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# Lost again on the way? : Measuring Human Map-Reading Ability

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Recently, various navigation systems have found a place in many aspects of our daily life. However, it is difficult for people to effectively use such a system because the ability to understand the maps generated by and the guidance given by the system differs from person to person. We think that the fact that the system gives the same guidance to everyone is a problem for some people. Therefore, it is necessary for us to investigate a person's ability to understand maps and the related guidance, that is, the human map-reading ability. Moreover, we consider that it is important that a navigation system analyzes the map-reading ability of its user and highlights the user's weaknesses in this aspect. In this paper, we have developed a system to simulate the way people find a particular place in real space. First, we performed outdoor experiments for studying how pedestrians find their way to a certain place by using the proposed system. Next, we proposed three major indicators of pedestrian behavior and finally measured the human map-reading ability using the proposed system. Consequently, we think that our approach will open up a new vista for personal guidance services.

## 1. Introduction

Recently, many online map services and navigational systems have become pervasive as pedestrians or drivers are easily guided by these smart systems. However, there are still some people who are struggling with route finding in spite of using navigation devices. We often complain about the routes that the navigational systems present on the increasingly popular positioning systems. However, before criticizing the limitations of the systems, we need to consider the human ability to recognize the real world and to find routes. That is, a primitive question arises: why do people get so lost and how does the ability to find the correct route differ among people?

The understanding of human beings' various capabilities has been applied as a universal theme in various fields from psychology to user-interface engineering. In this paper, we are challenged to reason the human map-reading ability in a new fashion with a methodology currently available. In this paper, we refer to the term "map-reading ability" as a rather generalized ability, including the capability to find ways well using maps. In general, we believe that the map-reading ability differs from person to person. While the complete understanding of such a capability requires many interdisciplinary studies, we can easily imagine that someone who has lived in a suburban area with small buildings for her lifetime would have a tendency to lose her way in a big city that has sophisticated structures [9, 10]. It can be understood that her geo-space recognition has not been developed to find ways for such sophisticated places as the canyon of city buildings [3, 4]. Ellard [1, 2] wrote in his book that it is important that we better understand how the human mind works, rather than look for technological solutions to all of our problems. He insists that there needs to be a greater connection to psychology for architects and urban planners to better design our physical spaces for facilitating human way finding. We think that his opinion is important. We consider that not only the architect but also the developer of a navigation system should consider the human map-reading ability. Then, the navigation system will be able to provide the most suitable guidance for a user. Therefore, we attempt to measure the human map-reading ability. To achieve our purpose of providing a simplified map to users, we think that the measurement of each person's map-reading ability is very essential.

However, unlike other information searches, recommendations [7], or user adaptive systems [6, 8], such an ability cannot be easily represented even by the people themselves. That is, while a person, who lacks a sense of direction, can know that she often finds herself struggling to find the right way to a place, it is difficult to explain what the problem is in detail. Therefore, we think that it is important for a navigation system to allow for the differences in the human map-reading ability and provide support in both a real space and a virtual space. This invisible and ambiguous capability should be measured in an objective and a quantifiable way. Therefore, our hypothesis is that we can model a user's ability for reading and understanding maps by analyzing the action of the user on the spot on the basis of a course and measure this ability with a computer-based simulation. This approach can estimate users' capability with a minimal effort and cost by emulating real-world walking or driving conditions. We repeated the experiment, except that subjects walked a real-world route, and we compared the results to those of the computer-based simulation.

The rest of this paper is organized as follows. Section 2 describes our approach to estimating the human map-reading ability in a systematic method. Section 3 explains the preliminary experiment. Section 4 demonstrates the designed measurements. Section 5 shows the simulation results of the developed system. Section 6 concludes the paper and discusses future work.

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## 2. Map-Reading Ability and Simulation System

### 2.1 System for Measuring Human Map-Reading Ability

The term map-reading ability refers to the ability of people to read and understand a map. This ability differs from person to person. Therefore, it is inappropriate that online map services and navigation systems show the same map for all users. For instance, in the case of a user who cannot find landmarks, these systems have to show a map in which landmarks are emphasized. In the case of a user who is weak at interpreting directions at crossings, the system should show a route that avoids crossings. In order to program navigation systems to do these things, we consider that we need to measure the human map-reading ability. Moreover, it is important that these systems themselves measure the human map-reading ability. Therefore, we have developed a way-finding simulation system for measuring the human map-reading ability.


Figure 1: Way-Finding Simulation System

### 2.2 Way-Finding Simulation System bBased on Street View

In order to simulate the outdoor navigation and evaluate the user's map-reading ability, we have developed a simulation system with two types of maps, as shown in Figure 1. In the interface, the left side shows a 2D map [5], whereas the right side shows a 3D street view of a Google map. From both these maps, a user faces a situation similar to that in the experiment that we performed in an outdoor field; that is, the left map corresponds to a paper map given to the user, and the right view gives the user the simulated real-world scenes. The user can operate the left map in a manner similar to browsing a paper map. On the other hand, the right view can simulate the user walking virtually and show the real scenes. In addition, to confirm the surroundings of a position, the user can see other sides by panning or tilting the view left/right or upward/downward. Of course, this simulation system cannot perfectly simulate a real-world situation. The human behaviors possible in outdoor environments are explicitly different from the ones possible in the system. However, this system provides a practical solution to measure such a sophisticated ability with less effort and time. By observing the user's navigation of a route given in this system, we can measure the user's map-reading ability as a numerical value and clarify, in detail, the reasons for a lack of sense of direction through the measurements. We can analyze the behaviors of a user by using the user's operation history. First, we analyzed the behavior of the user in a real space to make it possible to measure his/her map-reading ability more precisely. We will discuss the experiment next.

## 3. Preliminary Experiment

In order to find out the major reasons why people become confused when walking on an unfamiliar route, we performed an outdoor route finding experiment. Before the experiment, we conducted a survey to know each participant's route finding ability with a well-organized questionnaire. In this section, we will describe the questionnaire survey and the experiment and show the strong relationship between the two tests. As participants in the experiments, six students who were randomly selected from our department joined the following tests voluntarily.

Table 1: Details of Real-Navi Setting

| | |
|---|---|
| Investigation day | 2009,10,1 |
| Map | Paper map |
| Object route | R1(Route 1): 1, Shinzaike−honcyo, Himeji, Hyogo～Yashiro−tokojicyo, Himeji, Hyogo |
| | R2(Route 2): Yashiro−tokojicyo, Himeji, Hyogo ～Nishiyashirocyo, Himeji, Hyogo |
| #Crossing | R1: 15, R2: 11 |
| #Corner | R1: 7, R2: 8 |
| Participant | University student 6 |
| | (Man 3, Woman 3) |
| | (Age 21～23) |
| Route information | R1: Total distance: 780m, Travel time: 9min |
| | R2: Total distance: 600m, Travel time: 7min |

### 3.1 Questionnaire

Before performing the experiment, each participant was tested for his/her geo-spatial sensing ability with a well-organized questionnaire, as shown in Table 2, which was devised by Takeuchi [11, 12] to judge a person's sense of direction. We let them answer the questionnaire, because we wanted to recognize the subjective knowledge of each participant. The questionnaire was composed of 20 questions. Each question had to be given a score from 1 to 5; therefore, the total score was in the range of 20 to 100. However, this result does not necessarily accurately estimate the ability of each participant.

### 3.2 Observation of Way-Finders' Behaviors

In this preliminary experiment, we performed an actual route finding experiment in outdoor fields to build a set of measurements to represent the participants' map-reading ability. For the outdoor experiment called **Real-Navi**, we prepared two routes, as shown in Figure 2. The first one (Figure 2(a)) was a residential district; therefore, there were very few landmarks on this route. Furthermore, at the spot indicated by the red circle in Figure 2(a), the name of the shop was changed. The other path is shown in Figure 2(b). At the spot indicated by the red circle in Figure 2(b), there is a very small road, such as a back street, and it is very difficult for pedestrians to find this road. The two paths were unfamiliar to all the participants, and their visual representations were not given in advance. The other experimental settings are given in Table 1. We observed seven factors—"Total Time," "Missing Route," "Right and Left Confirmation," "Map Confirmation," "Stop," "Return," and "Rotating a Map." We express the "total time" in minutes and the other factors with numbers.

Table 2: Result of Questionnaire Survey

| | Sense of Direction Questionnaire-Short Form (SDQ-S) | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 1 | I lose the directions north, south, east, and west if I go to a new place. | 1 | 1 | 1 | 2 | 5 | 3 |
| ※2 | I do not make mistakes in identifying directions, even if I am in an unkown place. | 1 | 1 | 1 | 4 | 5 | 4 |
| 3 | I can understand an indication of a direction, if it is specified by ˝Left or Right˝ but not if it is specified by ˝North, South, East or West˝. | 2 | 2 | 2 | 4 | 5 | 4 |
| 4 | It is difficult to understand if the train is traveling north, south, east or west. | 5 | 2 | 1 | 4 | 5 | 5 |
| 5 | I do not have confidence in the direction I am walking if I do not know the place and I become uneasy. | 1 | 2 | 3 | 3 | 3 | 4 |
| 6 | I do not understand which direction the room faces when in a hotel room. | 1 | 2 | 1 | 1 | 4 | 3 |
| 7 | It is considerably difficult to go to a new place, even if I examined a map beforehand. | 1 | 3 | 4 | 5 | 5 | 4 |
| ※8 | I can find the position where I am located on a map immediately. | 3 | 2 | 3 | 4 | 4 | 2 |
| ※9 | I can easily and vividly remember the image of the map in my head. | 5 | 1 | 2 | 4 | 5 | 2 |
| 10 | I cannot memorize a mark at landmarks. | 3 | 3 | 5 | 5 | 3 | 4 |
| 11 | I cannot easily find object to be landmarks. | 3 | 2 | 5 | 5 | 5 | 4 |
| 12 | Even if a place is visited many times, I cannot remenber landmark in the area. | 5 | 3 | 5 | 5 | 5 | 3 |
| 13 | I cannot distinguish and remember differences in scenery. | 3 | 2 | 5 | 4 | 4 | 4 |
| 14 | When I drive to a destination with a lot of turns, I often forget the way I went to get there. | 2 | 1 | 2 | 4 | 5 | 3 |
| 15 | I often forget where I previously turned. | 2 | 2 | 2 | 4 | 5 | 4 |
| 16 | I do not confirm landmarks at turning points. | 3 | 3 | 5 | 4 | 4 | 4 |
| 17 | Although I was told the way to go, I could not follow the way correctly. | 4 | 3 | 4 | 5 | 5 | 3 |
| 18 | In a residential area, if there was a row of similer houses, I could not figure out the destination. | 1 | 2 | 2 | 4 | 3 | 3 |
| ※19 | I can immediately distinguish between roads of similar appearance. | 1 | 2 | 3 | 4 | 3 | 2 |
| 20 | Whenever I walk with other people toward a destination, I do not worry about whether the route is | 2 | 1 | 3 | 5 | 3 | 4 |
| | Total | 49 | 40 | 59 | 80 | 86 | 69 |
| | Direction score (1-9) | 20 | 16 | 18 | 31 | 41 | 31 |
| | Space score (10-16) | 21 | 16 | 29 | 31 | 31 | 26 |

Score: Yes(=1)～No(=5), but for question marked with (※) score: No(=1)～Yes(=5)


(a) Route 1 in Real-Navi


(b)Route 2 in Real-Navi

Figure 2: Routes Designated for Outdoor Experiment

In the field experiment, we performed the test according to the following procedure:

<u>Experimental Procedure in Real-Navi</u>:

**Step 1.** Each participant was positioned at the starting point and given only a paper map without any other guidance. There were two monitoring people. One was a camera man who recorded all the scenes with a video camera along the way. Another logger registered all the behaviors of the participant and noted his/her characteristic activities. The monitors did not give any guidance or intermit the navigation, but only observed the behavior of the participants during the short trip until the participants reached the destination.

**Step 2.** Each participant and two monitors walked the path toward the destination. At every crossing point, the logger registered the details of all the behaviors: for instance, what the participant gazed at intently, which way he/she faced, or whether he/she raised the map to re-confirm the way. In addition, if the participant lost his/her way, data such as how far he/she is from the right path was registered.

**Step 3.** Finally, near the destination, each participant announced to the monitors whether he/she could reach the destination as a confirmation.

We paid attention to the relation of a participant's behavior to the difference in the questionnaire score. We have tabulated the behavior of the participants in Tables 3 and 4. Then, the behaviors from the questionnaire survey were considered, and a correlation was obtained with respect to the three factors of "Missing Route," "Right and Left Confirmation," and "Map Confirmation." Therefore, we think that these three factors are important and focus only on them.

We could determine significant differences between the novices and the experts in our experiment. As a result of Tables 3 and 4, we could distinguish the participants into two groups: the novices and the experts. In the novice group, the number of these factors was definitely higher compared to the other group. However, the second factor "Missing Route" was also important, while the number of its occurrences was not helpful in separating the participants into two groups. In the case of the second route, all the participants made a mistake at the fifth cross point. At this location, most participants went straight toward the west; although they had to turn left at the point, they soon became aware of their mistake, came back to point 5, and were able to find the correct route.

Table 3: User Behavior Patterns in Route 1

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Questionnaire Score | 49 | 40 | 59 | 80 | 86 | 69 |
| Total Time(minutes) | 10 | 13 | 15 | 7 | 7 | 11 |
| #Missing Route | 0 | 0 | 1 | 0 | 0 | 0 |
| #Right and Left Confirmation | 55 | 58 | 32 | 26 | 21 | 49 |
| #Map Confirmation | 80 | 91 | 88 | 39 | 32 | 89 |
| #Stop | 3 | 0 | 2 | 2 | 2 | 2 |
| #Return | 0 | 0 | 1 | 0 | 0 | 0 |
| #Rotating a Map | 0 | 6 | 7 | 5 | 0 | 0 |

Table 4: User Behavior Patterns in Route 2

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Questionnaire Score | 49 | 40 | 59 | 80 | 86 | 69 |
| Total Time(minutes) | 8 | 11 | 8 | 10 | 8 | 9 |
| #Missing Route | 0 | 0 | 1 | 0 | 0 | 0 |
| #Right and Left Confirmation | 47 | 49 | 22 | 45 | 20 | 39 |
| #Map Confirmation | 84 | 87 | 60 | 50 | 21 | 77 |
| #Stop | 2 | 1 | 2 | 3 | 2 | 3 |
| #Return | 1 | 1 | 0 | 1 | 1 | 1 |
| #Rotating a Map | 0 | 7 | 8 | 8 | 0 | 0 |

However, participant C did not come back to point 5; instead, participant C followed another route but could still reach the destination. In other words, the participant's traversal routes were a little different from the given route. In addition, the expert group (D and E) did not confirm the direction or review the map as frequently as compared to the novice group (A, B, C, and F) on an average. For instance, the expert group (D and E) confirmed only an important point that a store name was changed; further, only when there was a main landmark, they referred to the maps well. Because they limited their references to a specific point on the map to confirm whether to go to the right or the left, they seemed to understand the information that was necessary for reaching their destination. On the other hand, because the novice group (A, B, C, and F) referred to the map and confirmed the right and left directions many times, they could not decide their own landmark.

## 4. Design of Measurement

In the preliminary experiments, we found the missing-way patterns as follows:

- **Frequent referring to a map:** People who lacked a sense of geo-spatial region often needed to confirm the content of the map.
- **Re-confirming the direction at crossing points:** People with a good sense of direction quickly determined their direction on the way.
- **Recovering the mistake and moving to the right path:** People who lacked a sense of direction could not recover their misses by going back to the previous points on the way.

The three factors that we observed in the real-world experiment were the same most occurring ones as those observed in our simulation in the case of users who could not reach their given destinations. In particular, these errors described how we could help users in finding their way on the basis of their shortcomings. Furthermore, each pattern could be measured in our system by previewing the route search, where each person reviewed the searched route as we did in our simulation. That is, by operating in the 2D map and 3D street views, we could speculate each person's ability in selecting the right way at a crossing point, maintaining their destination direction, and judging the most important regions to be focused upon. To measure these specific abilities, we developed the following measurable indicators:

- **SoM (Sense of Space Memorizing):** How many times does each participant need to refer to a map?
- **SoD (Sense of Direction):** How precise and quickly does the participant detect the direction to follow?
- **SoP (Sense of Positioning):** If the participant made a mistake, could he/she recover from the problem soon?

At the current stage, we deal with each measurement equally since one measurement does not seem to be more critical than another. The methodologies to measure each indicator are depicted in Figure 3. First, for judging where to focus on a map, a user generally needs to check important regions such as the intersections and the detailed area around the destination itself so as to not miss the final stage. For this, every corner along a route and the destination area were previously determined. Like the expression of SoM, the ratio of the actually viewed regions focused on to the prepared list was represented as a normalized value. Second, the maximum angle of route direction and user's eye direction were also acquired and normalized by calculating the SoD formula. Here, $route\_vector_i$ is the $i^{th}$ line-segment vector, and $eye\_vector_i$ is the widest vector at the $i^{th}$ position. When the angle is large, we believe that the user's attention is at a low level; the user did not gaze at a specific landmark or toward the goal, and instead looked at other less related objects. In addition, the user, while looking away from the route, could easily lose the direction toward the destination or correct paths. Therefore, it could be validated that the sense of direction would be weak when the user's eye angle is larger than the threshold. Lastly, by using the expression of SoP, we could obtain and normalize the differential area. These indicators have been measured with the following formulae:

$$SoM = \frac{count(user\_selected \cap candidate)}{count(candidate)} \bullet \frac{1}{(1+\#reconfirm)}$$

$$SoD = \frac{|route\_vector_i \times eye\_vector_i|}{|route\_vector_i||eye\_vector_i|}$$

$$SoP = \frac{1}{1+\left|\int user\_path - \int route\right|} \bullet \frac{length(route)}{length(user\_path)}$$

Finally, each result, given as a normalized value between 0.0 and 1.0, was summed up and divided by 3.0 in order to obtain the total map-reading ability.

**Map-Reading Ability** = (SoM + SoD + SoP)/3.0

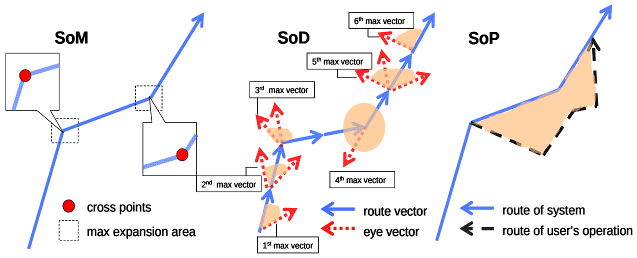



Figure 3: Indicators of Map-Reading Ability

With these measures, we reexamined the results of Real-Navi, scored them, and compared the results with those of the first questionnaire survey. As a result, we found that these two results had a strong relation, as shown in Figure 4. Therefore, we can say that our measurements can reflect the human map-reading ability with a considerable accuracy.

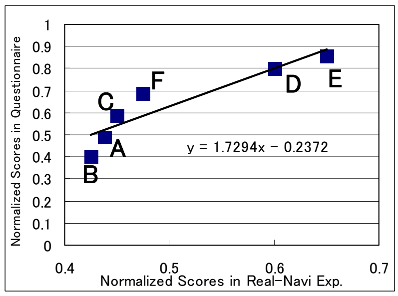



Figure 4: Correlation of Questionnaire Survey and Real-Navi

## 5. Measuring in Simulated Way-Finding

In this section, we describe a simulation system to evaluate the human map-reading ability on the basis of the measurements designed from the preliminary experiments. With this system, a user can navigate a given route and know his/her self-ability with an estimated value.

### 5.1 Experiment

For the computer-based simulation experiment called **Virtual-Navi**, we prepared two routes, as shown on the left map of Figure 5. The first one was very simple and easy. However, there are few landmarks on the route. Furthermore, in the spot indicated by the red circle in Figure 5(a), the street view had a malfunction. In this spot, the screen only showed the wall of a house. Therefore, the participants lost their sense of direction at this point. The other path, shown in Figure 5(b), had very similar scenery for a long portion of the route. In addition, it was difficult for the participants to look around the surroundings because there were high buildings. Of course, these two paths were unfamiliar to all the participants, and their visual representations were not given to the participants in advance. The other experimental settings are listed in Table 5.

Table 5: Detail of Virtual-Navi Setting

| | |
|---|---|
| Investigation day | 2009.10.5 |
| Object route | R3(Route 3): Nitto elementary school～A kindergarten attached to the Nihonbashi elementary |
| | R4(Route 4): Nishiumeda～Higobashi |
| #Crossing | R3: 11, R4: 19 |
| #Corner | R3: 5, R4: 4 |
| Participant | University student 6 |
| | (Man 3, Woman 3) |
| | (Age 21～23) |
| System information | Visual studio 2008 C# |
| | 2 screen (Left: Online Map, Right: Street-View) |
| | Record history(operation name, cordinate, angle) |
| Map operation | Moving, Centering, Zooming in, Zooming out |
| Street-View operation | Moving, Centering, Zooming in, Zooming out, Pan, Tilt |
| Route information | R3: Total distance: 600m, Travel time: 8min |
| | R4: Total distance: 2km, Travel time: 30min |

(a) Route 1 in Virtual-Navi

(b) Route 2 in Virtual-Navi

Figure 5: Routes Designated for Computer- bBased Simulation Experiment

<u>Experimental Procedure in Virtual-Navi</u>

**Step** 1. We allowed the participants to practice for the street-view operation. The participants had not previously used the street-view display. By allowing them to practice, we reduced the gap between the simulation and real-world navigation.

**Step** 2. We gave a route on the map and let the participants operate street view to go toward the destination. We fixed a camera so that the screen of the system entered and recorded all operations.

**Step** 3. Finally, near the destination, the participants announced to the monitors whether they could reach the destination as a confirmation. After the experiment, we also performed a verbal investigation to ask about where the most confusing point was, etc.

## 5.2 Experimental Result

Participants D and E had high scores, and the other participants had low scores. This resembles the questionnaire survey results, except in the case of F who had a low Virtual-Navi score yet a high questionnaire score. The correlation of the questionnaire survey and Real-Navi is low in the case of participant F, as shown Figure 4.

However, we can see a high correlation between Real-Navi and the computer-based simulation by using our measurements (Figure 6). In other words, we can measure the map-reading ability of a person by a computer-based simulation even if we do not go out into the field. Therefore, it can be said that our measurements are well organized and appropriate to estimate the human map-reading ability with high precision.

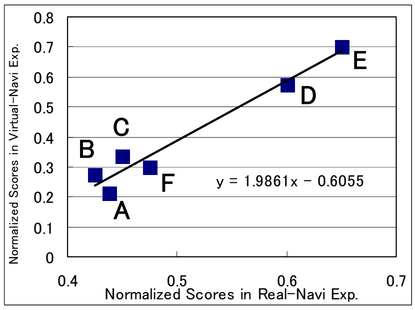
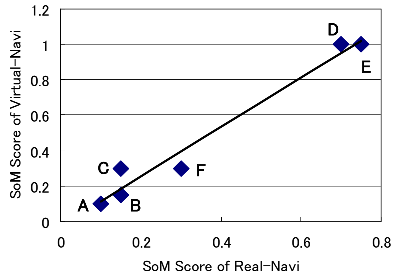
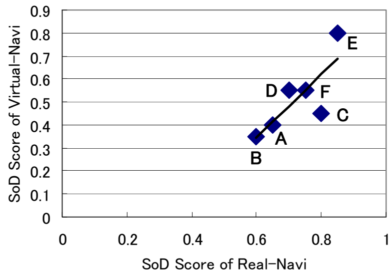


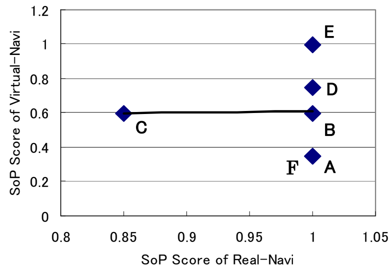

Figure 6: Correlation of Virtual-Navi and Real Navi




(a) Sense of Space Memorizing




(b) Sense of Direction




(c) Sense of Positioning

Figure 7: Correlation of Virtual-Navi and Real Navi (Three Measures)

Furthermore, we expressed a correlation according to each indicator of the map-reading ability, as shown in Figures 7(a)–(c). With respect to SoM, the correlation of Real-Navi and Virtual-Navi is very strong (Figure 7(a)). The novice group (A, B, C, and F) tend to always expand the online maps, such as SoM in SoD, and it is thought that SoM lacks as for them for these factors (Figure 7(b)). In addition, the correlation is very strong with respect to SoD. However, it follows that participant F resembled participant D, although their groups were different. We understood that the level of their SoD was about the same. Therefore we found that it cannot be said that all ability was high even if map-reading ability was high. It was proved by this result. On the other hand, the result of SoP was not very good (Figure 7(c)). From this, we understood that a review and the improvement of the indicator were necessary.

## 6. Conclusion

In this paper, we developed a system to estimate the human map-reading ability on the basis of the measurement of three measures. In order to design the measurements and validate their correctness, we conducted a questionnaire survey and outdoor experiments and found significant reasons why the participants lost their ways. We modeled such reasons with measurements for testing the participants' sense of space memory, sense of direction, and sense of positioning. Although these factors were often thought to be the major reason of losing one's way, we could find the reasons from our experiments and formalize them as measurable indicators. Based on these measures, we computed the correlation between the questionnaire survey and the outdoor experiment and showed a strong relation to validate our measurements. We also performed another experiment to estimate the same ability in our system with the same measurements. As a result, we found that the simulation could estimate the human map-reading ability almost similarly to the outdoor experiments or questionnaires. This means that with a little effort from users, the system can reveal their map-reading ability with high precision. Furthermore, the proposed system is considerably better than the questionnaire survey to analyze, in detail, the participant's ability to find his/her way. Therefore, we think that we can develop a personalized navigation system. For instance, navigation system can show route guide based on tendency of user by history of user's behavior. In a future work, we will investigate other measures that we could not clarify in this experiment and increase the emulating degree of the simulation in our system. In particular, with this type of ability measuring system, we expect that current navigation systems can understand the map-reading ability of their users and provide considerably better adaptive services depending on each user's ability.

## [Acknowledgment]

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