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Tracking Individual Travel Behavior Using Mobile Phone

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Tracking type data collection methods using mobile phone have been developed for monitoring and analyzing individual travel behavior. Previous methods using PHS (Personal Handy phone System) assumed that the location data of base stations were known. This paper shows a location positioning method of a mobile object when the location data of base stations are not available. Instead of base stations, signal strength vectors (reference vectors) are observed at many places in a target area. A mobile object also observes a signal strength vector (target vector). The similarity index of a reference vector and a target vector is used for calculating the location position of a mobile object. This method is applied to tracking travel behavior of tourists in Kobe Kitano area.

Introduction

Location positioning data are essential for navigation and location based services. Commercial service using PHS (Personal Handy phone System) based location positioning technology has started since 1998 for security and welfare purposes. A PHS handset of a mobile object observes the signal strength of several (seven at maximum) base stations. The signal strength from a base station is decreasing in proportion to the distance of the PHS handset and the base station. Applying triangle

survey technique, it is possible to calculate the location position (longitude and latitude) of the PHS handset when the location position data of base stations are known. The accuracy of the location positioning depends on the density of base stations, and is about 50-100 meters in a city. The PHS based location positioning service has been used for individual travel data collection and travel behavioral studies as shown in [1], [2] and [3].

The previous location positioning method using PHS assumed that the location data of base stations were available. The aims of this study are to develop

a location positioning method of a mobile object even if the location information of base stations is not known, and to apply the method to tracking type travel data collection of tourists in an actual field in Kobe City.

Location Positioning Methods

Signal Strength and Distance

When the distance between a base station and a receiver (hand set) becomes larger, the signal strength of the base station decreases almost in proportion to the distance. Due to several reasons such as the reflection by obstacles, the signal strength may not always decrease linearly. Figure 1 shows an example of distribution of the observed signal strength and the distance from a base station. Those data were obtained by the field observation at the athletic ground in Ehime University, where the reflection by obstacles might be small. Number of

samples was 289.

The maximum value of the signal strength is about 80dB at the nearest point from a base station. The signal strength decreases almost in proportion to the distance. The solid line in the figure shows the linear regression line. The estimated linear decreasing function is,

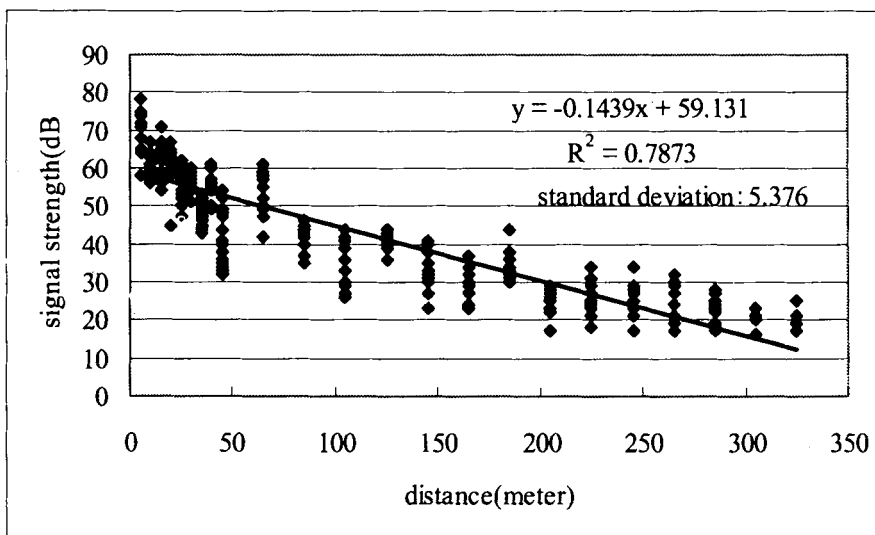
$$SS = 59.131 - 0.1439d$$

$$(91.32) \quad (32.59)$$

$$N = 289, \quad R^2 = 0.7873 \quad (1)$$

where SS and d denote the signal strength and the distance from a base station, respectively. The values in the parentheses are the t-statistics. R-square value and t-statistics show a sufficient level of fitness.

It is found that the signal strength observed at the same distance is fluctuating, and the width of the fluctuation is not so different for each distance. Thus, all observed data were pooled and the



〈Figure 1〉 Signal strength and distance

standard deviation of the signal strength at each distance was calculated. The value was 5.376dB. This value is used for the simulation analysis of the location positioning methods discussed in the following section.

Location Positioning Method Using Location Data of Base Stations

Assume that the signal strength from multiple base stations are observed and the location data of all base stations are available. It is easy to estimate the location position of a mobile object with a receiver (hand set). Here we define the observation vector of the signal strength as $\beta = \{\beta_k\}$.

The k-th element of the vector β_k denotes the signal strength of the k-th ($k=1,2,\dots,K$) base station. x_k and y_k denote the longitude and the latitude of the k-th base station. The location of a receiver (X, Y) is calculated as the center of gravity of (x_k, y_k) weighted by the signal strength β_k . That is,

$$X = \sum_{k=1}^K (\beta_k)^m x_k / \sum_{k=1}^K (\beta_k)^m$$

and

$$Y = \sum_{k=1}^K (\beta_k)^m y_k / \sum_{k=1}^K (\beta_k)^m \quad (2)$$

where m denotes a tuning parameter. When m becomes zero, (X, Y) yields to the geometric gravity

$(\sum_k x_k / K, \sum_k y_k / K)$ When m becomes infinite, (X, Y) goes to the nearest point of the base station with the maximum value of β_k . The optimal value of m can be estimated depending on the density of base stations.

When we obtain a set of signal strength data in series of time, the location of a mobile object at time t is calculated as,

$$X_t = \sum_{k=1}^K (\beta_{kt})^m x_k / \sum_{k=1}^K (\beta_{kt})^m \quad (3)$$

and

$$Y_t = \sum_{k=1}^K (\beta_{kt})^m y_k / \sum_{k=1}^K (\beta_{kt})^m$$

where β_{kt} denotes the signal strength of the k-th base station at time t .

Location Positioning Method without Location Information of Base Stations

Even if the location data of base stations are not available, it is possible to estimate the location position of a mobile object. Instead of the location information of base stations, the vectors of signal strength at different places (reference sites) in a study area are required. They are called as reference vectors. The vector $\alpha_i = \{\alpha_{ik}\}$ denotes the reference vector of the signal strength at the i-th referenced site, whose component shows the signal strength from the k-th base station. The reference vector should be observed beforehand. As described in the previous section, the vector $\beta = \{\beta_k\}$ denotes the vector of a mobile object, whose component shows the signal strength from the k-th base station. The vector $\beta = \{\beta_k\}$ is called as target vector.

The fundamental idea of the proposed location positioning method without location information of base stations is to compare the similarity between the target vector and the reference vector. When the location of a mobile object is very close to the i-th reference site, the target vector is expected to be the same as the reference vector of the i-th site. On the other hand, the target vector of a mobile object becomes different from the reference vector when a mobile object locates far from the reference site.

Considering those conditions, we define the similarity index of two vectors β and α_i as,

$$F_i = \sum_k (\alpha_{ik} - \beta_k)^2 / \left[\sum_k \alpha_{ik}^2 + \sum_k \beta_k^2 \right] \quad (4)$$

This index represents the standardized difference of two vectors β and α_i , and corresponds to the

inverse of the similarity of two vectors. The index has the following characteristics. When the target vector β is the same as the reference vector α , the index value becomes zero as the numerator of the equation becomes zero meaning the maximum similarity of the two vectors. When a mobile object locates far from the reference site, the component values of two vectors are expected to be completely inconsistent. Then the product of two vectors α, β becomes zero, and the index value becomes one meaning the minimum similarity of the two vectors. As each component of the vectors is positive, the product of two vectors is positive and the sphere of the similarity index remains $0 \leq F \leq 1$.

The similarity index shows the same tendency of the distance between the reference site and the location of a mobile object. When the mobile object is close to the reference site, the index becomes smaller and vice versa. Using these characteristics, it is possible to estimate the location position of a mobile object.

When we allocate many reference sites ($i=1, 2, \dots, l$) in a study area and prepare to observe the reference vector α_i at each site, the similarity indexes can be calculated for the target vector of a mobile object and the reference vectors of all possible reference sites. The location position of a mobile object (X, Y) is estimated as the geometric gravity of the coordinates of the reference sites weighted by the inverse of the similarity index. That is,

$$X = \sum_i \left(\frac{1}{F_i} \right)^m x_i / \sum_i \left(\frac{1}{F_i} \right)^m$$

and

$$Y = \sum_i \left(\frac{1}{F_i} \right)^m y_i / \sum_i \left(\frac{1}{F_i} \right)^m \quad (5)$$

Here x_i and y_i denote the longitude and latitude of the i -th reference site, respectively. Parameter m is a corresponding coefficient, which should be estimated for each study area. As mentioned in the

previous section, parameter plays the same role of location positioning. When parameter is set as a small positive value, the effects of the similarity index become lower. The location of a mobile object (X, Y) goes to the geometric gravity of the reference sites. When the parameter is set as an extremely large value, the location position of a mobile object is estimated as the same location of the reference site with the maximum ($1/F$) value meaning the nearest site. This suggests that a larger parameter value can be chosen if it is possible to allocate a lot of reference site.

When an object is moving and the target vector is observed at a time interval, the location position of the mobile object at time t is estimated as follows.

$$X_t = \sum_i \left(\frac{1}{F_{it}} \right)^m x_i / \sum_i \left(\frac{1}{F_{it}} \right)^m$$

and

$$Y_t = \sum_i \left(\frac{1}{F_{it}} \right)^m y_i / \sum_i \left(\frac{1}{F_{it}} \right)^m \quad (6)$$

Here F_{it} denotes the similarity index between the reference vector α_i and the target vector β_t of the mobile object at time t .

Simulation Tests of the Proposed Method

In order to know the numerical characteristics of the proposed location positioning method, simulation tests using hypothetical data were calculated. The accuracy of the estimated location is evaluated using the following measure.

$$G = \frac{1}{T} \sum_{t=1}^T \left[(\bar{X}_t - X_t)^2 + (\bar{Y}_t - Y_t)^2 \right]^{1/2} \quad (7)$$

Here (X_t, Y_t) denotes the estimated coordinate of a mobile object, and $(\bar{X}_t, \bar{Y}_t)$ denotes the true coordinate. The value of measure means the averaged error distance for all locations of a mobile

object traveling at time period 1 to T.

The test area is assumed 300 meters square which corresponds to the actual field experiment mentioned in the later section. Number of observation of a mobile object is set 100 ($T=100$) for all cases, and each observation is randomly executed in the test area. The observed signal strength is fluctuating and decreasing in proportion to the distance as shown in the previous section. The averaged value of the signal strength is assumed to decrease as the equation (1), and the standard deviation is also assumed indifference from the average value.

Test 1: Conventional Method

Base stations are allocated uniformly as a grid within the test area. Changing the number of base stations such as 16 (4x4), 36 (6x6), 64 (8x8) and 100 (10x10), the conventional location positioning method written in equation (3) is calculated. Different values of parameter m are examined. Table 1 shows the value of the accuracy measure G for different combination of number of base stations and parameter value. It is found that the location error becomes smaller when the density of base stations becomes higher. When 36 base stations are allocated in the test area, the averaged error distance is about 23 meters.

Test 2: Proposed Method

Number of the base station is fixed as 36 (6x6). The location of a reference site is chosen uniformly in the test area. Changing the number of reference sites such as 16, 36, 64 and 100, the proposed location positioning method written in equation (6) is calculated. The value of parameter m is also changed. The results of the proposed model are also shown in Table 1. The minimum averaged distance of the model will be 30 meters. This implies that the accuracy of the proposed model might be a little bit worse than the conventional method using location information of base stations. However, the averaged error distance itself is almost satisfactory level and it is recommended to allocate the reference site carefully when we apply the proposed method in an actual urban space.

Field Test in Kobe Kitano

The proposed location positioning method is examined its performance in an actual situation. Kobe Kitano area is chosen as a test site where is a popular sight seeing area in Kobe. The test site is about 300 meter square. 40 power antennas are located as base stations, and 63 reference sites are selected. PEAMON (Personal Activity Monitor) is

(Table 1) Averaged error distance of two methods (meters)

Number of Base Station					Number of Reference Sites				
parameter	100	64	36	16	parameter	100	64	36	16
m=0.5	102.5	103.9	106.5	115.3	m=0.5	196.7	97.2	95.2	95.1
m=1	35.8	37.8	43.3	56.7	m=1	76.9	79.5	74.8	75.2
m=3	21.5	23.7	26.2	35.7	m=3	30.8	30.0	29.7	32.5
m=5	20.9	22.5	24.2	30.3	m=5	31.2	31.0	33.2	41.0
m=7	20.5	21.6	23.0	27.7	m=7	33.5	34.1	37.3	47.6
m=10	20.2	21.2	22.5	28.2	m=10	35.2	36.7	40.2	52.3

used for observing the signal strength vector of reference site and mobile object.

In order to examine the accuracy of the location positioning method, the true location positioning data are obtained by a surveyor moving along a predetermined path. Number of observation point was 518 on the path. The value of similarity index is

compared with the distance between the location position of the test object and that of the reference point. The R^2 value of the similarity index and the distance is 0.77. This implies the index can be used as the alternative variable of the distance.

When the value of parameter m is 5.0, the averaged error distance defined as equation (7)

〈Table 2〉 Distribution of error distance in a field test

Error Distance #of	Observation	Frequency(5)	Accumulated Freq.(%)
0-10	94	19.2	18.2
10-20	114	22.1	40.3
20-30	119	23.0	63.3
30-40	74	14.3	77.6
40-50	51	9.9	87.5
50-60	23	4.4	91.9
60-70	27	5.2	97.1
70-80	4	0.8	97.9
80-	11	2.1	100



〈Figure 2〉 True movement



〈Figure 3〉 Estimated movement

yields to 28 meter which is the minimum value. Table 2 shows the distribution of the error distance. 80% of error distance is found less than 40 meters. Figures 2 and 3 show the true (predetermined) and the estimated movement of the object, respectively. These two figures are consistent each other, and it is possible to track the movement of the mobile object.

Behavior of Tourists

Kitano area attracts many tourists since historical buildings and streets are preserved. We invited 56 couples of two young ladies as tourists. Every couple was asked to move the area carrying a PEAMON in their bag. They are separated into three groups with

〈Table 3〉 Number of couples participated in the experiment

<i>Date</i>	<i>Weather</i>	<i>Group1</i>	<i>Group2</i>	<i>Group3</i>	<i>Sum</i>
Nov.2nd	Cloudy	3	5	9	17
Nov.3rd	Rain	5	6	5	16
Nov.22nd	Fine	7	9	7	23
Sum		15	20	21	56



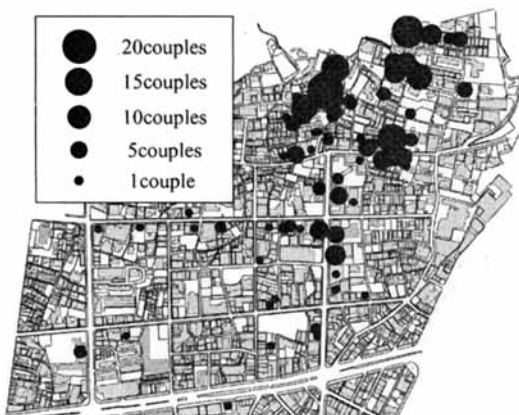
〈Figure 4〉 Example of tracking route of a couple

different quality of information. No information is given to the first group, a map of Kitano area is given to the second group and a recommended route in addition to the map is provided to the third group. As well as tracking data, travel diary and attitude data are obtained through questionnaire survey. Table 3 shows the number of couples participated in our experiment. Figure 4 shows the tracking route of a couple. This couple walked 1700 meters and visited 4 spots. It took 38 minutes for stay and 53 minutes for move. Based on the estimated location positioning data Based on the estimated location positioning data, travel characteristics of every tourist are calculated. Table 4 shows the averaged travel characteristics of each group. The averaged travel distance, the averaged

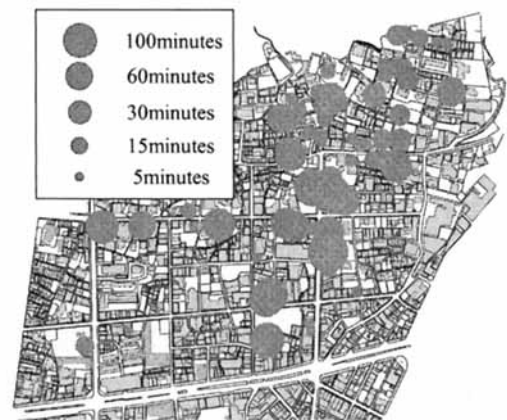
staying time and the averaged number of visited facilities in the area are 2,105 meter, 207 minutes and 6.0 facilities, respectively. The group 3 tourists with a map and a recommended route traveled longer distance and stayed longer in the area than the other two groups. The sightseeing information provided to the group 3 tourists might encourage the activity of the tourist. The group 1 tourists without any information traveled longer distance than the group 2 tourist with a map. They might be obliged to travel additional distance to find the way to the destination. The travel characteristics of group 2 (with a map) are less active than the other two groups. These differences of tourist behaviour suggest that the provision of touring information must be carefully designed so that it could improve

〈Table 4〉 Averaged travel characteristics of each group

Travel Characteristics	Group1	Group2	Group3	Sum
Total Travel Distance (meters)	2,157	1,891	2,291	2,105
Total Touring Time (minutes)	209	193	218	207
Number of Spot Visited	6.5	5.2	6.2	6



〈Figure 5〉 Number of visitors



〈Figure 6〉 Averaged staying time

the knowledge and increase the interest of the tourist. Number of couples visited each spot and the averaged staying time can be directly

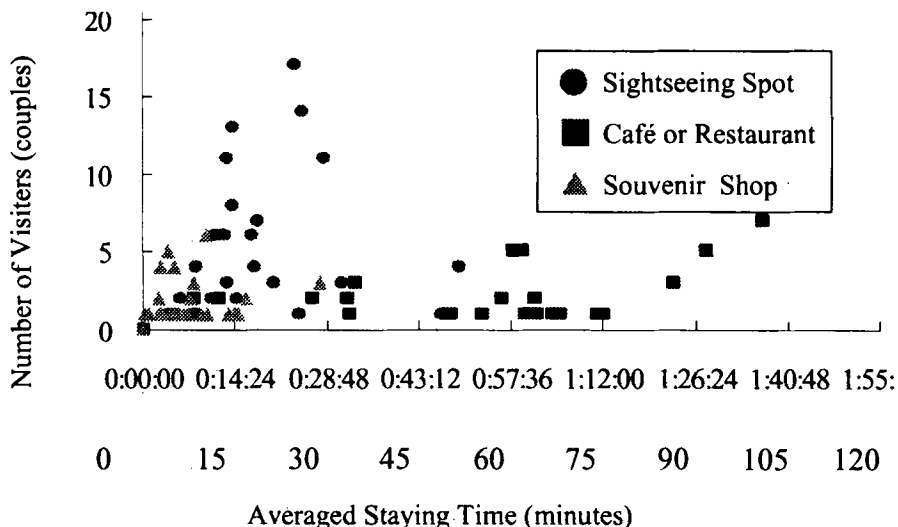
Number of couples visited each spot and the averaged staying time can be directly calculated using the tracking data. Figures 5 and 6 show the spatial distribution of the spots and facilities with the number of couples visited and the averaged staying time, respectively. It is found that the spatial distribution of the spots and facilities with longer staying time is different from that of the popular spots with attracting many tourists. Figure 7 shows the distribution of the number of visitors and the averaged staying time of spots and facilities categorized their characteristics. The popular sightseeing spots distributed at the north east corner of the area attracted many tourists. However, the averaged staying time was less than 30 minutes. Although the number of tourists visiting each cafe or restaurant was less than 5, they stayed there for

more than 30 minutes and sometimes longer than 90 minutes. The averaged visiting time of shops was the shortest.

It is found that the accurate time and location data observed with mobile communication instrument are useful to estimate the time use pattern and the spot-to-spot movement of tourists in the area. Detailed consumer's behavioural data would be also useful for discussing the marketing strategy of the area.

Conclusion

In this paper, a new method is proposed for estimating location position of a mobile object when the location information of base stations is not available. The similarity index calculated by the signal strength vectors is used as an alternative measure of the "distance" between the predetermined reference site and the target object.



〈Figure 7〉 Number of visitors and the averaged staying time

It is found that the proposed method shows a satisfactory level of performance through simulation tests and a field experiment in Kobe. As the accuracy of location positioning depends on the density of reference site, not a small number of reference sites may be allocated when this method is applied to a larger area. The density of reference site and the number of feasible observations of signal strength at each site should be further discussed considering a required accuracy level.

Using the proposed method, sightseeing behaviour of tourist in Kobe Kitano area was studied. The accurate space-time path diagram of an individual tourist provides valuable information for understanding travel behavior. Analysis of travel pattern using those tracking data is now under consideration. Aggregating the tracking data of tourists, it is possible to calculate various characteristics of tourist behavior including travel distance and time, number of tourists at any space or road sections in the area, and so on.

The tracking type travel behavior data collection using mobile instruments seems more effective for unusual travel behavior survey since travelers may feel difficulty to answer the accurate time and location of travel behavior with questionnaire survey. In addition to collect location data, mobile instruments are available for providing information to travelers. Analyzing the effects of travel and activity information on individual travel behavior is another interesting topic for further study. Using the mobile instrument with the function of providing information, we are now approaching to this interesting topic. Results of the analysis will be shown sooner.

Travel Behaviour using PHS based Location Positioning Service System, Proceedings of the 6th ITS Conference in Tronto(in CD-ROM).

ASAKURA, Y. and HATO, E., 2001, Analysis of Travel Behaviour using Positioning Function of Mobile Communication Devices. Travel Behaviour Research; the Leading Edge, Hensher, D. (ed.) Pergamon, 885-899.

Hato, E. and Asakura, Y., 2001, New Approaches for Collecting Time-Space Activity Data. Proceedings of the 80th TRB Annual Meeting.(CD-ROM), 12pages.

Shimada, M., Iryo, T. and Asakura, Y. , 2003, Evaluation of a Location Positioning Method Using PHS and Probe Stations. Proceedings of Infrastructure Planning, 4pages, CD-ROM.

References

Asakura, Y., Hato, E., Nishibe, Y., Daito, T., Tanabe, J. and Koshima, H., 1999, Monitoring