Development of a Navigation System with a Route Planning Algorithm Using Body-Worn Sensors

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ABSTRACT

There are many kinds of events where participants converge and move around freely looking at points of interest. Since in these event spaces, the participants go where they want, some problems may arise for the event manager such as people staying in one area too long or congestion that occurs at specific attractions. Therefore, we propose here a new navigation system that has a route planning algorithm to satisfy the objectives of the event manager. In an actual test of our system, we found that the participants' actions were in line with the objectives of the event manager. Moreover, we also found that our system performs better by using wearable computing technologies because detailed information on participants is acquired.

Categories and Subject Descriptors

H.4 [Information Systems Applications]: Miscellaneous

General Terms

Performance

Keywords

navigation system, route planning algorithm, wearable computing

1. INTRODUCTION

There are many kinds of events held in limited spaces where participants move around several areas, such as stamp rallies, where visitors have a book stamped at different exhibits, and amusement spots, where visitors enjoy various games and attractions. In these event spaces, the participants move around as they like. For example, some people collect the required number of stamps in the shortest time, or some people visit only the attractions or games that they want to play. Such unrestricted behavior may cause the following problems that are difficult for the event manager.

- Congestion of specific routes or attractions
  This increases the waiting time for participants, who may then be dissatisfied with the event and choose not to visit certain points that the event manager wants them to.
- Difficulty in managing the time restrictions
  It is very difficult to navigate the participants to time-restricted events at a specific attraction on time because of their individual actions.
- An event that finishes too early or too late
  The participants may get bored due to moving around in short distances or in a limited area, or they may drop out of the activity because of a fatigue.

To solve these problems we propose here a new navigation system with a route planning algorithm that achieves the objectives of the event manager. Our proposed system loosely controls the participants along the route that fits the manager's objective, such as controlling the finish time, increasing the number of finishers, and reducing the waiting time at each attraction. The participants can enjoy the event without having to consider the control of the system because they do not need to follow the system recommendations.

We tested our system at the Mobile Nature Rally in Expo Park held at Expo Memorial Park [1] in Osaka, Japan on June 3, 2007. The results indicated that the participants using our proposed method finished the rally at around the fixed time and moved around over a wide area, which were the event manager's requests. Moreover, we confirmed that the system ran efficiently using detailed user context data acquired with body-worn sensors.

This paper is organized as follows. Section 2 introduces related studies. Section 3 explains our proposed system, and Section 4 shows the results of evaluation. Our improved system using body-worn sensors is introduced in Section 5, the pe12rformance of our improved system is discussed in Section 6, and Section 7 concludes this paper.

2. RELATED WORK

2.1 Navigation system

Recently, several navigation systems have been proposed such as a system using GPS in cell phones called P-tour [2], a navigation system of Expo Memorial Park consisting of a wearable computer [3], and a device-independent human navigation system [4]. The first system presents the route that satisfies user requirements so that the user can go around within a specified time if the user sets some points they want to visit. The second system provides information about pavilions and guidance automatically without manual operation. The third system can present tour guide information according to the specifications of the user's devices such as a wearable computer, personal digital assistant (PDA), or cellular phone.

To our knowledge, however, there is no conventional navigation system that considers the requirements of the event manager. Moreover, in conventional systems, it is difficult to estimate the user's movements accurately because of the simple estimation method, and they do not change the routes dynamically.

2.2 Wearable computing

There has been increasing interest in wearable computing because of the downsizing of computers. Wearable computers have three features that differ from conventional computers [5].

- Hands-free: information can be obtained without manual operation because the user "wears" the computer.
- Power always on: the computer is always available because the power is always on.
- Daily-life support: daily activities can be supported because the computer is worn all the time.

In the wearable computing environment, by acquiring data on a user's actions and condition from body-worn sensors, services such as a health care system [6], a user-situated display system [7], and a navigation system with a head-mounted display [8] have been realized. These systems are able to work more effectively using various sensors, as described below.

The health care system, Life Minder, consists of a wristwatch-shaped wearable sensor module and a PDA. The system uses information from accelerometers, a pulse meter, a thermometer, and galvanic skin reflex (GSR) electrodes to guide the user in daily self-care in real time. The author of the paper [7] suggests that messages delivered during the transition of context may be received more efficiently than the same messages delivered at random times. The system detects the user's context information from wireless accelerometers and delivers messages when the user's physical activities change (e.g. from sitting to walking). The system proposed in another paper [8] can track the user's indoor position, where it is difficult to use GPS.

In this way, it is possible to provide more advanced services by obtaining a user's detailed information in real time from body-worn sensors.

3. SYSTEM DESIGN

3.1 Environmental assumptions

We assume that the proposed system will be used in event spaces where the participants visit various points. The participants capture a QR code by camera in their cell phone or a wearable computer at each point, and they access the website corresponding to the point. Each website provides information and a quiz about that point, as well as the point recommended as the next destination. Note that the participants do not have to follow it because it is just a recommendation.

3.2 System structure

Figure 1 illustrates the system, which consists of a website, database, and route planning program. The route planner can be customized to adopt the objectives of the event manager. The database maintains information on passed points, standard walking time between any two points, and the navigation contents to be shown at each point.

When a user gets to the point, they report their User ID, arriving point ID, and arriving time to the database by accessing the website. In addition, if a user wears a computer, more flexible control can be applied on account of the detailed information obtained from body-worn sensors. As soon as the participants arrive at a point, the system starts searching the optimal route that satisfies the event manager's requirements, and shows the next destination after the user answers the presented question. In detail, the system calculates a concordance rate between the event manager's objective and the participant's situation with respect to all routes that the participant can take, and the system shows the next destination on the route with the best score. By adjusting coefficients of each score, it is possible to assign a weight to each objective. Although the appropriate route may change, the participants do not perceive the change because the system does not show the whole route but just the next destination.

The proposed system uses Wearable Toolkit [5] to conduct information from the body-worn sensors. Wearable Toolkit is an application platform to make it easy to de-

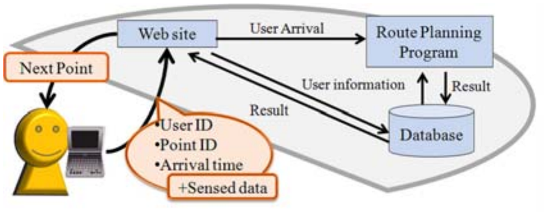


Figure 1: System configuration

velop wearable computing systems. The user contexts, walk and stand, are recognized by our system. This means the accurate walking time is reported to the server.

3.3 Design

We defined five scores, Time score, Congestion score, Distance score, Area score, and Point score. The smaller these scores are, the more the manager's intentions are satisfied. Each score is calculated as follows:

- Time score
Time score S_{T_R} means the difference between the estimated goal time T_R and the target goal time T', and it is defined in the following equation.

$$\begin{aligned} if(T_R > T') \quad & S_{T_R} = (T_R/T')^2 \\ else \quad & S_{T_R} = (T'/T_R)^2 \end{aligned}$$

Here, it is necessary to anticipate the goal time T' to calculate the score. We assume that the time the user stays at each point is predetermined and constant, and the system considers the participants to be resting when they take three times longer than the standard walking time to get to the next point. Supposing a participant has walked along a route $H = (p_0, \ldots, p_{n-1})$ and is at n^{th} point p_n now, where p_0 is the starting point, we define velocity ratio $V_{p_n} = t_{p_n}/t'_{p_n}$, where t_{p_0} and t'_{p_0} are the actual walking time and the standard walking time from p_{n-1} to p_n, respectively. A large V_{p_n} value indicates a slow walking speed. Using V_{p_n}, we define the average diversity of velocity DV_{p_n} as shown in the following equation.

$$DV_{p_n} = \frac{\sum_{k=1}^{n-1}(V_{p_{k+1}} - V_{p_k})}{n-1}$$

A large DV_{p_n} means that the walking speed is getting slower because of fatigue. Then, supposing the user walks along a route $R = (p_{n+1}, p_{n+2}, \ldots, p_{g-1})$, estimated goal time T_R is calculated by the following equation.

$$T_R = V_{base} \times (1 + DV_{p_n}) \times \sum_{p_k \in R} t'_{p_k}$$

Here, g is the number of points visited from start to goal, and V_{base} is the base velocity ratio of the participant. V_{base} is basically V_{p_1}, unless the participant rests between p_0 and p_1. V_{base} is the velocity ratio between points where the participant has not taken a rest first. If the participant uses a wearable computer, because the user's break time is acquired using body-worn sensors, it is possible to estimate the accurate goal time.

Here is an example. It is assumed that the standard walking time is 10 minutes between all points, and g is 5. If a user's walking times are 12 minutes, 13 minutes, and 11 minutes, V_{p1}, V_{p2}, and V_{p3} are respectively calculated to be 1.2, 1.3, and 1.1; then DV_{p_3} is calculated to be -0.05. $T_R(R = (p_4, p_5, p_{goal}))$, therefore, is calculated to be 34.2 minutes as follows.

$$T_R = 1.2 \times (1 - 0.05) \times (10 \times 3)$$

In this way, although the standard time from p_3 to p_3 is 20 minutes, because the user walks slowly, the system expects it to take more time.

- Congestion score
Congestion score S_{C_R} means the concentration of people at a specific point. S_{C_R} is defined as the following equation, where n, n', and c are the number of current participants, the estimated number of participants at the point, and the capacity of the point, respectively.

$$\begin{aligned} if(n' < c) \quad & S_{C_R} = 0 \\ else \quad & S_{C_R} = n'/n, \end{aligned}$$

- Distance score
Distance score S_{D_R} is applied in order to get participants to walk more than the target distance, and it is expressed as the following equation, where D_R and D' are the distance along the planned route R and the distance required by the event manager, respectively.

$$\begin{aligned} if(D_R > D') \quad & S_{D_R} = 0 \\ else \quad & S_{D_R} = (D'/D_R)^2 \end{aligned}$$

- Area score
Area score S_{A_R} is applied in order to get participants to walk through as many areas as possible. All points are divided into some areas in advance, and a constant cost is added to the score as the route misses one area. In addition, the same area cannot be indicated continuously.

- Point score
Point score S_{P_R} is applied to get participants to visit the specific points where the event manager wants them to go. A constant cost is added to the score as the route misses the point.

Finally, the next destination is indicated according to the optimal route R_{op}, which has the lowest sum of scores, as shown in the following equation, where $\alpha, \beta, \gamma, \delta$, and ϵ are weights of scores. If there are several routes that have the lowest sum of scores, only one route is chosen at random.

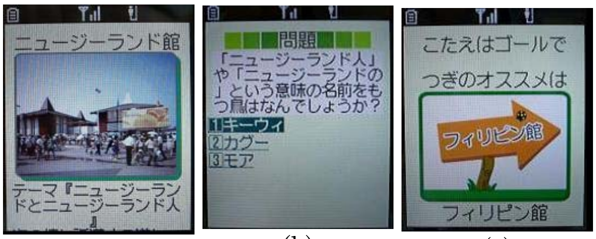
$$R_{op} = \arg\min_{R}(\alpha S_T + \beta S_C + \gamma S_D + \delta S_A + \epsilon S_P)$$

4. EVALUATION

4.1 Evaluation Environments

The proposed system was used at the Mobile Nature Rally in Expo Park [9] held at Expo Memorial Park on June 3, 2007. Figure 2 shows a snapshot of the event. There were 171 entries in the event. For convenience, only the participants' own cell phones were used in this event. The participants captured a QR code and accessed a website with

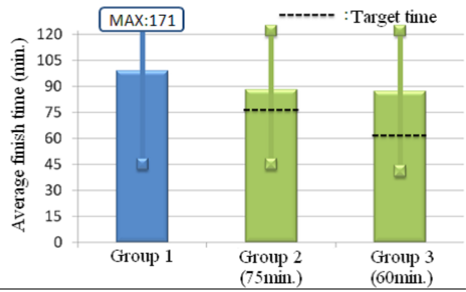
Figure 2: Snapshot on Mobile Nature Rally



(a) Point information | (b) Question | (c) Recommendation

Figure 3: Examples of screen shots

Figure 4: Distribution of visiting points



	Group 1	Group 2 (75min.)	Group 3 (60min.)
Standard deviation	30 min.	25 min.	23 min.
Explored area	71.1%	83.3%	76.4%
Accepted rate	79.7%	90.0%	91.8%

Figure 5: Results

their cell phones at each point. On each website, the participants browsed information about that point (Fig. 3(a)), answered a question about that point (Fig. 3(b)), then received a recommendation of the next destination (Fig. 3(c)). The participants had to visit at least 5 out of 15 points, which were set at the 13 pavilions (France, the USA, Brazil, Greece, Soviet, Bulgaria, New Zealand, Kuwait, Singapore, Italy, Cuba, the Philippines and Saudi Arabia) and 2 attractions (Air Road and Leaf Play Equipment), and they were divided into 5 areas, as shown in Figure 4. The Start and Goal were located at the central entrance.

Based on the two requirements of the event manager, we employed time score and area score in the system.

4.2 Results in actual event

In the event, we divided the participants into three groups. Group 1 did not have a target time. The system showed the next destination at random. Group 2 had a target time of 75 minutes with the proposed algorithm. Group 3 had a target time of 60 minutes with the proposed algorithm. They were not informed they were being divided into groups or controlled by the system. Figure 5 shows the results of evaluation. Time durations estimated as a break were removed from the elapsed time. We confirmed that the participants in Groups 2 and 3 explored more areas and finished in a time closer to the target, compared with Group 1. However, the finish time of many participants exceeded the target time. The presumed reasons are as follows.

- Target time setting
  Although we set the target time to 75 and 60 minutes, the standard walking time of the shortest route was 68 minutes due to the constraint in which points in the same area were not selected consecutively. Therefore, we should have used a longer target time or fewer check points.

- Threshold for break
  In this event, the system considers a participant to be resting or lost if he/she takes three times longer than the standard walking time between two points. However, there were some cases of unnaturally long time even if the system did not consider the participant to be resting. This problem can be solved by using a wearable sensor, which acquires detailed data on the condition of the user.

- Adjustment to change in walking speed
  We assumed that the average diversity of velocity DV_{p_n} would become stable. However, in reality, the walking speed was not stable and varied at each move. Therefore, it is necessary to consider the change in walking speed.

5. IMPROVED SYSTEM USING BODY-WORN SENSORS

5.1 System design

From the results of the actual operation, it became clear that the system needs information on the walking speed at

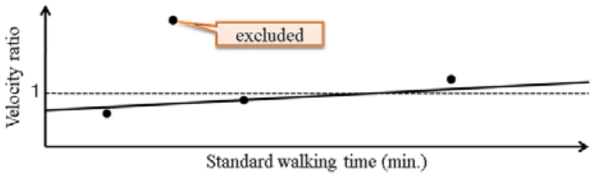


Figure 6: The speed prediction

all intervals to predict changes in the walking speed. Therefore, we use a linear approximation for the calculation of the subsequent walking speed (Figure 6). After removing the duration of rest from all past intervals, the velocity is calculated by the following equation.

$$\begin{aligned} y(\text{velocity ratio}) &= a * x(\text{standard time}) + b \\ a &= \frac{\sum_{x=1}^{n}\sum_{y=1}^{n}((y-\bar{y})*(x-\bar{x}))}{\sum_{x=1}^{n}(x-\bar{x})^2} \\ b &= \bar{y} - a\bar{x} \end{aligned}$$

However, since a plain approximation could result in the velocity ratio being less than 0 or extremely large, the upper and lower bounds of the estimated velocity ratio are set to 3 and 1/3, respectively. Next, the improved system employs a body-worn accelerometer positioned on the lumbar region of the participant to obtain more accurate information on the user's condition and to judge accurately if the participant is resting. The wearable computer recognizes the participants' walk and stop from their accelerometer. The duration of rest is calculated by the total stop time. The system is still not able to judge whether the participants have gotten lost , but it is designed to detect straying from the path when the interval time is twice and 15 minutes longer than the standard time, which is determined from the result of the previous actual operation and pilot tests.

5.2 Evaluation

We evaluated the improved system in an event similar to the previous one at the same place. All the conditions were the same as those of the event described in Section 4, but the target time of Group 3 was set to 90 minutes. The results for each group and of the previous system for comparison are shown in Figure 7. Rests taken after the last direction were removed from the finish time because they cannot be controlled by the system.

From the results, we confirmed that the participants with the improved system finished in a time closer to the target time and walked through more areas. This is because the system was able to determine how long the participants took to walk between each two points by considering their contexts using the body-worn sensor. Moreover, the system was able to estimate the velocity with a linear approximation method instead of the previous method.

5.3 Evaluation on the other scores

We conducted a simulation to evaluate Congestion score, Distance score, and Point score, which had not been used in the event. The average arrival ratio of the participants was set to 100 people/hour following a Poisson distribution, and the duration of the simulation was 3 hours. In the simulation, we used two scores, Time score and another score other than Time score. This is because there are many optimal routes with only one score. The target time was set to 75 or 90 minutes.

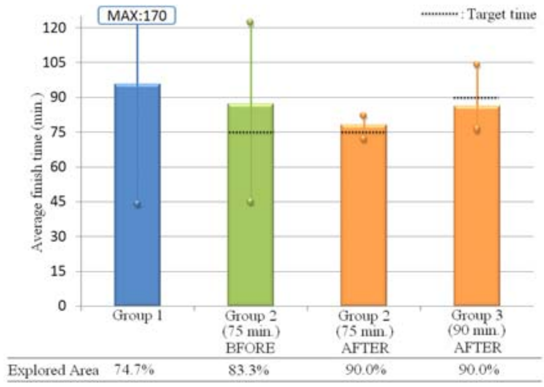


Figure 7: Results of improved system

In this simulation, n' in Congestion score was calculated as the number of participants that the system has navigated to the point, and c(threshold) was set to 30. In Point score, we set three target points, the pavilions of the USA and Singapore, and Leaf Play Equipment, and the cost added when the route failed to include them was set to 2/3 per one target point. D' in Distance score was set to the distance equal to the route whose standard walking time was 70 minutes because the system did not have information on the distance between each two points.

The results are given in Table 1. Compared with the results where participants navigated at random, the results with the score restriction fulfilled the manager's objectives. Navigated to crowd shows the ratio of participants navigated to crowded points, which are 16% and 12% when the target time was 75 and 90 minutes, respectively, whereas the ratio for the random method is 37%. Achievement ratio means the ratio of participants whose walking distance achieved the target distance. The score for the random method is 49%, while the results for 75 and 90 minutes are 36% and 73%, respectively. For the result for 75 minutes, it is difficult to fulfill the time score and the distance score at the same time, due to the time restriction. Passed points shows the average number of target points that the participants navigated. The results are 1.75 and 1.85 when the target time was 75 and 90 minutes, respectively, whereas it is 0.85 for the random method.

6. DISCUSSION

6.1 Demands of users

In this paper, only the scores satisfying the demands of the event manager are described. However, it is necessary to consider the demands of users, such as visiting particular points where they want to go. It is possible to reflect both the demands of event managers and users by inputting their demands into the system in advance. A proposed algorithm considering users' demands is our future task.

Table 1: Results of simulation

Score	Target time	Average	Min	Max	Standard deviation	Navigated to crowd	Passed points	Walk distance	Achievement ratio
————	-	85 min.	51 min.	145 min.	18 min.	37%	0.84	70 min.	49%
Time+	75 min.	75 min.	48 min.	92 min.	9 min.	16%	1.16	63 min.	29%
Congestion	90 min.	82 min.	55 min.	110 min.	12 min.	12%	1.03	68 min.	39%
Time +	75 min.	79 min.	54 min.	97 min.	8 min.	46%	0.95	63 min.	36%
Distance	90 min.	88 min.	46 min.	111 min.	11 min.	46%	1.10	74 min.	73%
Time +	75 min.	75 min.	52 min.	101 min.	11 min.	53%	1.75	65 min.	33%
Point	90 min.	85 min.	54 min.	114 min.	13 min.	55%	1.85	76 min.	71%

6.2 Adaptation to dynamic change in the enviroment

The standard walking time between each point is fixed in advance. However, this depends on other factors such as day and weather. To support these cases, we plan to use a learning function like a neural network.

6.3 Addition of contexts

In this paper, although only two contexts, "walk" and "stop", were used for calculation, more detailed control can be achieved by using other contexts such as "run" and "sit". In addition, we are thinking about adding other wearable computing functions, such as displaying a map when the user stops.

6.4 Adaptation to straying from route and side trips

For the sake of simplicity, our system uses an accelerometer. The reason we did not use a GPS is that there are some areas where GPS is not available in Expo Park. However, it is difficult to detect when users stray from the route using only an accelerometer. This problem can be solved by using other position measurements such as inertial navigation with an accelerometer and a gyroscope instead of a GPS.

7. CONCLUSION

In this study, we have developed a navigation system with a route planning algorithm that satisfies the requirements of event managers, and we tested the system in an event. We confirmed that participants were helped to efficiently navigate the route by our system along with the purposes of the event manager. Moreover, we enhanced the system by using a wearable sensor, and confirmed the effectiveness of the enhanced system in a simulation.

Our future work is to develop an algorithm that also considers users' demands, to improve the system for dynamic environments, and to use other sensors to obtain more accurate contexts.

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