Experimental Study on Cognitive Aspects of Indoor Evacuation Guidance Using Mobile Devices

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***Abstract*— Goal of our project is the development of "indoor refuge system using mobile devices" that can provide evacuation route and information about a hazardous situation to users immediately and clearly. The aim of this study is the development of a design of the system with cognitive engineering approaches. The situation assumed is where the network system failed down; the Global Positioning System (GPS) and the compass function are unavailable; and guidance by building's caretakers is limited. The targets of this empirical study are two: designing of an indicator for route guidance and a display to urge the user to follow the guidance. A QR code with arrow marks is proposed as the indicator for the guidance. A user is requested to follow an arrow of the same color displayed on the user's mobile device. An experiment with participants shows that they could select the correct direction without difficulty, and that the appropriate size of the QR code is 35 cm by 35 cm. The second topic is about user's trust in the guidance of the system. An experiment with participants was conducted to confirm the effectiveness of a display design describing details on the dangers, which are acquired by the network sensors. The result shows that the ratio of who followed the guided route was higher when they used the display than a display without the description. Through the studies, we acquired the practical knowledge about effective guidance methods, usage of information on hazardous situations, and user interface design to obtain user's trust in the guidance route.**

***Index Terms*— indoor evacuation guidance, information display, human interaction, trust**

I. Introduction

CONSTRUCTION of large buildings and large-scale use of the underground have been made in the widely around the world. Generally, there are not many choices of evacuation routes in any buildings [1][2]. If the situation gets worse in emergencies, the practicable routes are even less. Therefore, evacuation guidance must be an extremely important service for those who first visited the site or do not know well about the place [3][4].

The usefulness and limits of the major methods are discussed below. In the discussion, we examined each method from three aspects: the possibility that the system can provide the user with the correct evacuation route ("route correctness"); the possibility that users can grasp the information presented by the indicator ("information availability"); and the easiness of user's estimation of his/her current position and azimuth using the indicator.

A. *Evacuation Signs*

An evacuation guidance method widely used is "signs," indicating the shortest route to the nearest exit. The effectiveness of the method for guiding has been improved. As an example, Chu and Yeh proposed a method for designing evacuation guidance signs in complex building by solving as a maximum-coverage problem [5]. The goals of this method are making the number of signs within the limit and maximizing the coverage in a building.

The evacuation guidance is effective, only when the predefined route is actually passable and evacuees can read the signs. In the situation, the requirements "route correctness" and "information availability" are satisfied. The estimation of the current position and azimuth is not necessary for evacuees.

The correctness is not satisfied when a part(s) of the predefined route turned to be hazardous. Moreover, an evacuee may fail to read signs, when smoke, dust, or other refugees block them from the view. The "route correctness" and "information availability" are discarded in those situations.

B. *Dynamic Guidance System*

Dynamic evacuation guidance systems are proposed to accommodate situations where predefined routes are not appropriate for evacuation. The system gathers information about conditions of the area, and the electronic signs indicate an evacuation route planned to take passable paths with avoiding dangerous points.

An example of the system is the Flexit system, which provides a situation aware calculation of best evacuation paths, taking into account sensory information from the fire alarm system [6]. Hsu and the colleagues proposed intelligent digital signage systems using wireless sensor networks (WSN) [7]. The WSN was used to collect environmental data, i.e., temperature, humidity, and illumination. The system identifies the origin of the fire and draws a real-time fire evacuation map to guide users along appropriate evacuation route.

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This situation-adaptive method can provide a correct route even if the situations changed dynamically. However, the "blocking" of the signs is still a possible problem, i.e., information availability is discarded. In addition, it is impossible to acquire hazard information continuously in the event of a failure of the sensors or a power outage. Therefore, situation-adaptive guidance cannot be expected in those situations. The route correctness is not guaranteed.

C. *Mobile Guidance System*

An approach to clear the condition "information availability" is a guidance system by using the user's mobile device. The personalized information about evacuation routes and the current situation can be informed to any user by the indication on the device. Therefore, the information availability is not declined even in poor visibility situation. Jimenez-Mixco and the colleagues discussed requirements and methodologies in the development of mobile evacuation guides [8]. It shows that the guidance using mobile device has a promising possibility to reach a broad range of users.

The easiness of estimation of user's current position and azimuth is now a requirement to be considered. The Global Positioning System (GPS) is out of function in most of indoor places, because of unavailability of satellites. Feasibility and usability of alternative positioning systems are discussed in Section III.A. Some mobile devices have an electric compass function, which can be used to show the user's azimuth. However, the feasibility of the function is questionable, because of disturbance by steels in the wall. The problem about the route correctness is still an unsolved problem.

II. Aim and Target Problems

The aim of this study is the development of a design of the refuge system for indoor space by using cognitive engineering approaches. Four topics are discussed in Chapter III:

a) position estimation without the GPS,
b) pointing the azimuth without the compass function,
c) acquiring information about hazardous conditions without lined network systems, and
d) designing guidance displays, which can support users to understand information and situations easily and correctly.

The topics a), b), and c) are the results from the discussions in Chapter I. The topic d) is a demand from the cognitive interface designing. The feasibility and problems of the target methods were discussed during the process of the conceptual designing.

In Chapter IV, the methods proposed for two of the problems were evaluated through experiment with participants. The topics are i) usefulness and appropriate size of the QR code with pointing arrows, and ii) appropriate human interface design (HID) for securing the reliability of evacuation route supporting.

III. Conceptual Design of the Evacuation Support System and Problems

In this chapter, a conceptual design of the systems is discussed to confirm the feasibility and problems concerning the HID of indoor evacuation guidance systems. The situation assumed is where network, the GPS, and the compass function are unavailable.

A. *Current positioning using QR codes.*

Positioning with QR code is selected in this study, instead of the GPS function which is not effective in most indoor spaces.

Various technologies are proposed for measurement of positional information in an indoor space, such as RFID (Radio Frequency Identification) [9], two-dimensional code (e.g., QR codes) [10], optical communication, IMES (Indoor Messaging System), PDR (pedestrian dead reckoning), iBeacon, etc. Measurement location using the QR code is low-cost, and easily feasible. There is no need for additional equipment. Even if the power of the building had failed, the position measurement by the QR code is harmless.

Another advantage of the code is the error tolerance: the code is readable even if it is partially damaged. If the conventional bar code is damaged, it becomes impossible to read the code. Correction code is embedded in the QR code itself, so a reader device can fix the data in the damaged code. According to [11], it was confirmed that the data fixation is effective when 1/3 of the QR code is readable.

B. *QR code with arrows to present a recommended direction*

For normal pedestrian navigation system, a heading-up function using the GPS or electronic compass indicates the exact direction based on self-centered coordinates. However, the function may not be feasible because of the influence of several metal materials in walls around the users. In the case, it may be difficult for the user to identify the correct direction to take on the intersection in front of him/her. Without the support by the GPS information, matching the direction of the map orientation and the current location is a difficult task for users.

To solve this problem, we propose a QR code with arrows, as shown in Fig. 1. The arrows indicate the possible courses. A user enters a QR code to the mobile device by taking a photo of the code depicted on the floor. Then the device displays a photo showing the recommended direction and a map with the escape route. A specific display example is shown in Fig. 2. The color of the arrow in the image indicates an arrow in the QR code on the floor. It is expected that the user can easily select correct direction at each intersection to follow the escape route.

An experiment with participants was conducted to confirm the effectiveness and the limitation of the proposed method. The details of the experiment are described in section IV. A.

C. *Route Guidance using Sensor Information of Hazardous Situation*

Without any help, it must be difficult for evacuees to obtain information about the remote station in the middle of evacuating. For example, we cannot feel the CO concentration or the smoke of a remote location. And, we should not try to evaluate the risk by ourselves, because the death is the result of the trial in the worst case. There is a strong possibility that evacuees encounter secondary damage, and/or the delay of evacuation time is getting worse. When

Fig. 1. A QR code with arrows. The arrows are used to indicate a path recommended by the evacuation support system.

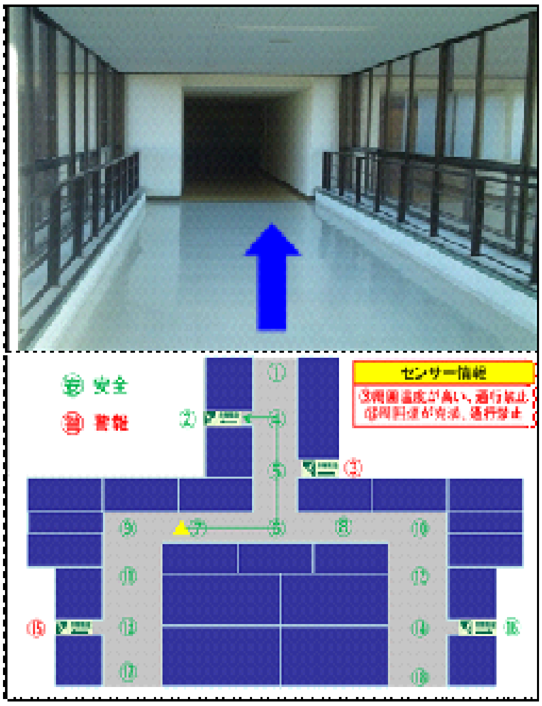

Fig. 2. An example of the display of the evacuation support application. The upper part is a photo with the recommended direction. The lower part is an evacuation route map.

the state of temperature, CO, or smoke of a place is dangerous level after a disaster, the safety of evacuees cannot be guaranteed at the place.

When a disaster occurs, it is highly likely not be able to connect to the Internet. When communications between the sensors, the server, and the users' mobile devices cease, it is impossible to convey information about a recommended route or disaster situations to the users. This is a crucial problem in leading people to safety using mobile devices.

Through our survey of existing wireless sensor networks, we have found a wireless sensor network system which can transmit the information collected from several types of sensors directly to the mobile devices (e.g., a product of Effort System Corporation in Japan), without using the Internet. Three types of sensors are introduced in this concept design of the system, i.e., sensors of temperature, CO, and smoke. The information detected will be provided to the users by using Wi-Fi or 3G connections. This shows the feasibility of the sensor network system adopted in this design, assuming the Internet is out of order. The system will recommend a route that avoids the dangerous place.

D. Display Design for the Guidance

For safe evacuation, evacuees should understand the situation to avoid high risk situations. Since evacuee's visibility in indoors space is limited, they need to get the information about remote places from other ways, e.g., a guidance system. In emergent situations, quick acquisition of the information, quick understanding of the state, and quick commencement of optimal actions are necessary.

To achieve the requirements, two topics will be discussed in this section with cognitive engineering approaches: a display form for route guidance, and information on the display to urge the user to follow the guidance.

1) Evacuation Route Map and Photographed Images with the Direction

Fig. 2 is the display form for the evacuation guidance by a mobile device, which is a set of an evacuation route map and a photographed image with the direction of travel. The basic effectiveness of the form was confirmed in our other study [12].

In the figure, yellow triangle represents the current location of the user. A circle with a number, such as 1, 2, and 3, represents the location of a sensor. The color of the number indicates the result of the sensing. Green indicates the area is safe, and red indicates that the sensor detected the abnormality in the area. Thus, the paths that connect the green circles can be candidates of safe escape routes.

2) Presentation of Specific Hazardous Condition by Text

Information about hazardous condition is indicated on the display (right of center in Fig. 2). The texts say "Since the temperature is high, the area around sensor #3 is dangerous" and "Since the smoke filled, the area around sensor #15 is dangerous."

If the display does not include the specific information acquired by the sensors, the user must have difficulty to examine the validity of the proposed route. This may have an impact on the reliability of the system by the user.

If the hypothesis is not correct, the text is useless and the time to read the text may cause delay in user's decision making. We concluded that the hypotheses should be examined through an experiment. An experiment with participants was conducted (the details are explained in Section IV. B).

IV. Experimental Studies for Specifying the System Design

Two experimental studies were conducted to examine the proper design conditions. The one is a study on the usefulness of the QR code with pointing arrows and the appropriate size of the code mark, discussed in Section III.B. The other is a study on the appropriate information on the display for securing the reliability of evacuation route, discussed in Section III.D.

The experiment plans were worked out considering the disadvantages and risks of the participants in accordance with the ethics rules of our university. The plans included measures to keep human rights of the participants, explanations about the experiment, and obtainment of their consent to participate the experiment.

A. Usefulness and Appropriate Size of the QR code with Pointing Arrows

1) Aim and plan of the experiment

In this experiment, we evaluated the utility of the arrowed QR code proposed. It was confirmed whether participants

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can easily select a traveling direction by using the code. In addition, the appropriate size was evaluated by testing different sizes of the codes.

The tasks for the participants were: a) take a QR code painted on the ground on a smartphone, and b) take a step to the front, rear, left or right in accordance with the indication displayed on the mobile devices. Seven different sizes of QR codes were used: 10 cm by 10 cm, 15 by 15, 20 by 20, 25 by 25, 30 by 30, 35 by 35, and 40 by 40. The unpaid participants were eleven, who were three females and eight males. The ages were between 25 and 43. The duration was around 50 minutes.

2) Results

The measurements were: correctness of the selection task, the time required to select the direction to go (from the shooting until the participant takes a step), the distance of the participant and the QR code at the time of photographing.

After the end of the experiment, they were asked to subjectively evaluate the ease of identifying the direction, the level of anxiety, etc.

(1) In the task of selecting the direction, they all have succeeded in any size, i.e., no failures. This shows that the proposed method has a basic efficacy.
(2) Table I shows the average time taken to select the direction at each size of the QR code. The time was the shortest when they were using the QR code of 35 by 35 cm.
(3) In Table II, it showed the number of participants who subjectively evaluated "the ease of identification" as the value. The value 5 means "very easy" and 1 "very difficult." All eleven participants rated the ease of using the code with 35 by 35 cm as five, i.e., the highest grade.
(4) On the other hand, all participants reported that they had difficulty recognizing the arrows and selecting the direction when the size was 10 by 10 cm or 15 by 15.
(5) About the ease of using a QR code painted on the ground, six participants clearly mentioned "Because the amount of the provided information is limited, I could understand the indication and determine the direction quickly."

The facts (1) and (5) show that the QR code with pointing arrows is useful to instruct people to follow the route. It can be concluded that the appropriate size of the code is 35 by 35 cm based on the facts (2), (3), and (4).

TABLE I
THE AVERAGE TIME TAKEN TO SELECT THE DIRECTION

Size of QR code	The average time
10 by 10 *cm*	5.79 s
15 by 15	5.35
20 by 20	5.28
25 by 25	5.45
30 by 30	5.54
35 by 35	*4.83*
40 by 40	5.18

TABLE II
THE NUMBER OF PARTICIPANTS WHO EVALUATED THE EASE OF IDENTIFICATION

Size of QR code	the Ease of Identification 5	4	3	2	1
10 by 10 *cm*	0	0	0	2	9
15 by 15	0	0	0	3	8
20 by 20	0	1	6	3	1
25 by 25	0	5	6	0	0
30 by 30	6	5	0	0	0
35 by 35	*11*	0	0	0	0
40 by 40	5	5	1	0	0

(5: "VERY EASY" <=> 1: "VERY DIFFICULT")

B. Appropriate Information Indication for Securing the Reliability of Evacuation Route Supporting

1) Aim and plan of the experiment

In the second experiment, we evaluated for impact on the user's reliability of the recommended route by the indication of information about remote locations.

A set of an evacuation route map and photographed images with the direction arrow was used as the basic display for the evacuation guidance by a mobile device. The display with the hazard information (Fig. 2) was compared with the basic one. An experiment was conducted to observe actual acts of the users using the two different types of displays, especially whether they follow the recommended routes or not.

The task of the participants was a mental simulation of evacuation, assuming that a disaster had occurred in a building. They had to evacuate to an emergency exit using the given information.

There were two types of conditions in the experiment: the type of display and the condition about routes. The displays used were the basic display and the display with the hazard information. The screen of a mobile device, printed on paper, was presented to the participants. Two situations were planned to test the participant's reliability of the system. A common condition is that the state of the nearest evacuation exit is "danger."

Situation A: The distance from the current position to the exit recommended and to the nearest exit are approximately equal.
Situation B: The distance to the nearest exit is far shorter than to the exit recommended by the system.

After performing mental simulation in a situation, the participants were asked to report whether they immediately followed the path as recommended, or went the nearest exit to confirm the condition. After each trial, they were asked to subjectively evaluate "the ease of understanding" of the display at the condition. The scale for the evaluation is five levels, where 5 means "very easy" and 1 "very difficult."

The unpaid participants were twelve, five females and seven males. The ages were between 21 and 43. The duration was around 30 minutes.

2) Results

Based on the results of participant's assessment of "the ease of understanding" and from the interview after the experiment, the two types of display were compared and evaluated. The results are shown below.

a) In Situation A

11 out of 12 participants rated the basic display at 3, i.e., "neutral," or less (1 or 2), that is negative assessments of the

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ease of understanding. However, ten participants reported that they trusted the system, and had evacuated, according to the escape route recommended. On the other hand, two participants did not follow the evacuation route. They mentioned in the interview, "I noticed that the alarm had come up, but I decided to go and see the condition. When it is okay, I will evacuate from the exit. That way, I thought I could escape much earlier."

The display with hazard information was rated at 4 or 5, i.e., positive assessments, by the all 12 participants. All participants trusted the system and followed the escape route recommended.

b) In Situation B

All 12 participants rated the basic display at 2 or 1, i.e., negative assessment. Five participants reported that they trusted the system, and had evacuated, according to the escape route recommended. Seven participants did not follow the evacuation route, and decided to go and see the situation of the nearest exit. They mentioned in the interview, "The nearest exit is much closer than the recommended exit. So, I decided to go through it with caution even though the alarm is on."

The display with hazard information was rated at 4 or 5 by the all 12 participants, as well as in the Situation A. All participants trusted the system and followed the escape route recommended.

3) Summary

These results show that the information about the condition is essential for users to trust routes recommended by the guidance system. When users use the basic screen, which lacks the information, they may have suspicions about the recommended route of the system, and may be led to go and see the condition of other exits. This suggests that providing the concrete information about the hazard condition to the user is an effective way to induce users to accept the recommended route.

V. Conclusion

The aim of this study is the development of an effective design of refuge system using mobile devices for indoor space. A conceptual design of the systems was discussed to confirm the feasibility and reveal the problems by using cognitive engineering approaches.

Four topics are discussed: a) position estimation without the GPS, b) pointing the azimuth without compass function, c) acquiring information about the hazardous conditions without lined network system, and d) designing guidance displays, which can support users to understand information and situations easily.

Based on the discussions, two empirical studies were conducted. The one is about an indicator for route guidance, and the other is about a display to urge the user to follow the guidance. A QR code with arrow marks is proposed as the indicator, which is depicted on the floor of each intersection. A user is requested to follow an arrow of the same color which is displayed on the device. An experiment with participants shows that they could select the direction without difficulty, and that the appropriate size of the QR code is 35 cm by 35 cm. The second topic is about user's trust in the guidance. An experiment with participants was conducted to confirm the effectiveness of a display describing details on the hazardous conditions. The results show that the information is essential for users to trust routes recommended by the guidance system.

Three topics are considered for our future work. The first topic is additional execution of the experiments to perform the statistical analysis. The number of participants is the key to achieve the analysis. The second topic is consideration about necessary information for user's decision and about appropriate forms for the indicator. The third topic is an evaluation of the practical effectiveness of the system. Development of the practical application is necessary to achieve it.

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