of acquiring both the position and the pose of the user in real time. Figure 6 shows a participant wearing the HMD. Our method superimposed the arrow objects that represented the turning point and the travel direction by rendering them on the display based on the position and the pose of the user. We reconstructed a three-dimensional (3D) map to represent the surroundings of the road to be navigated in advance of the experiments. Figure 7(a) shows the reconstructed 3D map. The HMD renders the arrow on the 3D map shown in part (b) in the participant's field of view, which is illustrated in part (c). We also set the locations of the starting, turning, and destination points on this map in advance. We assumed that no obstacles were present on the road during the period in which user was walking.

3 Questionnaire-based subjective assessment of turning point and travel direction

3.1 Design of the subjective assessment

Sixteen participants (13 males and three females, with an average age of 22.3 ± 1.6 years old) participated in the study. We used Scheffe's paired comparisons method [20] (Ura Variation [21]) in the assessment. We set various pairs of the navigation methods 12 ($= {}_4C_2 \times 2$) times. For each pair of methods, the

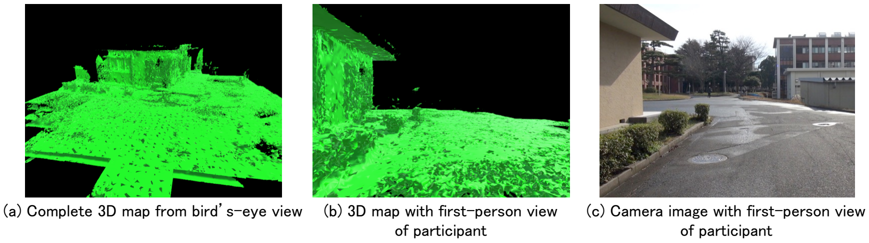
(a) Complete 3D map from bird' s-eye view (b) 3D map with first-person view of participant (c) Camera image with first-person view of participant

Fig. 7. Reconstructed 3D map of the surroundings of the road shown in part (a). The HMD renders the arrow on the 3D map shown in part (b) in the participant's field of view, which is illustrated in part (c).

participant used first the former and then the latter navigation method. We then asked each participant the following questions:

Questions
Q1: Which navigation method made it easy to understand the turning point?
Q2: Which navigation method made it easy to understand the travel direction?

Answers (four response levels)
- Absolutely the former navigation method (-1.5)
- Maybe the former navigation method (-0.5)
- Maybe the latter navigation method (0.5)
- Absolutely the latter navigation method (1.5)

We also asked the inverse questions of Q1 and Q2, i.e., to determine which method made it more difficult to understand the travel direction and the turning point. Each participant selected an answer for each question of each pair. We showed the pairs of questions to the participants in random order.

3.2 Results of the subjective assessment

Figure 8 shows the subjective scores from the questionnaire. Yardstick Y indicates that there is a significant difference of 5% or 1% when the difference in subjective scores between the navigation methods is larger than $Y(0.05)$ or $Y(0.01)$, respectively. In the answers to Q1 and Q2, there were significant differences between method M4 and the other three methods. We can therefore claim that each user found it easier to understand the turning point and the travel direction when using method M4, as compared with methods M1 to M3. In the answers to Q1, no significant difference was observed between methods M2 and M3. Despite the fact that M2 superimposes the turning point in the user's field of view, we cannot claim that the user found it easier to understand the turning point when using M2 as compared with M3. In the answers to Q2, however, there was a significant difference between M2 and M3. We can thus claim that the user found it easier to understand the travel direction when using M3 rather than M2 because M3 superimposes the travel direction in their field of view.

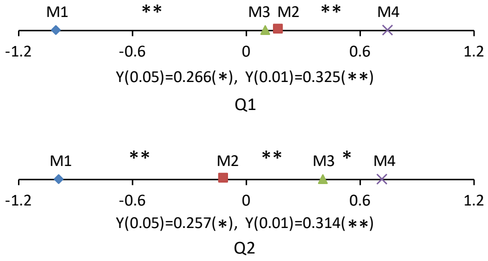

Fig. 8. Rated scores of participants' understanding obtained via comparison of navigation methods M1 to M4.

3.3 Assessment of likeability

We also evaluated the likeability of the navigation methods that superimposed the turning point and the travel direction in the user's field of view. We used the same procedure that was described in Section 3.1. We asked the participants the following questions:

Q3: Which navigation method guided you intuitively?
Q4: Which navigation method guided you comfortably?

We also asked the inverse questions of Q3 and Q4, i.e., to establish which of the navigation methods guided the users less intuitively or comfortably. The answers were given with the same four response levels.

Figure 9 shows the subjective scores that were obtained from the questionnaire. In the answers to Q3 and Q4, significant differences were again found between method M4 and the other three methods. We can therefore claim that M4 increases the likeability of the navigation method for the users when compared with methods M1 to M3. We also observed that M3 obtained better subjective scores than M2. We believe that the users preferred the dynamic movement of the arrow in M3 in accordance with the movement of the users when compared with the static fixed arrow in M2.

4 Assessment of the visual effect of the route

4.1 Design of the route navigation method

We evaluated the visual effects of superimposing a route that contained both the turning point and the travel direction in the user's field of view using the following method:

M5: The navigation method showed the route within the range in which the user is looking.

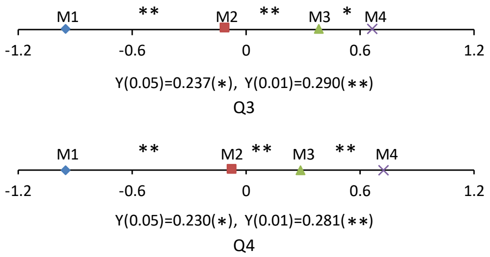

Fig. 9. Rated likeability scores obtained via comparison of navigation methods M1 to M4.

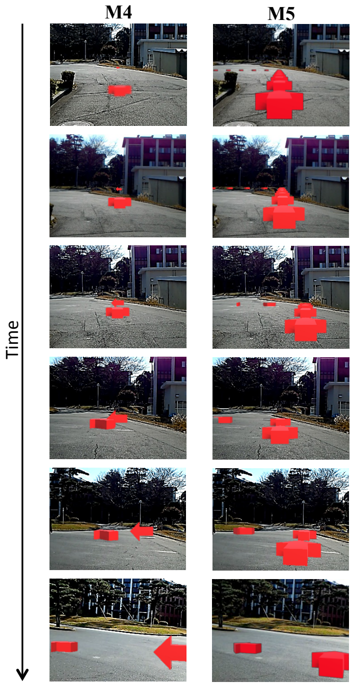

Fig. 10. Navigation method M5 for evaluation of the visual effects of a route that contains both the turning point and the travel direction.

The method again used the arrow objects to represent the route. We set the arrow objects at 1 m intervals over the route from the starting point to the destination point. Figure 10 shows an example of the superimposed arrow objects used for method M5. Each participant evaluated navigation methods M4 and M5. The reason for the use of the arrow objects here was that we intended to maintain consistent experimental conditions between M4 and M5.

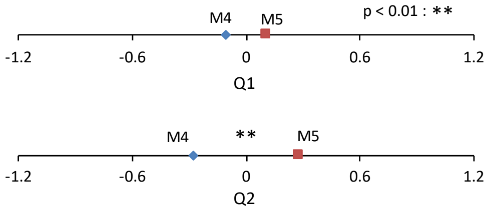

Fig. 11. Rated scores of participants' understanding obtained via comparison of methods M4 and M5.

4.2 Results of superimposing the route

Ten participants (eight males and two females, with an average age of 22.9 ± 1.3 years old) participated in the study. We compared the subjective scores of the participants for methods M4 and M5 using Q1 and Q2 from the questionnaire that was described in Section 3.1. Each participant used methods M4 and M5 in random order and then answered the questionnaire.

Figure 11 shows the subjective scores that were obtained from the questionnaire. We used the Wilcoxon signed-rank test in this case. There were no significant differences ($p < 0.01$) between the methods for Q1. We believe that the users felt that they were able to understand the turning point that was provided by M5 in a similar manner to that provided by M4. However, there was a significant difference for Q2. We believe that the users felt that it was easier to understand the travel directions provided by M5 when compared with M4 because method M5 superimposed the future travel directions in the field of view in addition to the current travel direction.

4.3 Likeability of superimposing the route

We also evaluated the likeability of the navigation methods in which the route is superimposed. We used the same procedure that was described in Section 4.1 with questions Q3 and Q4.

Figure 12 shows the subjective scores that were obtained from the questionnaire. No significant differences were observed between M4 and M5. We therefore cannot claim that M5 increased the likeability for the users when compared with M4. After completion of the experiments, we issued a free-form questionnaire to the participants. From this questionnaire, we obtained the opinion that a single moving arrow was sufficient for navigation, while there was also the opinion that it is preferable to superimpose a number of arrows simultaneously. The results for the likeability of the route were different for each participant. We therefore need to perform a further subjective assessment of the method of displaying the route.

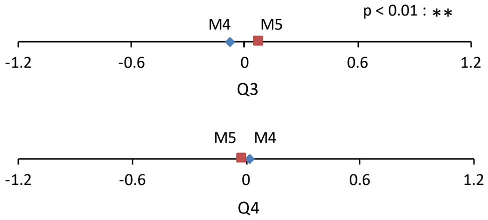

Fig. 12. Rated likeability scores obtained via comparison of methods M4 and M5.

5 Conclusions

We have demonstrated the visual effects of showing the turning point and the travel direction in navigation systems by superimposing them in the user's field of view using a commercial HMD. The combination of the turning point and the travel direction produced higher subjective scores in terms of user understanding when compared with use of only one of these directions. A route that contained the turning point and the current and future travel directions increased the subjective score in terms of both user understanding and likeability of the travel direction when compared with the simpler combination of the turning point and the travel direction.

In future work, we will expand our assessment of the system's usability, and we also intend to develop a navigation method using more complex outdoor routes.

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