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オンライン地図操作に基づく ユーザの地図読解能力分析システム

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現在，携帯端末においてオンライン地図やナビゲーションなどの道案内サービスが普及している．しかし，様々な道案内サービスを利用しているにも関わらず，道に迷うユーザが多く存在する．これは，ナビゲーション手法や技術の問題だけでなく，根本的にユーザごとに異なる地図読解能力が考慮されていないことが原因であり，それを明らかにする必要があると考えられる．本論文では，この地図読解能力を明らかにするために，屋外における被験者の行動パターンを観察する実験を行い，地図読解能力の指標を提案する．さらに，我々は現実空間に近い状況で仮想空間においてシミュレーションすることを可能にするために，分析システムを開発し，提案した指標を用いて地図読解能力を測定することを実現する．この地図読解能力の測定値を利用することによって，今後より一層ユーザに易しく適切な案内サービスを提供することが期待される．

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

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While a lot of online map services are currently available on mobile terminals for helping our everyday location or route searches, there are still many difficulties when utilizing such real-world guidance systems. However, before criticizing each navigation system's guidance methods or its presented contents, we need to first explore the human ability to recognize real-world spaces, that is, fundamentally to answer the question: why do people so frequently get lost, even if given a detailed map toward a goal from a mobile or navigation system? In this paper, we are challenged to reveal such a human ability in a systematical method which is performed on a route finding simulation system to measure the ability. For this, we conducted a prior survey with a questionnaire, outdoor experiments, developed three major indicators to detect human defects causing the way-missing, and finally measured human map-reading ability in our developed system. Based on our efforts, it would be possible that more appropriate route guidance can be given depending on individual map-reading ability in a more user-friendly way.

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1. Introduction

Recently, many online map services and navigational systems have become pervasive as pedestrians or drivers are easily guided by their smart systems. However, there are still some people who are struggling with route finding, even if they are using navigation devices. We often complain about the routes the navigational systems present on the increasingly popular positioning systems. However, before criticizing the limitations of the systems, we must 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 this ability differ among people?

The understanding of human beings' various capabilities has been applied as a universal theme in various fields from physiology to even user interface engineering. In this paper, we are challenged to reason human map-reading ability in a new fashion with a methodology currently available. Historically, it has not been long that we started to publicly use map like today's paper maps or on-line versions. Furthermore, education on map-reading also started just several decades ago [6, 9]. Strictly speaking, the map-reading ability would be different from geo-space recognition capability. However, in this paper, we refer to the term as a rather generalized ability including the capability to find ways well using maps. In general, we believe that each person has a different map-reading ability generally. While the complete understanding of such a kind of capability would require many interdisciplinary studies, we can easily imagine that someone who has lived a suburban area with small buildings for her lifetime would have a tendency to lose her way in a big city featuring sophisticated structures. It could be understood that her geo-space recognition was not developed to find ways for such sophisticated places like the canyon of city buildings. Likewise, men vs. women, young vs. elderly, Asian vs. Western, etc., people have developed their own capability to adapt themselves in their living spaces. Some studies found that women usually use color or shape in route finding [1, 2]. Meanwhile, men are generally superior in remembering topology or sensing a distance. Of course, there are also individual differences in the ability. To achieve our purpose to support a simplified map to users, we think that the measuring of each person's map-reading ability is the most essential factor.

However, unlike other information searches, recommendations [5], or user adaptive systems [4, 7], 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 she finds herself often struggling in way-finding, it is hard to explain what the problem is in detail. This invisible and ambiguous capability should be measured in objective and quantities way. Thus, our hypothesis: we can model the ability for map reading and understanding by analyzing the action of the user on the spot based on a course and can measure it with a computer based simulation. To find patterns of losing the way, we performed a simulation in our system integrated by 2D map and 3D street view. In this experiment, participants were given a mission to follow a route in a 3D street view using only a given 2D route map [3]. In the 3D street view, users could only go forward or backward or turn right/left which is usually available in Google's street view. This is quite a restricted condition where users can see the surrounding world only through the 3D street view display. But, this approach can estimate users' capability with a minimal effort cost by emulating real-world walking or driving. We repeated the experiment, except that subjects walked the real world route and compared it to the computer based simulation.

In the remainder of this paper, Section 2 describes our approach to estimate the human map-reading ability in a systematical method. Section 3 will explain the designed measurements. Section 4 shows simulation results with our developed system. Section 5 will conclude the paper and discuss future work.

2. Systematic Approach to understanding Map-Reading Ability

In order to find out the major reasons why people become confused when walking on an unfamiliar route, we made 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 experiment and the pre-survey, and show the strong relationship between the two tests.

2.1 Observation of Way-Finders' Behaviors

In this preliminary experiment, we conducted actual route finding experiment in outdoor fields to build a set of measurements to represent map reading ability.

As participants in the experiments, 6 students who were randomly selected in our department joined our following tests voluntarily. In particular, we choose same number of men and women, since we would like to examine whether it is true that women are generally weaker than men in way-finding. Before conducting the experiment, each participant was tested for his or her geo-spatial sensing ability with a well organized questionnaire as shown in Table 1, which was devised by Takeuchi [8] to judge sense of direction. The questionnaire was composed of 20 questions, which each one has five phases of scores from 0 to 5; thereby the total score will be in the range of 20 to 100. As a result, in average, the male group (D~F) achieved a score 78.3, and the female group (A~C) scored 49.3.

Next, for the outdoor experiment called **Real-Navi**, we prepared two routes as shown in Figure 1. The first one (Fig. 1 (a)) is toward a goal point located on the north-west side of the starting point. Its total distance was 780 meters and was expected to be reached in 9 minutes in the best scenario. It also has 15 intersections where the subject would have to choose which way to go next and 7 corners where the road bends. The region was a residential district, so very few landmarks were existent. Furthermore, at the spot indicated by the red circle in Figure 1, the name of the shop was changed. The other path shown in the Figure 1 (b) was set a rather shorter length, 600 meters, and was expected to be reached in only 7 minutes in the best scenario. In this case, there were 7 intersections and 8 corners. The two paths were unfamiliar to all the participants and their visual figures were not given in advance. The other experimental settings are given in Table 2.

(a) Route 1 in Real-Navi

(b) Route2 in Real-Navi

Figure 1: Routes used in Outdoor Experiment

Table 1: Result of the Questionnaire

	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 correct or not.	2	1	3	5	3	4
	total	49	40	59	80	86	69
	average	2.45	2	2.95	4	4.3	3.45

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

Table 2: Detail of Real-Navi Setting

Investigation day	2009,10,1
Experiment situation	Field
Object route	2 route in Himeji
	①1, Shinzaike-honcyo, Himeji, Hyogo～Yashiro-tokojicyo, Himeji, Hyogo
	②Yashiro-tokojicyo, Himeji, Hyogo～Nishiyashirocyo, Himeji, Hyogo
Crossing	①15, ②11
Corner	①7, ②8
Route direction	①South→North, ②North→South
Participant	University student 6
	(Man 3, Woman 3)
	(Age 21～23)
Route information	①Total distance: 780m, Travel time: 9min
	②Total distance: 600m, Travel time: 7min

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

Experiment Procedure in Real-Navi:

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 write characteristic activities. They did not give any guidance or intermit the navigation, but only observed the behavior of the participants during the short trip until they reached the goal.

Step 2. The participant and two monitors walked the path toward the goal. At every crossing point, the logger registers in detail all the behaviors: for instance, what the participant gazed at intently, which way he or she faced, or whether he or she raised the map to re-confirm the way. In addition, if the participant lost the way, data such as how far he or she is from the right path is registered.

Step 3. Finally, near the goal point, the participant announced to the monitors whether he or she could reach the final goal as a confirmation. After the experiment, we perform a verbal investigation to ask about where was the most confusing point, etc.

a. Confirming landmark **b.** Confirming bus stop by map
c. Confirming crossing in signal **d.** Confirming small street

Figure 2: The Video Shots in the Route Searches

We could determine the significant differences between the novices and the experts in our experiment as shown in Figure 2. In Tables 3 and 4, we characterized the behaviors into three frequently observed patterns such as ‘miss route’, ‘right and left confirmation, and ‘map confirmation’.

Table 3: User Behavior Patterns in Route 1

	A	B	C	D	E	F
Total time(min)	10	13	15	7	7	11
Miss 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

Table 4: User Behavior Patterns in Route 2

	A	B	C	D	E	F
Total time(min)	8	11	8	10	8	9
Miss route	1	1	1	1	1	1
Right and left confirmation	47	49	22	45	20	39
Map confirmation	84	87	60	50	21	77

As a result, the number of 'right and left confirmation' and 'map confirmation' can distinguish the participant into two groups: the novice and the expert. In the novice group, the number of these patterns was definitely higher compared to the other group. But, the second pattern 'miss-route' was also important, while the number of occurrences was not helpful in separating the participants into two groups. In the second route, all the participants made a mistake at cross point 5 in Figure 1 (a). At this location, most participants went straight toward the west, although they had to turn left at the point, they soon became aware their mistake, came back to point 5, and were able to find the correct path. However, participants A and B had not come back to the point 5, instead, they had gone another path, but could still reach the goal. In other words, their traversal paths were a little different from the given path. In addition, the expert group (D, E, and F) did not confirm the direction or review the map as frequently as compared to the novice group (A, B, and C) on average.

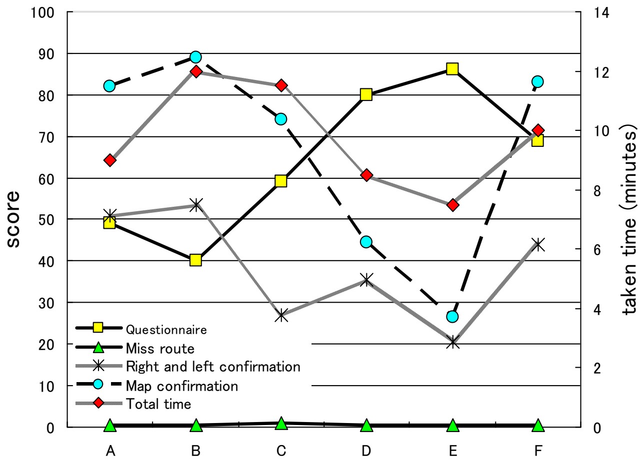

Figure 3: Result of Preliminary Experiment

3. Design of Measurement

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

- **Frequent referring to a map:** People who lack 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 to the right path:** People who lack a sense of direction cannot recover their misses by going back to the previous points on the way.

The three major problematic patterns we observed in the real world experiment were the same most occurring ones in our simulation from the users who could not reach their given goals. In particular, these errors describe how we can help users in the way-finding based on their shortcomings. Furthermore, each pattern is measurable in our system by previewing the route search, where each person can perform the review of the searched route as we did in our simulation. That is, through operating in 2D map and 3D street view, we can speculate each person's ability in selecting the right way at a crossing point, keeping their goal direction, and judging the most important regions on which to be focused. To measure these specific abilities, we developed measurable indicators for each one as follows:

- **Measure 1 Sense of Space Memorizing (SoM):** How many times does each participant need to refer to a map?
- **Measure 2 Sense of Direction (SoD):** How precise and quickly does the participant detect the direction to go?
- **Measure 3 Sense of Positioning (SoP):** If the participant made a mistake, can he or she recover the problem soon?

In 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 4. 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 goal itself to not miss the final stage. For this, every corner along a route path and the goal area were previously determined. Like the expression of SoM, the ratio of the actually viewed regions focused on to the prepared list is represented as a normalized vale. Second, the maximum angle of route direction and user's eye direction are also acquired and normalized by calculating the formula of SoD. 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, can easily lose the direction toward the goal or correct paths. Thus, it can be validated that the sense of direction would be weak when the user's eye angle is larger than the threshold. Lastly, the expression of SoP, the differential area is obtained and normalized. These indicators have been measured with the following formulae.

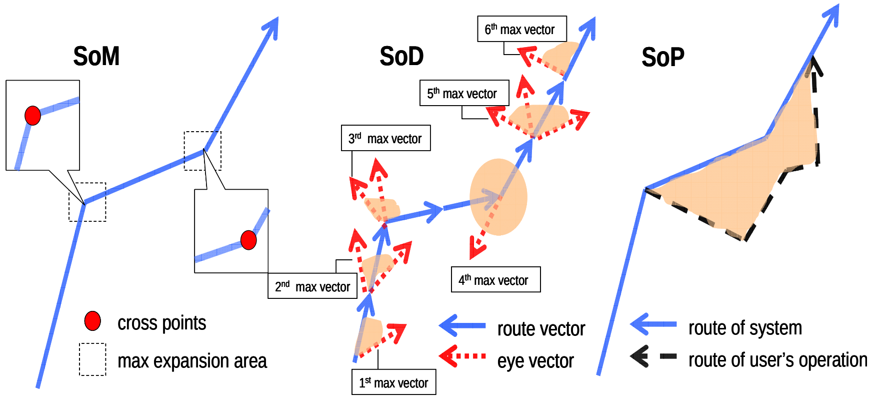

Figure 4: Indicators of Map-Reading Ability

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

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

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

Finally, each result, given as a normalized value between 0.0 and 1.0, is summed up and divided by 3.0 as a total map-reading ability.

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

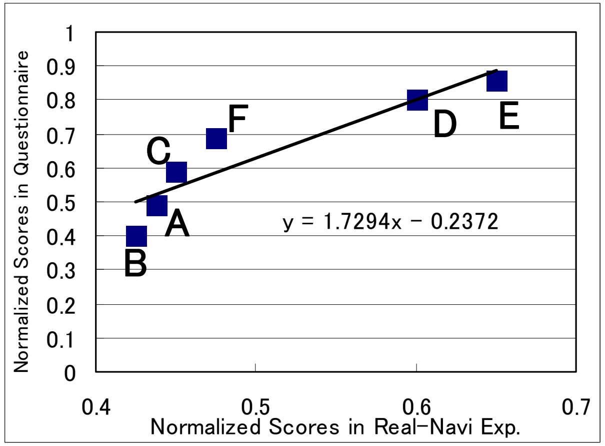

Figure 5: Correlation of Questionnaire and Real-Navi

With these measures, we reexamined the results of Real-Navi, scored them, and compared the results with the first questionnaire. As a result, these two results have a strong relation as shown in Figure 5. Thus, we can say that our measurements are able to reflect the human map reading ability to a high degree.

4. Measuring in a Simulated Route Finding

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

4.1 A Map-Reading Ability Measuring System

In order to simulate the outdoor navigation and evaluate the user map-reading ability, we developed a simulation system with two kinds of maps as shown in Figure 6. In the interface, the left side shows the 2D map while the right side shows the 3D street view of a Google map. From both maps, a user can be in a situation similar to the experiment we performed in the outdoor field; that is, the left map corresponds to a paper map given to a participant and the right view gives the user the simulated real-world scenes. Similar to browsing a paper map, a user can operate the left map, but have more controls such as zooming in or out to different levels. On the other hand, the right view can simulate the user walking virtually and showing the real scenes. In addition, to confirm the surroundings of a position, a user can see other sides by panning or tilting the view left/right or upward/downward. Of course, this simulating system cannot perfectly simulate the 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. Simply by navigating a route given in this system, the ability can be measured as a numerical value and can clarify the reasons for a lack of a sense of direction in detail through the measurements.

4.2 Experimental Result

For the computer based simulation experiment called **Virtual-Navi**, we prepared two routes as shown on the left map of Figure 6. The first one was to a goal point located toward the south-east side of the starting point. Its total distance was 600 meter and was expected to be reached in 8 minutes in the best scenario. It also has 11 intersections where we had to choose which way to go and 5 corners where the road is bent. This route is very simple and easy. However, there are few landmarks on the route. Furthermore, in the spot indicated by the red circle in the Figure 6 (a), the street view had a malfunction. In this spot, the screen only showed the wall of a house. Therefore, the participants lost a sense of direction. The other path shown in the Figure 6 (b) was set rather longer, 2 km, and was expected to reach in only 30 minutes in the best scenario. In this case, there were 19 intersections and 4 corners. There was 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 figures were not given in advance. The other experimental settings are given in Table 5.

In the experiment, we conducted a simulation according to the following procedure:

Route Finding Simulation in Virtual-Navi

Step 1. We allowed the subjects to practice in street view operation. The subjects had not previously used the street view display. By practicing, we reduced the gap with the real world.

Step 2. We gave a route on the map and let the subjects 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 goal point, the participants announced to the monitors whether he or she could reach the final goal as a confirmation. After the experiment, we also performed a verbal investigation to ask about where was the most confusing point, etc.

Finally, we gathered to data into a graph as shown in Figure 7. The results show that the subjects, except for participants D and E, made a considerable amount of confirmation operations of right and left and of the map in general. In addition, it took too much time

(a) Route 1 in Virtual-Navi

(b) Route 2 in Virtual-Navi

Figure 6: Routes used in Computer based Simulation Experiment

because they made several mistakes along the way. Participant B enlarged too much of a map and lost the way. In addition, participant A had begun to advance in the opposite direction of the course at a certain spot. Because they made many mistakes in the route, it also took considerably too much time. Furthermore, as for the situations where they mistook the path, many right and left operations were the major problem. They operated it many times and lost the direction by looking at places other than the course direction. Because they performed a lot of right and left operations, they seemed to have lost the direction. The result by our measurements is given in Table 6. Participants D and E had high scores, and the other subjects had low scores. This resembles the questionnaire results, except the case of F who had a low Virtual-Navi score yet a high questionnaire score. The correlation of questionnaire and Real-Navi is low in participant F as shown Figure 5.

However, we can see a high correlation between Real-Navi and the computer based simulation by using our measurements (Figure 8). In other words, we can measure a map-reading ability 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 human map-reading ability to a high precision.

Table 5: Detail of Virtual-Navi Setting

Investigation day	2009,10,5
Experiment situation	PC
Object route	2 route in Osaka
	①Nitto elementary school～A kindergarten attached to the Nihonbashi elementary school, ②Nishiumeda～Higobashi
Crossing	①11, ②19
Corner	①5, ②4
Route direction	①South→North, ②North→South
Participant	University student 6
	(Man 3, Woman 3)
	(Age 21～23)
System information	Visual studio 2008 C#
	2 screen (Left: 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	①Total distance: 600m, Travel time: 8min
	②Total distance: 2km, Travel time: 30min

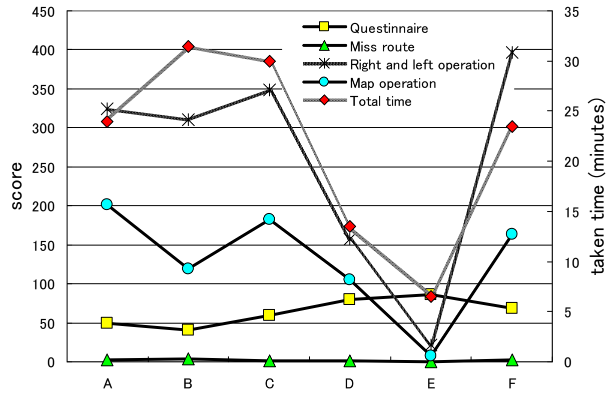

Figure 7: Result of Experiment (Virtual Navi)

Table 6: Calculation Result of the Measure

	A	B	C	D	E	F
route1	0.3	0.15	0.25	0.55	0.675	0.25
route2	0.125	0.4	0.425	0.6	0.725	0.35

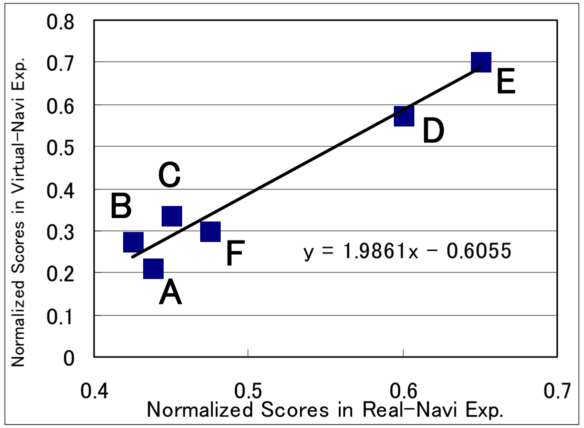

Figure 8: Correlation of Virtual-Navi and Real Navi

5. Conclusion

In this paper, we developed a system to estimate human map-reading ability based on three indicating measurements. In order to design the measurements and validate their correctness, we conducted a questionnaire and outdoor experiments and found significant reasons why the participants lost their ways. We modeled such reasons with measurements for testing a sense of space memory, a sense of direction, and a sense of positioning. Although these factors were often called as 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 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, the simulation can 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 the ability to a high precision and furthermore it is much better than the questionnaire to analyze the weak points in way-finding of the participant in detail. In future work, we will investigate other measures which we could not clarify in this experiment and increase the emulating degree of the simulating in our system. Especially, with this kind of ability measuring system, we expect that current navigation systems could understand the ability of their users and provide much better adaptive services depending on each user's ability.

6. Acknowledgments

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