A data collection system for detailed person movements in an urban space based on mobile communication technologies: seeking a market survey technique for urban management.

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SYNOPSIS
Precise monitoring of individual behavior in a field research area such as an enclosed urban subspace, traffic terminal, underground shopping complex, shopping center, etc., is fundamental to designing pedestrian navigation systems and planning marketing strategies for urban management. General location-positioning systems may not be suitable for tracing activity in such areas. For example, GPS-based systems are not available inside buildings, and PHS-based location systems result low accuracy. Therefore the authors have proposed a new system for tracing individual behaviors in an enclosed subspace that can be used for activity surveys in urban public/commercial facilities. The paper describes methodologies to determine the location of a pedestrian. The results of field research conducted in Osaka, Japan are presented. Pilot surveys in a shopping center confirm the usefulness of the system and methodologies.

KEYWORDS: Monitoring human behavior, Personal location system, PEAMON

1. INTRODUCTION
Travel data collection methods using advanced information and communication technologies have attracted great interest in the past few years. It has become possible to utilize various mobile devices such as the global positioning system (GPS) and personal handyphone system (PHS) to perform tracking surveys. These overcome the disadvantages of the questionnaire-type travel survey. As well as for observing individual travel behavior, the travel data measured with mobile devices can be used for evaluating the level of service of transport systems in urban areas. For instance, a floating car survey methodology in traffic engineering can be extended to various other modes when sampled individuals are equipped with a mobile communication handset.

The location-positioning data of a mobile object are represented by a sequence of points in space and time. This includes any survey system, mobile device, or mobile object (a vehicle or traveler). In order to use the observed sequence of points for travel behavior analysis, algorithms were developed to identify a point as either stationary (staying) or moving, and trip characteristics are identified through the location-positioning data of individual travelers.

There are some previous studies on the use of GPS and mobile communication devices (PHS-based devices collecting positioning data, etc.) for collection in transport planning and traffic management. Zito et al. (1995) studied the possibility of using GPS for real-time monitoring of the location, speed, and direction of a vehicle. Sermons and Koppelman (1996) used GPS to detect arterial incidents. Both studies deconstructed the ability of GPS to monitor vehicle movement. In Japan, Ohmori et al. (1998) tried to monitor the origin, destination, and route of subjects, comparing three different modes of travel: walking, bicycles, and automobiles. Asakura et al. (1999) conducted a 2-week travel survey using a PHS-based positioning system in Osaka. They proposed a method for transforming positioning data to an activity diary, and demonstrated the validity of the methodology.

2. POSITIONING TECHNOLOGY USING MOBILE COMMUNICATION DEVICES
2.1 GPS-Based Travel Survey
Vehicle navigation systems using GPS as positioning devices combined with DRM (digital road map) have attracted more than 3 million customers in Japan. Development of map-matching technology and differential GPS, as well as overcoming selective availability (SA) factors, has reduced the positioning error of GPS-based systems; the accuracy of vehicle navigation systems has improved. So, GPS can monitor a vehicle’s movement; however, when we use it to survey a passenger’s travel behavior, he/she is obliged to carry an unnecessary device even if it is small. Furthermore, the signal is sometimes disturbed in downtown areas with higher buildings. It is not available in some places, for example, inside of buildings, in enclosed shopping malls, and underground.

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2.2 PHS-Based Location-Positioning Systems

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2.2.1 On-Line Travel Behavior-Monitoring System

LOCUS (http://www.locus.ne.jp/), a private company in Osaka, Japan, has started a location information service using PHS. The PHS system uses lower signal power than usual cellular phone systems, and it requires densely located base stations. The antennas of a service carrier are set up about every 100 meters in an urban area. The LOCUS system measures the signal strength of multiple (three–five) base stations. It can overcome the effects of reflection and shield by buildings and obstacles. The system gives precise location positioning within a range of 20–150 meters, depending on the allocation of base stations.

It is available even in underground shopping malls as well as inside of buildings. The handy terminals for PHS on the market are specified as 54 cc, 58 grams, and usable 5–400 hours. (Refer to Fig. 1.) Commercial service has been available in Japan since April 1998. It is used for various socio-economic activities such as welfare, security, entertainment, and so on.

2.2.2 Off-Line Monitoring System

We have developed a mobile-type travel data collection instrument named PEAMON (PErsonal Activity MONitor). PEAMON integrates modules including a PHS receiver, three-dimensional acceleration sensor, central processing unit (CPU), compact flash memory card, and lithium ion battery in a handy unit. The size of the unit is 120mm high by 70mm wide by 12mm thick, and it weighs 125g. (Refer to Fig. 1.) The instrument is portable in the pocket or bag of an individual. The location-positioning data (longitude, latitude, and time) are obtained through the PHS function (LOCUS) of PEAMON every 15 seconds. The data are stored in the unit’s memory. The location-positioning algorithms for PHS are shown in detail in Asakura et al. (1999). It uses the signal strength and the ID number of three to seven base stations of the PHS communication system. The amount positioning error depends on the density of base stations, less than 50 meters in a central city area. This is sufficient to trace the travel movement of an individual in urban space.

2.2.3 Off-Line PEAMON and PA Monitoring System

In order to enhance the accuracy of positioning, a PA (personal antenna) is distributed to complement the existing PHS cell stations around a survey area. The PA is small enough to use for a field survey (105 × 120 × 12mm; weight 110 g). Figure 2 shows two types of PA. One type (right in Figure 3) is the normal PA, which has a fixed signal strength. This type of PA is distributed to any PHS user with a weak signal. The other type of PA has eight levels of strength and is designed to attenuate signal strength. We installed this type of antenna in the survey area. The PA must be carefully installed to ensure that each antenna’s signal pattern effectively covers its assigned area. Location of PAs also depends on the distribution of shelves or facilities in the store that might interfere with the PA signal in the area surveyed.

Figure 1 PEAMON (left) and PHS (right)

Figure 2 Personal antenna
3. FIELD RESEARCH

For the field research, we recruited 139 persons who were visiting the area as monitors. Table 1 shows the design of the field research. The field research location is shown in a simple map in Figure 3 (Left: Ground level). The field included an underground shopping area called CRYSTA NAGAHORI and SHINSABASHI in Osaka. The area is famous for shopping and entertainment for young people. The PEAMON data collection interval was set to 15 seconds.

<table>
<thead>
<tr>
<th>Date</th>
<th>2002/03/24 10:00~22:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place</td>
<td>Underground Shopping Center in OSAKA</td>
</tr>
<tr>
<td>Monitor</td>
<td>139 Person</td>
</tr>
<tr>
<td>Device</td>
<td>PEAMON (82) Antenna(26)</td>
</tr>
</tbody>
</table>

Table 1 Design of the Field Research

A service provider (LOCUS) for positioning information using PHS already exists in Osaka. This system provides precise positioning within a range of 20-150 meters, depending on the local base station configuration. PHS is also available in underground shopping centers and inside most buildings and public transport where base-stations are located.

The antennas (base stations) of the service carrier are placed about every 100 meters in urban areas, with a corresponding positioning error of less than 50 meters. Underground and inside buildings, however, the positioning error is much larger owing to fewer antennas, and in suburban areas, the average positioning error is more than 100 meters. In most cases, this amount of error is unacceptable for identifying travel behavior for use in urban management.

The PA was originally developed to support PHS users living and working in the unreliable suburban areas where it is difficult to situate stations densely enough. The PHS carrier installed PAs at the request of users. Installing a sufficient number of PAs is the simplest method to allow observation of individual travel behavior.

We distributed 26 PAs in the field research area, as shown in Figure 3 (Right: Underground level). During the pre-trial survey, we realized that the PHS signals were very weak and could not be observed in some parts of the field, mainly because of the terrain. Instead of an exact movement, we intended to trace an individual's movement between zones in the underground shopping center. Zoning (A to I) in the area was determined considering the type of retail offered. Although each zone covered a specific area, neighboring zones were not allowed to overlap, which meant that there were gaps in coverage between some zones. A couple of PAs were located in each zone.

4. RESULTS

4.1 Ground-Level Pedestrian Movement

On ground level, monitors carrying PEAMON were identified using the systems described in 2.2.2. They traveled by walking and were allocated a total travel time of about 3 hours. Data for the movement of 139 persons for an average of 3 hours were collected, and a space–time analysis was performed. These location data then become the basic data of urban planning and traffic planning. It is essential to transform positioning data to travel data when we analyze the travel behavior of an individual.
The idea is to distinguish between an observed point, "stay point," and "move point." We calculate the distance between two points that are in sequence in time of a day. When the distance between two points in a time sequence is short, the monitor is recognized as being at the same point in urban space. However, when the distance between two points is long, the monitor has moved in urban space. Details of the data transfer algorithm are presented in Asakura et al. (1999).

Table 2 shows the result of discriminations between stay and move. The result of discriminations in grand-level are calculated by the Asakura method; however, in undergrad-level we regarded stay as more than stay time for 2 minutes. There are several points to distinguish between a stay and move as we capture the traffic behavior pattern of a person (as they turn to walk into shopping areas, staying time, moving time, etc.). So, these data are important for urban planning and traffic planning.

<table>
<thead>
<tr>
<th>Stay Place</th>
<th>Zone</th>
<th>Arrival</th>
<th>Departure</th>
<th>Stay Time</th>
<th>Discrimination (Grand-level)</th>
<th>Discrimination (Undergrad-level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRUSTA G</td>
<td>16:24:53 16:25:23</td>
<td>0:00:30</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUSTA E</td>
<td>16:27:00 16:28:00</td>
<td>0:01:00</td>
<td>Stay</td>
<td>Move</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shinsaibasi</td>
<td>16:28:30 16:29:15</td>
<td>0:00:45</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAIMARU North</td>
<td>16:29:36 16:32:51</td>
<td>0:03:15</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAIMARU South</td>
<td>16:33:06 16:35:36</td>
<td>0:02:30</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAIMARU North</td>
<td>16:52:21 17:23:06</td>
<td>0:30:45</td>
<td>Stay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAIMARU North</td>
<td>17:23:21 17:38:06</td>
<td>0:14:45</td>
<td>Stay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shinsaibasi Street</td>
<td>17:39:06 17:52:21</td>
<td>0:13:15</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUSTA D</td>
<td>17:52:38 18:26:30</td>
<td>0:33:52</td>
<td>Stay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUSTA E</td>
<td>18:27:38 18:29:15</td>
<td>0:01:37</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUSTA F</td>
<td>18:29:23 18:37:38</td>
<td>0:08:15</td>
<td>Stay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRUSTA G</td>
<td>18:38:00 18:38:53</td>
<td>0:00:53</td>
<td>Move</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2 Ground Level and Underground Level

Figure 4 shows a time series for the number of persons carrying PEAMON and the staying number of persons staying in CRUSTA. We ascertained the number of monitors staying in CRUSTA (underground shopping) by analyzing the collected data. There can be observed a crowded period of time from 14:30 to 15:00 (tea time?), and from 17:30 to 18:00 (dinner time or going home?).

![Figure 4 Time series for the number of persons carrying PEAMON and the staying number of persons staying in CRUSTA](image-url)
4.3 Movement in the Underground

Figure 5 shows the zone flow indication system, which displays the position data of a monitor with a time change. We formed an appropriate position coordinate for this system reproducing the situation of movement. The subwindow shows tantalization results for staying in the zone, and outflow and inflow of persons in every zone. The visual monitoring of individual behavior affords more detail than conventional analysis. This system is important to be able to characterize individual behavior for effective urban planning and urban management. In addition, we make simulations possible; for example, the arrangement of stores can be changed and new public accommodations added.

![Figure 5 The zone flow indication system](image)

Figure 6 shows the stay number of persons and maximum stay time for every zone. Zones E and F consist of an outfitting store (people do not stay there long), but Zones G and H consist of a store selling food and beverages (people stay there longer). A functional characteristic of the underground shopping center appears in each zone. There are characteristic stay numbers of persons and maximum stay times for each zone.

![Figure 6 The stay number of persons and maximum stay time for every zone](image)
5. CONCLUSIONS

In this paper, we have shown how we measure individual travel behavior in urban space using mobile communication devices. There are various measurement system concepts for travel behavior. GPS, PHS and PEAMON (PEAMON and PA) can be used as data collection tools. The essential merit of data collection systems using mobile instruments is that the time and location (latitude and longitude) data for individual travel behavior are more accurate than those obtained by conventional questionnaire-type travel surveys. Travel data obtained by these advanced methods can be used for microscopic analysis of travel behavior. They are also effective for performance measurement of transport systems in urban areas.

We have proposed a travel surveillance system using mobile communication devices. The PEAMON mobile handset is capable of monitoring ID numbers from multiple base stations and their respective signal strengths. For areas with weaker signal strength, such as indoors and underground, PAs can be installed as base stations. Using the ID numbers and the signal strength of these PAs, we were able to trace the location of a PEAMON-carrying individual.

We completed a field study in Nagahori, Osaka, Japan. The results suggest that the proposed surveillance system using PEAMONs and PAs can be used in actual enclosed and underground shopping centers to collect travel behavior data. In addition, we developed the zone flow indication system. The detailed travel data it provides, including zone-to-zone travel flows and each zone’s stay time characteristic, may be useful for transport planning and urban management.

The management of travel data with positioning information can be different from conventional trip-based data management. Data management using mobile communication devices is one of the fundamentals for planning urban management. The results using PEAMON and PA data indicate they are more appropriate when microscopic movement of mobile objects in closed urban spaces such as shopping centers and underground shopping malls must be described.

References