USER-ADAPTIVE NAVIGATION FOR ELDERLY PEDESTRIANS BASED ON PREFERENCE INFORMATION

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ABSTRACT

The aim of our project is to develop a route planning method that can provide each user with an appropriate route, taking into consideration the walkability, safety, and pleasantness peculiar to the elderly. To achieve this goal, we constructed a quantitative model that expresses the relationship between the attributes of elderly users and their preference for route selection and proposed a method of individual adaptation of the model using post-walking preference evaluations of route factors. We used "acceptable detour time" to quantify user preferences. A paper survey and a walking experiment were conducted to examine the feasibility of the proposed method. It is confirmed that the targeted user attributes are useful in estimating the preferences of the elderly for the routes. In some situations, we were able to identify improvements in the participants' evaluation of the routes. The result indicates the feasibility of the user adaptation method. By adjusting the update parameters and using more data, it is expected to plan routes that are adapted to individuals with high accuracy.

KEYWORDS

Pedestrian Navigation, Elderly, User Adaptive Model, Preference Estimation, Intelligent Transport Systems

1. INTRODUCTION

Pedestrian navigation services have become standardized on mobile phone terminals with GPS functions. In addition, path-finding methods that incorporate demands other than the shortest distance have also been studied. On the other hand, researchers have reported numerous factors that hinder the outgoing activities of the elderly (Muronaga and Morozumi, 2003, Yoshikawa, 2011, Mizuno, 2011). To improve the quality of life (QOL) of the elderly, support methods that enhance outdoor activities are attracting attention. However, conventional pedestrian navigation systems that only provide the shortest routes are not sufficient to assist the elderly when they go out.

We are developing a route-finding method using a model that quantitatively considers physical difficulty, psychological vulnerability, sense of security, and preferences with respect to environmental factors on the route, i.e., an environmental factor cost model, in order to realize an effective route guidance method to improve the QOL of the elderly. In particular, we have attempted to identify factors that can consider the physical and mental conditions of elderly users and construct a quantitative cost function based on these factors. Here, we found that the difference in individual subjective evaluation is remarkable; therefore, using only the average value model is insufficient to obtain high user satisfaction (Furukawa, 2015).

As a countermeasure, we got the idea of personalized navigation considering the subjective evaluation of walkability, safety, and pleasantness (Furukawa and Wang, 2020). Although research on personal adaptation methods has been conducted worldwide, it has the potential to diverge from the actual situation of users due to limitations in model construction methods and lack of adaptability (Novack, et al., 2018, Torres, et al., 2018). The issue that we focused on for the practical application of this method is the "automatic response to individual differences of users." This target is particularly important in improving the quality of life of the elderly and in making emergency decisions during disaster evacuation.

The conditions set for the practical application of the proposed method are shown below.

- To eliminate the influence of individual differences, we create a "set of environmental factor cost models" for each user.

- In order to ensure the convenience of the navigation system, detailed interviews regarding user preferences will not be conducted.

- For the same reason, the hearing of evaluations of environmental factors to users at the time of use should be minimized.

Under these conditions, the research question is, "Is a model for estimating environmental factor costs that automatically adapts to each user using the user's attributes useful in finding a route that satisfies the requirements of each elderly person?" If this becomes possible, the cost model will be adjusted semi-automatically at the time of use, and the user will receive a personalized route guidance service with only a few responses to the evaluation mechanism.

2. RELATED WORKS

Research on personalized navigation has been conducted worldwide to improve pedestrian navigation services. The following is a summary of representative studies and their differences from this study.

Darko et al. proposed a route search method adapted to each user's physical condition for people with disabilities (Darko, 2022). A model based on the hierarchical analysis method is created for each user's preference for sidewalks, depending on the time of day, sidewalk conditions, weather, etc. It has some limitations, such as the fact that the target is limited to the evaluation of sidewalks, and the physical condition and the importance of each factor must be obtained from each user in advance. The advantage of our research is that it minimizes the amount of information acquired in advance and automatically adapts based on measurement data at the time of use.

Ertz et al. proposed a method to generate comfortable pedestrian routes in the presence of green spaces, social areas, and quiet roads (Ertz, 2021). Environmental factors and process methods are based on questionnaire surveys, and the necessity and sufficiency of route factors and the validity of quantification of each cost for factors have not been confirmed. Through multiple evaluation experiments, we have already obtained a wealth of reliable knowledge (Furukawa, 2015, 2020), which gives us an advantage. In this study, we focus on the user-adaptive method of quantitative cost.

Jonietz focused on the user's physical ability and preferences, similar to our study, and extracted environmental attribute data (aesthetic buildings, number of stairs, road surface conditions, green space, etc.) in the area visited by the user from walking history data, and proposed a route recommendation method using this (Jonietz, 2016). They do not use the "subjective evaluation by users," which is taken into account in our study. It also positions the visit as highly rated, which has the potential to deviate from the actual situation of the user. The cost used is also difficult to modify by the user.

3. A METHOD FOR QUANTIFYING PREFERENCES

Considering the diversity of users, it is difficult to quantify preferences (i.e., walkability, safety, and pleasantness) in a form that can be reflected in route guidance. In this study, we use the acceptable detour time proposed by Matsuda et al. (2004).

Two situations are assumed for the acceptable detour time (Matsuda, 2004). Figure 1 (a) shows the situation, where the detour time is the additional time accepted by the user to avoid a place with a high physical load (e.g., a steep slope) or high risk (e.g., a road without a sidewalk). In the situation shown in Figure 1 (b), the detour time is defined as the additional time that the user can accept to select the route with a preferred spot that is easier to walk, lower risk (e.g., an intersection with traffic signals), or more pleasure (e.g., a park).

Based on the concept of the acceptable detour time, the cost considering the user's preference is defined as Equations (1) and (2).

the revised cost of the detour path = α (the cost based on the physical distance of the detour path), (1)

α = (travel time for the shortest path) / (travel time for the shortest path + the acceptable detour time). (2)

When the value of the detour route for a user increases (that is, the acceptable detour time becomes longer), the revised cost decreases. The revised cost will be used instead of the original cost, when the path has one of the spots (described in Table 1 for this study). This cost function makes it possible to take pedestrian preferences into consideration in route planning.

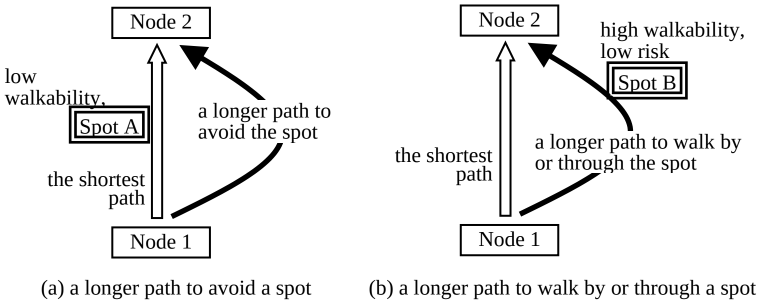

Figure 1. The situations assumed for the definition of the acceptable detour time

4. PREFERENCE ESTIMATION MODEL USING THE ACCEPTABLE DETOUR TIME

4.1 Preference Estimation Model Based on User Attributes

As an approach for estimating personalized routes that meet the demands of the elderly, we propose a method for estimating preferences for route factors based on user attributes, i.e., a model for estimating the acceptable detour time for each route factor. As user attributes, it is conceivable to use the user's age, physical strength, and the like.

While age and gender are easy to use, physical fitness has many definitions and is difficult to quantify using a single standard. Considering the convenience of the system, it is not appropriate to measure the user's physical strength before use or to ask the user many questions. It is hard to say that it is a comfortable support if it takes a lot of time to prepare before use. Therefore, we aimed to develop a preference estimation model that uses the four attributes obtained from users in advance, such as age, gender, frequency of daily outings (at work, shopping, and recreation), and the interval at which they wish to take a break.

4.2 Building a Model Based on Reported Data on the Acceptable Detour Time

4.2.1 Paper Survey on Acceptable Detour Time

To reveal the relationship between user attributes and their preferences for route factors, we conducted a paper survey of the experiment participants to obtain the acceptable detour time for each route factor. In this study, we used the factors whose usefulness was confirmed in the related study (Furukawa and Wang, 2020). Further interviews were conducted and additional factors (e.g., routes with convenience stores) were added to the list of possible candidates. A total of 14 factors used are listed in Table 1, where each factor has relationships with walkability, safety, or pleasantness. A paper survey was conducted to answer the acceptable detour time for each factor. Fifty elderly people (over 60 years old) participated in the study and were paid an honorarium.

4.2.2 Building the Estimation Models from Acquired Data

For each of the 14 route factors, multiple regression analysis was conducted with user attributes (age, frequency of outings, desired break intervals, etc.), weather, and temperature as independent variables, and acceptable detour time as the dependent variable. The models were made separately for females and males. Based on the data obtained in advance, we evaluated the possibility of estimating the user's route preferences. Table 1 shows the adjusted R^2 values as results of the multiple regression analysis.

Table 1. Adjusted R2 values of the regression analysis models for the 14 route factors

Factors	adjusted R^2		Factors	adjusted R^2	
	male	female		male	female
1) steep slope/stairway	0.261	-0.09	8) school	0.223	0.186
2) crowded street	0.236	0.197	9) a park	0.230	0.331
3) a sidewalk	0.243	0.208	10) waterfront	0.199	0.345
4) an intersection with a traffic signal	0.277	0.158	11) a police box	0.266	0.327
5) road with guardrails	0.179	0.257	12) narrow road with poor visibility	0.230	0.408
6) a pedestrian overpass	0.258	0.178	13) convenience store	0.231	0.323
7) a bright path	0.207	0.244	14) a guide map	0.224	0.341

The results indicate that the factors that strongly influence male and female route selection are different and that separate models should be used for route finding for males and females.

The adjusted R^2 value for multiple regression analysis is quite low and the model is not highly reliable. The multiple regression model using the attributes targeted in this study does not have sufficient accuracy, and it is considered difficult to provide comfortable routes to users. There are two possible approaches to this improvement. One is to add other attributes to the model as independent variables that may have an impact. Another possible method is to adaptively improve the model for individual users by using the information after each walk. Considering the large individual differences in preferences, we use the constructed model as a basic model, and examine a method for sequentially improving the model by using each user's route evaluation and walking data.

5. AN ADAPTIVE IMPROVEMENT METHOD FOR THE ESTIMATION MODELS

To present routes that meet user preferences and are easy to walk, it would be effective to update the cost model by using information during walking and post-walking evaluations of the routes. On the other hand, considering the convenience of navigation, it is not appropriate to impose questions on the user that require time and attention to answer. It would be desirable to use simple questions that do not burden the user, or to use data that can be passively obtained from the user. Therefore, in this method, as a method for adapting the model to individual users, a method using the user's actual walking speed and the user's evaluation results for route factors was adopted. The former corresponds to data that can be acquired passively, and the latter corresponds to route evaluation by the user. In this research, we evaluate the basic effectiveness and feasibility of the idea by using a simple method.

5.1 Model Improvement by Modifying Actual Walking Speed

Since the acceptable detour time is used as a measure of preference, the user's walking speed is necessary for the calculation of the route cost. Walking speed is difficult to estimate accurately in advance, as it may vary with age, gender, exercise habits, and personality. In this study, the system measures the user's walking speed and uses it to generate the next route.

5.2 Model Improvement Based on Preference Evaluation Results

To improve the cost estimation model by adapting it to the individual, it is necessary to use subjective evaluation data on route factors that users prefer and reject. If users are asked to answer "acceptable detour time" for each factor while using a navigation service, they must make a generalized evaluation of each route factor independently of the situation in which they are traveling. This implementation is expected to require a certain amount of time and attention from the user, and may impair its convenience. In this method, instead of the "acceptable detour time," the evaluation value of the user's preference for the route factors that were present on the route traveled is used. The evaluation value is obtained on a 5-point scale (5: want to go through - 1: don't want to go through). The cost model is improved by using the results to adjust the acceptable detour time.

Specifically, the user's preference estimation model is updated by multiplying the "acceptable detour time" by the following cost update parameter. Different methods are used for positive factors and negative factors.

For favorable factors: [*cost update parameter*] = 1/4 * [*rating value of the factor*] + 1/4 (3)
For factors to be avoided: [*cost update parameter*] = -1/4 * [*rating value of the factor*] + 7/4 (4)

In these formulas, the correction is 1.5 times the current acceptable detour time when the preference evaluation value is maximum, i.e. 5, and 0.5 times the current acceptable detour time when the preference evaluation value is minimum, i.e. 1.

6. A VALIDATION EXPERIMENT ON THE MODEL IMPROVEMENT METHOD

The purpose of this experiment is to confirm the effectiveness of the proposed cost-improvement method in improving user walkability and comfort on the planned route. In this experiment, participants were asked to actually walk the routes planned by the model before the improvement and the routes planned after the improvement. Then, the comprehensive evaluation results for each route are compared. In addition, we tried to find out the user's burden and improvement points by interviewing the fatigue level after walking and the factors that bothered him/her while walking.

6.1 The Flow of the Experiment

(1) Using the estimation model based on the acceptable detour time created in Section 4, we planned routes for each participant.

(2) Using the navigation system, participants are asked to walk to three different destinations.

(3) For each route, we ask them to perform a comprehensive evaluation (0-100) of walkability, safety, and pleasantness.

(4) We ask participants to evaluate their preference (5 levels) for each of the route factors that existed on the route.

(5) Using the model improvement method, i.e., Equations (3) and (4), using the participant's preference values for the route factors, a set of the acceptable detour time for each participant is updated.

(6) Using each participant's updated acceptable detour time and the acquired walking speed data, a new route planning is performed for each participant.

(7) Using the navigation system, participants are asked to walk to the same three destinations as before.

(8) For each route, we ask them to perform a comprehensive evaluation (0-100) of walkability, safety, and pleasantness.

6.2 Experimental Conditions

The experiment participants were nine elderly people (female: 3 in their 60s, 2 in their 70s, male: 3 in their 70s, 1 in his 80s). The participants were chosen who were not familiar with the experimental areas, assuming that the user is a first-time visitor to the area. Before the experiment, the significance, purpose, methods, risks, and responses were explained to the experiment participants. Only those who consented actually participated in the experiment and paid a reward. This research plan was reviewed and approved by the Ethics Review Committee of the Institute of Systems and Information Engineering, University of Tsukuba (Review approval number 2019R349).

The proposed route planning method using the acceptable detour time requires accurate speed measurements because the travel time between nodes has a significant impact on the cost calculation. In this experiment, the participants were asked to wear a dedicated GPS device (i-gotU GT-600). Participants are asked to walk to their destinations while using a navigation application on a smartphone. The smartphone used is "SONY Xperia XZ3 SO-01L." The navigation application was originally created for this experiment using the map development kit "GeoTechnologies MapFan SDK."

6.3 Areas Covered by the Experiment

This experiment was conducted in the vicinity of Nagareyama Otakanomori Station in Nagareyama City, Chiba Prefecture, Japan (the corresponding area map is shown in Figure 2). This area has many target route factors such as school buildings, waterfront areas, and narrow and intricate roads.

Figure 2. Area covered by the walking experiment

Brief descriptions of the three areas walked by the participants follow.

6.3.1 Area 1: Wide and Well-Maintained Roads

This is the area surrounding the route from the starting point (1) to the destination (2). Many of the roads are quite well maintained. Since it is near a train station, there are many pedestrians and the sidewalks are quite wide. The road width is a little narrow in residential areas, but it is easy to walk without ups and downs. There are many factors related to the landscape, including riverfront roads and a relatively large number of parks.

6.3.2 Area 2: Narrow Busy Roads with Sidewalks

This is the area surrounding the route from the starting point (2) to the destination (3). Compared to Area 1, many roads are not well maintained. There are places where sidewalks are narrow and places where there are none. Some of the narrow roads have slopes.

6.3.3 Area 3: Busy Roads with No Sidewalks

This is the area surrounding the route from the starting point (3) to the destination (4). Many roads do not have sidewalks. There are a lot of pedestrians because it is near a hospital. Off the main streets, fairly narrow roads along the railroad tracks exist.

6.4 Analysis of Experimental Data and Results

A box-and-whisker diagram of the comprehensive evaluation (0-100) for each area is shown in Figure 3. As a result of the t-test, no significant difference was found in the mean of the comprehensive evaluation values for the routes of the initial model and the improved model (significance level 5%). Each participant's data in Area 1 showed little or no change between the two ratings or a decrease in value. For Area 3, the evaluation values of 8 out of 9 participants increased, indicating that the improvements in the cost model were successful. Since the initial routes were quite unsafe, model improvements based on participants' preference ratings would have greatly improved the safety of routes and increased their ratings.

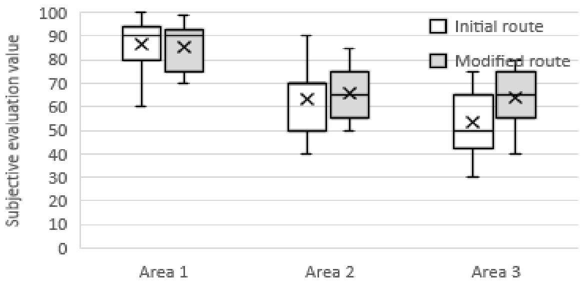

Figure 3. A box-and-whisker diagram of the comprehensive evaluation for each area

Next, statistical analysis of the data was conducted by classifying the participants' attributes as conditions. A t-test was conducted separately for males and females, and the results showed no significant differences in the means of the comprehensive evaluation values of the initial and improved models in each (5% level of significance). Box-and-whisker plots of the comprehensive ratings for each area for males and females are shown in Figures 4 and 5, respectively. For males, there is not much improvement in evaluation. Among females, there is a trend toward improved evaluations. Females' comprehensive evaluations of the initial routes are often low, suggesting that they may place more emphasis on the "safety" of routes. In analyses classified by other attributes (age and frequency of outings), no effect on comprehensive evaluations was found.

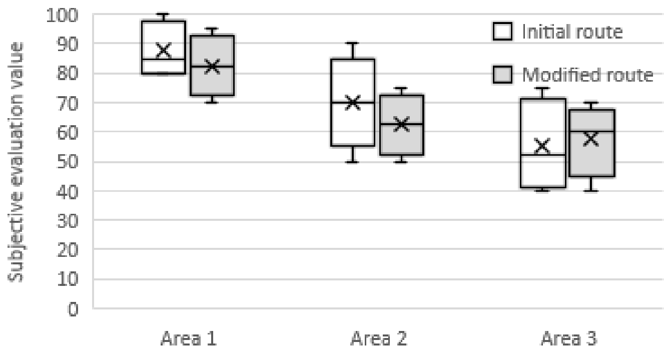

Figure 4. A box-and-whisker diagram of the comprehensive evaluation for males

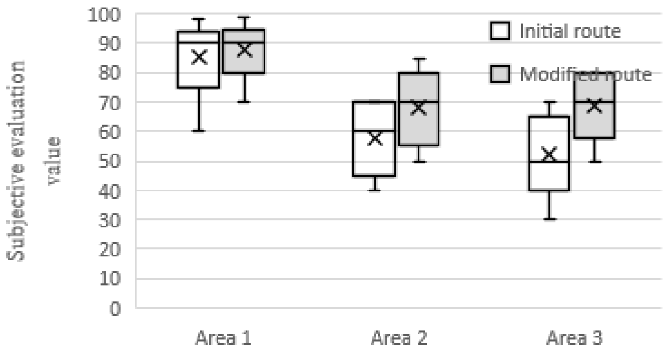

Figure 5. A box-and-whisker diagram of the comprehensive evaluation for females

6.5 Discussion

6.5.1 Effectiveness of the Cost Improvement Method

Although no statistically significant difference was observed in route evaluation, improvement in evaluation could be confirmed in some situations. In Areas 2 and 3, there were many roads that were dangerous or had cars on them in the initial route, and these were avoided in the updated route, which probably improved the evaluation from the viewpoint of safety. This trend is particularly noticeable in females' results.

In Area 1, many users rated the initial route highly, while the updated route received a lower rating. In the initial route, which was highly evaluated, there is a possibility that the accuracy of the model deteriorated due to the overcorrection of the model parameters based on the evaluation values of the participants. In this study, since we focused on confirming the "improvement of route evaluation by the proposed route modification method," we set the update parameter so that it can take a large value. To improve the versatility of the model, the variation range of the update parameters should be reduced, and the modification method should utilize a large number of evaluation data for the passage locations.

Since the comprehensive evaluation of walkability, safety, and pleasantness was used for the participant evaluation of the routes in this study, it may make the results vague and difficult to discuss the effects.

6.5.2 Appropriateness of Preference Evaluation Methods for Route Factors

In this study, a 5-point scale was used to obtain ratings of the route factors (cf. Section 5.2). Considering the burden on the user, the required time, and the improvement in model accuracy, this format can be said to be appropriate. In order to further reduce the user's burden, we are also considering a method of grouping route factors and reducing the number of evaluation items.

6.5.3 Appropriateness of Route Factors

In the route factors used, sidewalks, parks, and riverside areas were highly rated by many participants and had a significant impact on route selection and are therefore considered appropriate. On the other hand, many participants commented on the "amount of car traffic" and "narrowness of sidewalks," which were not included in the study, thus requiring the further study of different route factors.

7. CONCLUSION

7.1 Summary

In this project, we aim to develop a route planning method that can provide each user with an appropriate route, taking into consideration the preferences, i.e., walkability, safety, and pleasantness, peculiar to the elderly. To achieve this goal, we constructed a quantitative model that expresses the relationship between the attributes of elderly users and their preference for route selection, and examined the feasibility of a user adaptation method based on the user's preference evaluation for route factors.

In this study, we used "acceptable detour time" to quantify user preferences. The results of the paper survey of the elderly revealed that user attributes such as "age" and "the desired interval between breaks" influenced route selection, and that the impact of these attributes differed by gender. This suggests that the targeted user attributes are useful in estimating the preferences of the elderly for the routes. When planning user-friendly walking routes, separate models should be built for males and females.

Next, we proposed a method of individual adaptation of the model using post-walking evaluations of route factors, and verified its effectiveness through walking experiments. In some situations, we were able to identify improvements in the participants' evaluation of the routes. This indicates the feasibility of the user adaptation method based on the user's preference evaluation for route factors. On the other hand, there was also a route in which the evaluation by the participants declined. In this study, evaluation data after walking three routes were used to improve the cost model. By adjusting the update parameters and using more evaluation data, it is expected to plan routes that are adapted to individuals with high accuracy.

7.2 Future Works

The first work is to conduct a new validation experiment with a sufficient number of participants to confirm clear conclusions through statistical analysis. Also, in order to clarify the results, it is necessary to use dedicated evaluation indicators for walkability, safety, and pleasantness in the evaluation of planned routes. Second, it is necessary to obtain additional route factors. In order to deal with route factors not covered in this study, a comprehensive survey of factors affecting route selection is needed. The third is the improvement of the model adaptation method. To improve the versatility of the model, the update value from a single evaluation value by the user should be kept small, and updates from the accumulation of a large number of evaluation data should be employed.

The basic idea of the proposed method can be applied to evacuation route planning in the event of a disaster. As a tool to prevent panic among evacuees, the authors are developing a pedestrian navigation method with a model that quantitatively evaluates the fear that people feel during evacuation actions depending on the road conditions, with the goal of providing evacuees with a route that does not cause fear (Furukawa and Koshimizu, 2022). Although the results show that the mean value of the level of fear is lower for the revised method than for the shortest path, the significant individual differences in fear estimation should be addressed to improve the estimation accuracy. We believe that the method of individual adaptation of the model using post-walking evaluations of route factors has the potential to resolve the issue.

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