Pedestrian Navigation System Reflecting Users Subjectivity and Taste

Yuta Akasaka*, and Takehisa Onisawa**
*Onisawa Lab., Graduate School of Systems and Information Engineering, University of Tsukuba, Japan
(Tel : +81-29-853-6188; E-mail : akasaka@fhuman.esys.tsukuba.ac.jp)
** Institute of Engineering Mechanics and Systems, University of Tsukuba, Japan
(Tel : +81-29-853-5060; E-mail : onisawa@esys.tsukuba.ac.jp)

Abstract: This paper proposes the pedestrian navigation system which deals with subjective information. This system consists of the route setting part and the instruction generation part. The route setting part chooses the route with highest subjective satisfaction degree. The instruction generation part gives users the instructions based on the users' sensuous feeling of distance with linguistic expressions. Fuzzy measures and integrals are applied to the calculation of the satisfaction degree of the route which reflects the users' taste for routes. The instruction generation part has database of users' cognitive distance. Users' cognitive distances are expressed by fuzzy sets that correspond to linguistic terms. The system generates the instructions with linguistic terms which have the highest fitness value for the users' sensuous feeling of distance. This paper also performs subjective experiments in order to confirm the validity of the present system.

Keywords: Pedestrian Navigation System, Users Subjectivity and Taste, Fuzzy Theory

1. Introduction

A car navigation system has come into wide use recently, which usually shows the shortest path from the given origin to the given destination. If users consider only the time it takes to go to the destination from the origin, they may satisfy the route instructed by the usual navigation system which uses the Dijkstra method [1], i.e., the typical method to solve the shortest path problem. However, as a navigation system is used widely, users increase in the number, who consider that a navigation system should provide various pieces of information including navigation information. As a cellular phone has the GPS function, the pedestrian navigation system by a cellular phone is expected to come into wide use [2]. Users hope that the pedestrian navigation system also has not only the guidance function to the destination but also the value-added function such as the retrieval system to retrieve shops which are expected to be users' favorite [3]. Such a system must deal with subjective information of users' taste.

There has been a study that aims at the construction of the navigation system considering users' subjectivity, i.e., users' sensuous feeling of distance [4]. The system gives users the routes from the origin to the destination with linguistic expressions that reflect the users' sensuous feeling of distance. However, the system uses the users' sensuous feeling of distance, it does not consider users' taste for routes. Therefore, the system basically shows the shortest route that are obtained by the Dijkstra method. If a navigation system presents the route that reflects users' taste for routes, even if the presented route is a little longer than the shortest one, users find satisfaction in information presented by a navigation system.

The present study aims at the construction of the pedestrian navigation system that reflects users' subjectivity in choosing a route and gives users more usefulness than the conventional navigation system. Fuzzy sets, and fuzzy measures and integrals, are applied to the design of the system.

Chapter 2 describes the system structure and explains the application of fuzzy theory to the route setting and the route guidance. Simulation experiments to confirm the validity of the proposed system are performed in Section 3. Conclusions are described in the final chapter.

2. System Structure

2.1 Overview of System

The present system consists of two main parts, the route setting part and the instruction generation part, as shown in Fig. 1.

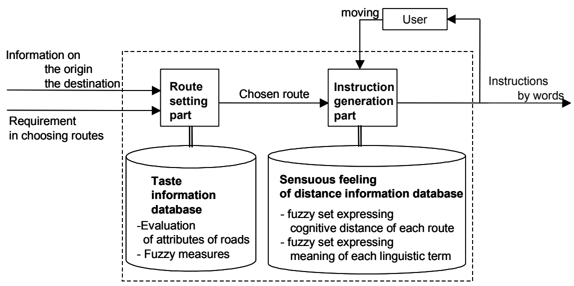


Fig. 1 System structure

The route setting part has information on users' taste for routes, called taste information database, which has users' subjective evaluations of road attributes such as *pleasantness*, *quietness*, and fuzzy measures that express the weights of the importance about road attributes in choosing routes. Given the origin, the destination and users' requirement in choosing routes, the route setting part chooses the route from the origin to the destination that reflects users' taste for routes. For example, if a user gives the system his/her requirement that he/she would like to have a walk on a lively route, the system chooses lively routes that satisfy him/her.

The instruction generation part has information on users' sensuous feeling of distance, called sensuous feeling of distance information database, which has fuzzy sets expressing users' cognitive distance of each road and fuzzy sets expressing the meaning of linguistic terms expressing users' cognitive distance. The instruction generation part presents the route chosen by the route setting part with linguistic expressions, e.g., *go straight for a while*. Users move on the route according to the given instructions. Then the system shows the next route according to the situation whether users move on the chosen route or not. Users are given instructions repeatedly until they reach the destination.

2.2 Human Interface for Traveling

Users move on the map shown in Fig.2 using the human interface for traveling shown in Fig. 3. Each road has landmarks or views and the photo of a landmark on a road or the photo of a view from a road is presented for users when they move there. Fig. 4 shows an example of the landmark photo when users move in front of *CAFÉ*. Users are given impressions of the road by the photos.

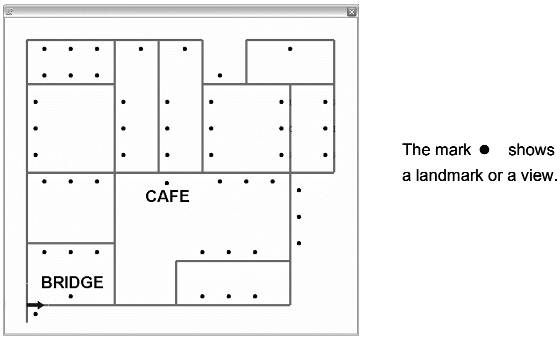


Fig. 2 Example of traveling map

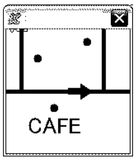


Fig. 3 User interface for traveling

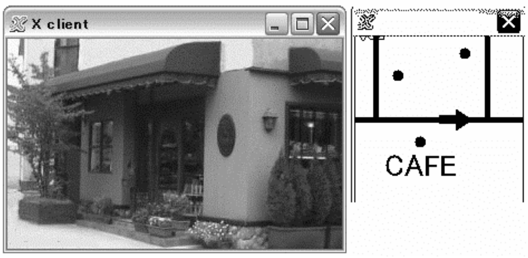


Fig. 4 Example of photo of landmark

2.3 Route Setting Part

Given the origin, the destination and users' requirement in choosing routes, the route setting part chooses the route that suits users' taste for routes among all routes from the origin to the destination. In this paper the evaluation of the road depending on users' taste for routes is obtained by fuzzy measures and integrals which are useful for modeling of human subjective evaluation [5].

The Choquet integral as fuzzy integrals of a measurable function h with respect to fuzzy measures g is defined by Eq. (1)

$$(C)\int h(x)dg = \int_0^1 g(\{x \mid h(x) > \alpha\})d\alpha , \quad (1)$$

where h is a function $h: X \to [0,1]$ and X is some universe of discourse. When the function h is a simple function defined by

$$h(x) = \sum_{i=1}^{n} (\alpha_i - \alpha_{i-1})\chi_{A_i}(x) , \quad (2)$$

$$(0 = \alpha_0 \le \alpha_1 \le ... \le \alpha_n \le 1,\ A_1 \supset A_2 \supset ... \supset A_n) ,$$

the Choquet integral of the function h is

$$(C)\int h(x)dg = \sum_{i=1}^{n} (\alpha_i - \alpha_{i-1}) \times g(A_i) , \quad (3)$$

where $\chi_{A_i}(x)$ are characteristic functions of sets $A_i(i = 1,2,\cdots,n)$ defined by Eq. (4).

$$\chi_{A_i}(x) = \begin{cases} 1 & x \in A_i \\ 0 & x \notin A_i \end{cases}, \quad (i = 1,2,\cdots,n) . \quad (4)$$

Fig. 5 illustrates the Choquet integral defined by Eq. (3). The horizontal axis shows the values of fuzzy measures g and the vertical axis shows the values of the function h. The area of the shaded part in Fig. 5 is the value of the Choquet integral.

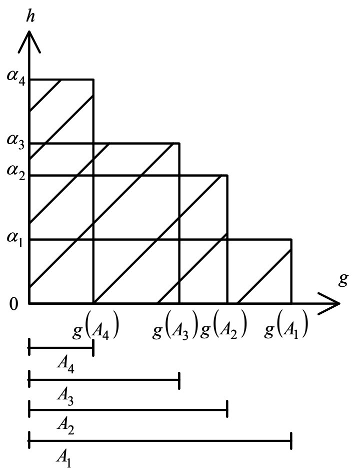


Fig.5 Choquet integral

Let O be an evaluation object which has n attributes $X = \{x_1, x_2, \cdots, x_n\}$. When the evaluations of attributes $x_i(i = 1,2,\cdots,n)$ of an object O are given by $h(x_i)$ $(i = 1,2,\cdots,n)$, and fuzzy measures $g(A_i)$ $(i = 1,2,\cdots,n)$ are obtained, the total evaluation of an object O is obtained by Eq. (3), where $x_1, x_2, \cdots, x_n$ are rearranged in the order of $h(x_1) \le h(x_2) \le \cdots \le h(x_n)$ and $A_i = \{x_i, x_{i+1}, \cdots, x_n\}$. Fig. 6 shows the concept of the evaluation model with fuzzy measures and integrals.

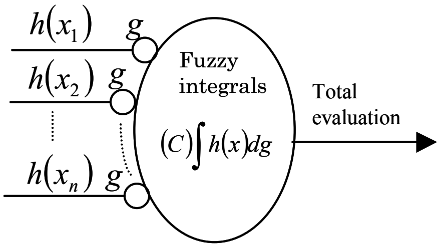


Fig. 6 Evaluation model with fuzzy measures and integrals

In this study the taste information database has $h(x_i)$ $(i=1,2,\cdots,n)$ which are the subjective evaluation values of road attributes such as *pleasantness*, *quietness*, and fuzzy measures g which express the weights of the importance about road attributes. The total evaluation of the route, called *the satisfaction degree of the route*, in a given situation is obtained by Eq. (3) using $h(x_i)$ and g. The evaluation values of road attributes and fuzzy measures are subjective quantities depending on users and are obtained by questionnaire mentioned below.

2.4 Algorithm for Route Setting

The route setting part chooses the route of which normalized sum total of satisfaction degrees of roads is the highest among all routes from the given origin to the given destination, where the normalized sum total is normalized by the total distance of the route as defined by Eqs. (5) and (6).

$$Sum = \sum_{p=1}^{r} (Satisfaction\ Degree)_p \ , \quad (5)$$

$$Normalized\ Sum = \frac{Sum}{\sum_{p=1}^{r} d_p} \ , \quad (6)$$

where the route consists of r roads, $(Satisfaction\ Degree)_p$ is the satisfaction degree of the p-th road and d_p is the distance of the p-th road. The following conditions are considered in the choosing algorithm: (1) The distance of the chosen route from the origin to the destination is within the twofold distance of the shortest route. (2) The same road is chosen only once.

2.5 Instruction Generation Part

The instruction generation part gives users the instructions of the route chosen by the route setting part. The instructions are expressed in the form of (*the distance to the crossing users turn next*, *the direction users go to after passing the crossing*), e.g., *go straight for a while and turn to the right*. The given instructions suit the users individual sensuous feeling of distance. Information on users sensuous feeling of distance is expressed by two kinds of fuzzy sets which are preserved in the database. The ones are fuzzy sets that express users' cognitive distance of each road and the other are fuzzy sets that express the meaning of linguistic terms expressing users' cognitive distance. These fuzzy sets are obtained by the Sketch Map method [6] mentioned below.

2.6 Algorithm for Instruction Generation

In order to express the route with linguistic expressions which reflect the users' individual sensuous feeling of distance, the instruction generation part calculates the fitness value of two fuzzy sets defined by Eq. (7).

$$Fitness = \frac{1}{2}[Sup\{\mu_A(x) \wedge \mu_B(x)\} + Inf(\mu_A(x) \vee \mu_{B^C}(x)\}] , \quad (7)$$

where $\mu_A(x)$ and $\mu_B(x)$ are membership functions of fuzzy sets A and B, respectively, B^C is the complement of fuzzy set B, $\wedge$ and $\vee$ stand for the minimum and maximum operations, respectively, and Sup and Inf are the supremum and infimum operations, respectively. In this study fuzzy set A expresses users' individual cognitive distance of each road and fuzzy set B expresses the meaning of linguistic terms expressing users' cognitive distance.

After users turn each crossing, the instruction generation part calculates the fitness value and gives linguistic terms expressing the distance to the next crossing and the direction. This procedure is repeated until users reach the destination. If users are out of the chosen route, this part gives users the instruction *go back* and shows the route from the losing point to the destination with linguistic expressions.

3. Simulation Experiments

3.1 Construction of Taste Information Database

Five subjects perform the experiments. Therefore, five subjects individual taste information databases are constructed. Twenty-three roads with several landmarks or views are prepared in order to obtain fuzzy measures. The subjects have their impressions of the road from the photos of landmarks or views. In the experiments three situations, S_1 : *They would like to walk aimlessly in their holiday*, S_2 : *They would like to take a walk alone in a quiet mood*, S_3 : *They would like to take a walk with a friend visiting them*, are considered. After the subjects walk along each prepared road in each situation, they evaluate the satisfaction degree of the road in the situation with 5-point scale, 0: *dissatisfied*, 1: *a little dissatisfied*, 2: *neutral*, 3: *a little satisfied*, 4: *satisfied*. And they also evaluate impressions of the road from the viewpoints of four road attributes, x_1 : *the road has pleasantness*, x_2 : *the road is solitary*, x_3 : *the road is quiet*, x_4 : *the road has refreshment*, with 5-point scale, 0: *they don't think so at all*, 1: *they don't think so very much*, 2: *neutral*, 3: *they think so a little*, 4: *they think so*. Let Z_{ij} be the satisfaction degree of the i-th road in situation S_j $(i = 1, 2, ..., 23, \ j = 1, 2, 3)$. Twenty-three roads prepared for the identification of fuzzy measures have data $(h_1, h_2, h_3, h_4, Z_{ij}, S_j;\ i = 1, 2, ..., 23,\ j = 1,2,3)$ where h_1, h_2, h_3 and h_4 are evaluations of road attributes x_1, x_2, x_3 and x_4, respectively, in situation S_j. Fuzzy measures of attributes of each road in each situation are obtained using the fuzzy measures identifying algorithm [8] under the following quantifications of questionnaire results; $0 \to 0.0$, $1 \to 0.25$, $2 \to 0.5$, $3 \to 0.75$, $4 \to 1.0$. The identifying algorithm obtains fuzzy measures so that the mean square error between the satisfaction degrees obtained by Eq. (3) and those obtained by questionnaire is minimized. Identified fuzzy measures are users individual subjective quantities and are preserved in the subjects' own taste information database.

Next, the subjects walk along other roads which are not used for the identification of fuzzy measures, and evaluate attributes of each road from the viewpoints of h_1, h_2, h_3 and h_4, where these roads compose the traveling map as shown in Fig. 2. These evaluation values of attributes of each road are also users individual subjective quantities and are also preserved in the subjects' own taste information database.

3.2 Construction of Sensuous Feeling of Distance Information Database

The Sketch Map method [6], which is used in the field of spatial cognition research, is applied to the acquisition of quantitative users' sensuous feeling of distance. In this method the subjects move along given roads and keeps them in mind. And then the subjects sketch surroundings from memory which include the routes they move on, landmarks they see and so on.

In this study only the human interface as shown in Fig. 3 is presented for the subjects while they walk along roads on the map as shown in Fig. 2. Therefore, the subjects perceive only the part of surroundings while walking. They should memorize the relative position between the origin and the destination, the distance between them and landmarks along roads. After walking along roads on a map, the subjects draw the route with a line based on their sensuous feeling of distance of the route from memory using the human interface shown in Fig. 7. Fig. 7 shows a drawing example of the route from BRIDGE to CAFÉ in Fig. 2.

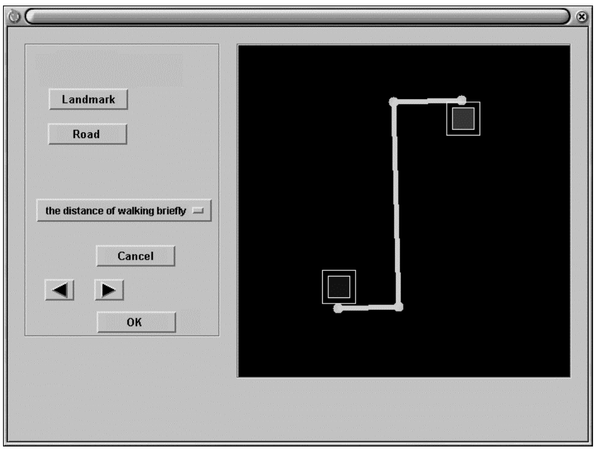


Fig. 7 User interface for drawing routes

After drawing the route, the subjects express the sensuous feeling of distance of the route with linguistic terms such as *the distance of walking briefly*, *the distance of walking a little*, *the distance of walking for a while*, *the distance of walking by far, and the distance of walking for quite a long time*. Using drawn data, two kinds of fuzzy sets expressing subjects' cognitive distance and expressing the meaning of each linguistic expression are obtained. Let a and w be the parameter values, i.e., the center and the width values, of the membership function of the fuzzy set obtained by the Sketch Map method shown in Fig. 8. These parameter values are determined by Eqs. (8) and (9).

$$a = \frac{1}{3q}\sum_{m=1}^{q}\sum_{l=1}^{3} d_{lm}, \tag{8}$$

$$w = 4 \times \sqrt{\frac{1}{3q}\sum_{m=1}^{q}\sum_{l=1}^{3}\left(a - d_{lm}\right)^2}, \tag{9}$$

where q is the number of data depending on the number of drawn roads, d_{1m} and d_{2m} are modified distances considering scaling errors in the horizontal direction and the vertical direction, respectively, and d_{3m} is modified distance considering the geometric mean of scale errors in both horizontal and vertical directions. These modified distances are defined by

$$d_{1m} = d_m \times \frac{U}{u}, \tag{10}$$

$$d_{2m} = d_m \times \frac{Y}{y}, \tag{11}$$

$$d_{3m} = d_m \times \sqrt{\frac{UY}{uy}}, \tag{12}$$

where d_m is the distance of the drawn road on the interface shown in Fig. 7, u and y are the width and the height of the drawn map on the interface shown in Fig.7, respectively, U and Y are the width and the height of the route users move on a map actually. Fig. 9 illustrates the relationship among these parameters.

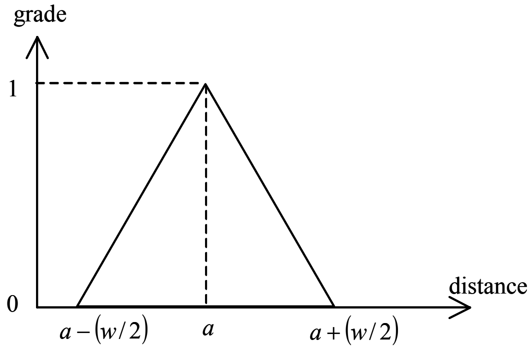


Fig. 8 Membership function

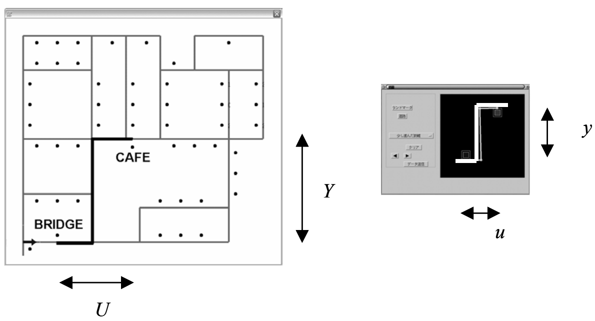


Fig. 9 Modification of distances

3.3 Experiments

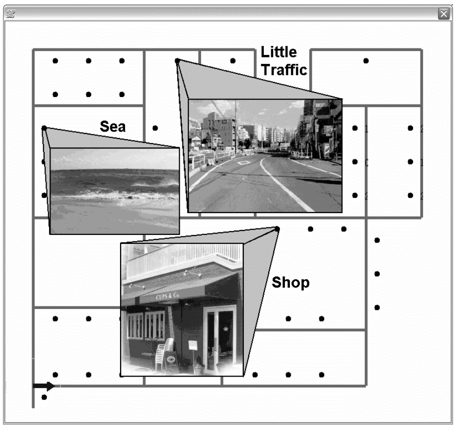


Fig. 10 Prepared map in experiments

Fig. 10 shows the prepared map with landmarks or views in the experiments. The subjects walk along three kinds of routes in each situation and in any order. The one is the route chosen by the present system using subjects individual taste information database and sensuous feeling of distance information database. This is called the subjective route here. The other two are routes chosen at random and their distances are almost the same as the distance of the subjective route. These are called random routes here. After walking along one route, the subjects evaluate the satisfaction degree of the route with 5-point scale. The subjects walk along 9 routes in total and evaluate the satisfaction degree of each route.

3.4 Experimental Results and Remarks

Table 1 shows errors between satisfaction degrees obtained by the questionnaire and those obtained by Eq. (3) with identified fuzzy measures. It is found that all values are less than 0.25. Fuzzy measures are identified well in the sense that the errors are within the difference between two points in the 5-point scale considering that questionnaire results are quantified in the following way; $0 \rightarrow 0.0$, $1 \rightarrow 0.25$, $2 \rightarrow 0.5$, $3 \rightarrow 0.75$, $4 \rightarrow 1.0$.

Table 2 shows the satisfaction degrees of presented subjective routes and random routes in each situation, where the satisfaction degrees of random routes are the average values of satisfaction degree of two random routes for each subject in each situation. Comparing satisfaction degrees of subjective routes with those of random routes, the former degrees are equal to or higher than the latter ones in 12 trials out of 15. Especially, as for evaluation results of subjects 1, 3 and 4, the degrees of subjective routes are higher than those of random routes in all situations.

Fig. 11 and Fig. 12 show subjective routes and random routes presented for each subject in situation S_1 , respectively. Random routes are common to all subjects in the same situation. That is, in situation S_1, random route 1 shown in Fig. 12 (a) and random route 2 shown in Fig. 12 (b) are presented for all subjects. Random route 3 and 4 are prepared in situation S_2 , and random route 5 and 6 are prepared in situation S_3. Fig. 13 shows subjective routes of subject 4 in situations S_1, S_2 and S_3. From the analysis of subject 4's fuzzy measures, it is found that $g(x_1)$ and $g(x_3, x_4)$ have large values in all situations, that is, subject 4 attaches great importance to x_1 or $(x_3 \textit{ and } x_4)$ in all situations. His evaluation of attribute x_1 of the first half part of the presented routes is higher than that of attribute x_1 of other routes. Therefore, the routes shown in Fig. 13 are presented for subject 4 as the first half part of the routes. In situations S_1 and S_3 his evaluation of attribute x_1 of the latter half of the presented routes is higher than evaluations of other attributes of all routes. In situation S_2 his evaluations of attributes x_3 and x_4 of the latter half of the presented routes are higher than those of other attributes of all routes. Therefore, different routes are presented for him as the latter half part of the routes as shown in Fig. 13.

Fig. 11 shows that although the origin and the destination in presented routes are all the same, various routes are presented for the users, and Table 2 shows that their satisfaction degrees of the presented subjective routes are high. Fig. 13 shows that although one subject walks on the same map, various routes are presented according to situations, and Table 2 shows that his satisfaction degrees of the presented routes are high. From these results, it is found that the subjective route presented to the subjects reflects their taste for routes well.

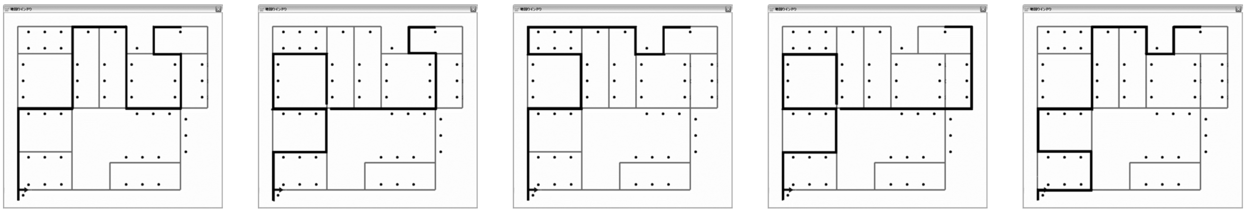
Table 1 Errors in identifying fuzzy measures

Situation	Subject1	Subject2	Subject3	Subject4	Subject5	Average
S1	0.21	0.14	0.20	0.16	0.12	0.17
S2	0.14	0.18	0.21	0.12	0.12	0.15
S3	0.18	0.19	0.17	0.14	0.21	0.18
Average	0.18	0.17	0.19	0.14	0.15	0.17

Table 2 Comparison of satisfaction degrees between subjective routes and random routes

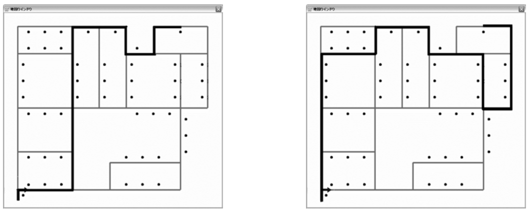
Situation	Route	Subject1	Subject2	Subject3	Subject4	Subject5
S1	**Subjective**	**1.00**	**0.75**	**0.50**	**1.00**	**0.75**
	Random	0.63	0.88	0.38	0.50	0.63
S2	**Subjective**	**0.75**	**0.25**	**1.00**	**1.00**	**1.00**
	Random	0.63	0.63	0.50	0.75	1.00
S3	**Subjective**	**1.00**	**0.75**	**1.00**	**0.75**	**0.00**
	Random	0.88	0.38	0.63	0.50	0.88

Subject 2 gives lower evaluation values to the subjective routes in situations S_1 and S_2, and especially, subject 5 gives much lower evaluation value to the subjective route in situation S_3. Some subjects mention in free talks after the experiments that impressions of the last part of a route have an influence on their evaluation of routes. Considering that the evaluation of routes is not static but has a time variable characteristic, impressions of the last part of a route sometimes remain strongly and have influence on the evaluation. As for subject 5, the road with little traffic is presented for him in the last part of the route in situation S_3 : *They would like to take a walk with a friend visiting them*. The evaluation of this part, *dissatisfied*, is his evaluation of the whole route in this situation. Indeed, he mentions after the experiments that he gives the worst evaluation to this route since although he expects that more interesting road is presented to him in the last part of the route, no interesting road is presented for him. Therefore, it is considered that because of bad impressions of the last part of the presented route, some evaluations of subjective routes are worse than those of random routes.



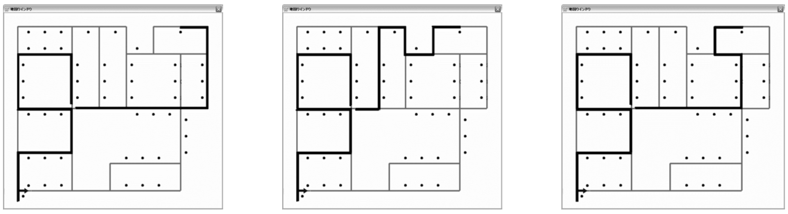
(a)Subject1 (b)Subject2 (c)Subject3 (d)Subject4 (e)Subject5

Fig. 11 Subjective routes of each subject in situation S_1



(a)Random route 1 (b) Random route 2

Fig. 12 Random routes in situation S_1



(a)Situation S_1 (b)Situation S_2 (c)Situation S_3

Fig. 13 Subjective routes of subject 4 in situations S_1, S_2 and S_3

4. Conclusions

This paper proposes the method that processes subjective information in choosing routes as the first step of the development of the pedestrian navigation system. The system has the route setting part and the instruction generation part. The route setting part has taste information database, and fuzzy measures and integrals are applied to the choice of the route which suits users' taste for routes. The instruction generation part has sensuous feeling of distance information database and fuzzy sets are applied to linguistic expressions of route instructions which reflect users' sensuous feeling of distance. Subjects experiments are performed in order to confirm the validity of the present method. The experimental results show that various routes dependent on subjects and situations are chosen and that satisfaction degrees of the routes chosen by the method is higher than these of routes chosen at random.

There are some problems to be solved in a future. The present method gets subjective information, i.e., fuzzy measures expressing the weight of importance of attributes in choosing a route, fuzzy sets expressing sensuous feeling of distance and the meaning of linguistic terms expressing cognitive distance, by off-line using questionnaire data and the Sketch Map method, respectively. It is necessary to get these pieces of information by on-line using some learning method for the simple use of the system. It is also necessary to reconsider the route choosing algorithm in order to deal with the problem that the evaluation of the last part of the presented route has sometimes an influence on the evaluation of the route.

References

[1] B. Golden, "Shortest-Path Algorithms - A Comparison," *Operations Research*, Vol.24, No.9, pp.1164-1168, 1976

[2] M. Tsuda, Y. Isoda, K. Ohta and T. Sugimura, "A Prospect of K-tai Computing," *Journal of Japanese Society for Artificial Intelligence*, Vol.16, No.6, pp.756-761, 2001

[3] T. Yamazaki, "Theoretical Structure and Future Trends of Navigation Systems," *Journal of Japanese Society for Artificial Intelligence*, Vol.15, No.2, pp.226-233, 2000

[4] T. Onisawa and S. Sakakibara, "Study on Cognitive Map and Its Linguistic Expressions," *Proc. of 17th Fuzzy System Symposium*, Japan, pp.109-112, September, 2001

[5] Japan Society for Fuzzy Theory and Systems Ed., " Lecture Fuzzy 3, Fuzzy Measures " , *Nikkan-Kogyo-Shinbun-Sha*, Tokyo, 1993

[6] N. Foreman and R. Gillett, "Handbook of Spatial Research Paradigms and Methodologies," *Taylor & Francis*, 1997

[7] T. Onisawa and M. Iwata, "A Model of Route Decision and Facial Expression," *Proc. of the 6th International Fuzzy Systems Association World Congress*, Brazil, Vol.1, pp.629-632, July, 1995

[8] K. Ishii and M. Sugeno, "A Model of Human Evaluation Process Using Fuzzy Measures," *Int.J.Man-Machine Studies*, Vol.22, pp.19-38, 1985