Developing Systems Based on the Pedestrian Navigation Concept Reference Model: A Case Study

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***Abstract*—This paper describes designing a new pedestrian navigation system using a comprehensive framework called the pedestrian navigation concept reference model (PNCRM). We implement this system as a publicly-available smartphone application and evaluate its positioning performance near Omiya station's western entrance. We also evaluate users' subjective impressions of the system using a questionnaire. In both cases, promising results are obtained, showing that the PNCRM can be used as a tool for designing pedestrian navigation systems, allowing such systems to be created systematically.**

I. Introduction

Developing pedestrian navigation systems is an active research field, due to the demand for intuitive pedestrian mobility environments (e.g., [1]–[10]). However, current systems are designed in a haphazard and trial-and-error way. Since they are used in a wide variety of environments, we need a way to efficiently and effectively design and develop them, but there has been little work in this area.

We believe that pedestrian navigation systems can be developed systematically using a comprehensive framework, and have therefore proposed the pedestrian navigation concept reference model (PNCRM) [11]. This is a framework for classifying, organizing, and analyzing such systems that divides them into three layers with a total of 13 elements, standardizing, for example, the points to be considered and driving new research and development.

In previous research, the PNCRM has been used to analyze pedestrian navigation systems [12]. Specifically, it has been used to compare three types of system with the same purpose but different approaches, to clarify the distinctive features of each approach.

As well as analyzing existing systems, the PNCRM can also be used to systematically design new systems. In this paper, we demonstrate this by using it to design a new navigation system for Omiya station's western entrance.

II. Pedestrian Navigation Concept Reference Model (PNCRM)

The PNCRM is a comprehensive framework for classifying, organizing, and analyzing pedestrian navigation systems [11]. It divides such systems into the following three layers, as shown in Fig. 1.

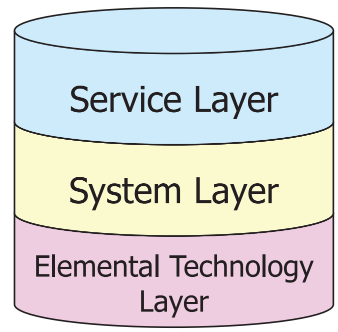

Fig. 1. Overview of the pedestrian navigation concept reference model (PNCRM).

TABLE I
ELEMENTS COMPRISING THE PEDESTRIAN NAVIGATION CONCEPT REFERENCE MODEL (PNCRM)

Layer	Elements
Service layer	(1) Target users (2) Functions (3) Coverage (4) Information provided
System layer	(1) User devices (2) Fundamental architecture (3) System behavior (4) System extensibility
Elemental technology layer	(1) Positioning (2) Information communication (3) Human-machine interface (4) Spatial information database and route-planning (5) Sensing

- Service layer: elements characterizing the service provided to users by the system
- System layer: elements characterizing the system's basic structure
- Technology layer: technological elements necessary for implementing the system

These layers, in turn, are composed of a total of 13 elements, as shown in Table I. All components and values of each layer are described in Appendix.

In a previous study [12], the PNCRM's constituent elements were used to compare three types of pedestrian navigation system that took different approaches (namely terminal-, mail server-, and Web server-based systems). In other words, it was used as an analysis tool, helping to clarify the different characteristics of each system. In contrast, in this paper, we attempt to use it as a tool to systematically design a new navigation system.

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Fig. 2. Photograph of Omiya station's western entrance.

III. Designing A System Using The Pedestrian Navigation Concept Reference Model (PNCRM)

In this paper, we demonstrate that the PNCRM can be used as design tool to systematically create a pedestrian navigation system. As a case study, we create a system that provides directions near Omiya station's western entrance. This area is surrounded by high-rise buildings, as shown in Fig. 2, making it difficult to accurately and precisely locate the user's position using a global navigation satellite system (GNSS), an approach commonly used by existing navigation systems.

In this section, we apply the planned system's requirements to each PNCRM element. The tables below use "*" to indicate that there are no applicable requirements for that element.

A. Service Layer

Table II shows the results of applying the requirements to the PNCRM service layer.

(1) Target users: typical pedestrians are targeted.
(2) Functions: almost same as the typical map-based navigation systems.
(3) Coverrage: outdoor area near Omiya station's western entrance is intended.
(4) Information provided: there are no requirements.

B. System Layer

Table III shows the results of applying the requirements to the PNCRM system layer.

(1) User devices: a mobile-type device such as a smartphone is used.
(2) Fundamental architecture: dedicated systems are not needed.
(3) System behavior: almost same as the typical map-based navigation systems.
(4) System expansibility: smartphone is a typical platform-oriented system.

C. Elemental Technology Layer

Table IV shows the results of applying the requirements to the PNCRM technology layer.

(1) Positioning: precise and stable positoning is vitally important.

TABLE II
SERVICE LAYER REQUIREMENTS

Requirement	**Value**
(1) Target users	
Physical traits	Not handicapped
Movement	Pedestrian
Purpose	Trip
(2) Functions	
Navigation type	Destination location and information
Navigation range	Whole route-oriented
Physical support	Not required
(3) Coverrage	
Available area	Outdoor
Range	Local
(4) Information provided	
Information acquision method	*
Number of operations to get information	*
Information reliability	*
Freshness degree	*
Personalization degree	*
Number of languages	*

TABLE III
SYSTEM LAYER REQUIREMENTS

Requirement	**Value**
(1) User devices	
Necessity	Needed
Type	Smartphone device
Size	Size of the user's smartphone
Weight	Weight of the user's smartphone
Purpose	Communication with the system
Input recording and output display methods	Rewritable
(2) Fundamental architecture	
Utility form	Commodity
Network type	*
Infrastructure depenance	*
(3) System behavior	
Operation schedule	Event-driven
Response	*
(4) System expansibility	
Ease of migration	*
Degree of platform	Platform-oriented

(2) Information communication: almost same the typical map-based navigation systems using a smartphone.
(3) Human-machine interface: almost same the typical map-based navigation systems using a smartphone.
(4) Spatial information database and route-planning: route-planning function is needed as same as the typical map-based navigation systems.
(5) Sensing: there are no requirements.

IV. Implementation

We implemented the designed system as an Android smartphone application. As noted above, the high-rise buildings surrounding Omiya station's western entrance made it difficult to obtain accurate and precise positioning data via GPS. Since generating precise and stable position data

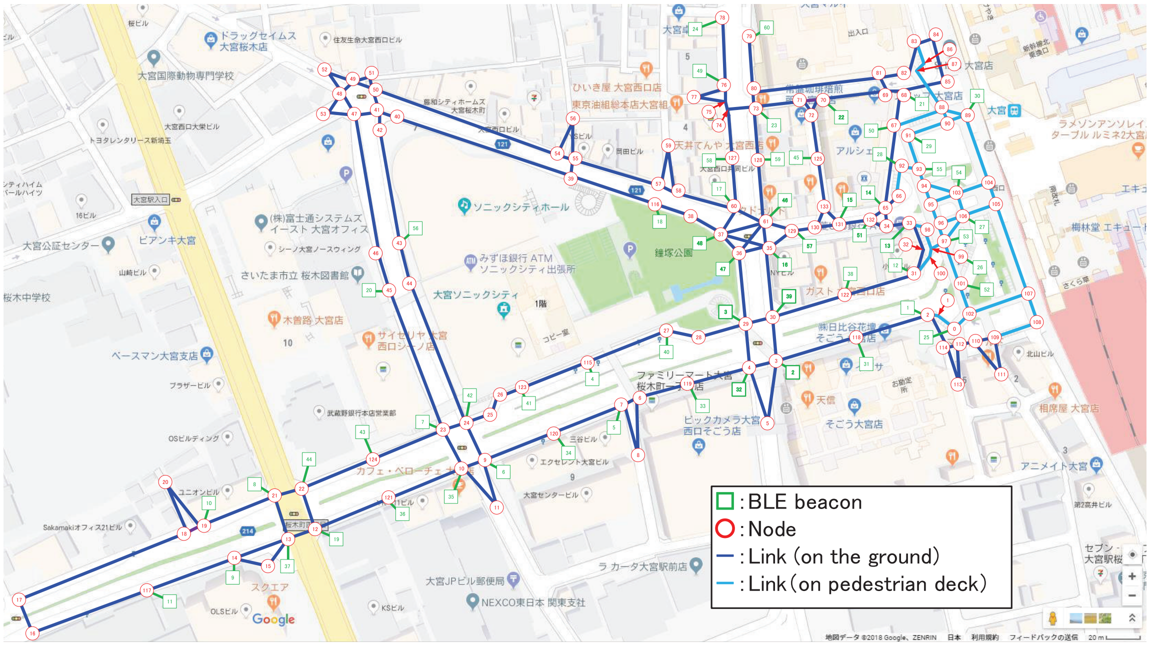


Fig. 3. Placement of BLE beacons, nodes, and links.

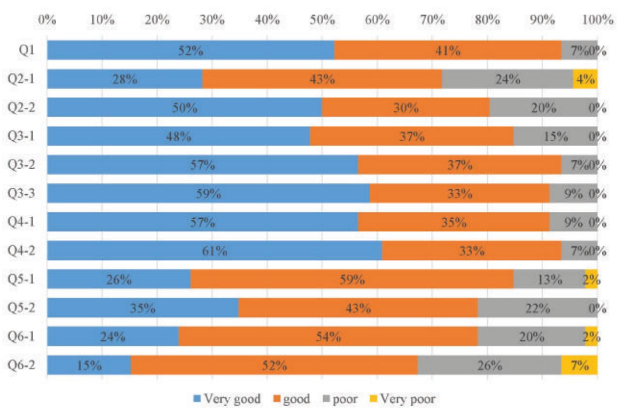


Fig. 5. System usability questionnaire results.

is a positioning technology design requirement (Table IV), we instead used Bluetooth Low Energy (BLE) proximity beacons in this implementation. Fig. 3 shows the placement of the BLE beacons (MyBeacon Pro MB004 by Aplix Corporation), nodes, and links. Each beacon was given a unique ID and associated with its location's latitude and longitude.

On receiving a beacon's signal, the smartphone application extracts its unique ID and uses the corresponding latitude and longitude to plot the user's current location on the map. When the application receives multiple signals simultaneously, the beacon with the strongest received signal strength indicator is used to determine the current location.

V. Evaluation

The performance of the system constructed in Section IV was evaluated in terms of the following two criteria.

- Positioning performance: it has a substantial impact on the system's effectiveness.
- System usability: it is evaluated subjectively by users.

A. *Positioning performance*

The performance of the positioning subsystem affects the effectiveness of all location-based services, including navigation systems (see e.g., [13]). In this section, we evaluate the system's positioning performance in the area used for the case study, namely Omiya station's western entrance. In addition to the BLE proximity beacons discussed above, GPS, network, and fused location data, obtained from the relevant Android application programming interfaces (APIs), was used to identify the target location. A Nexus 5 smartphone (LG-D821; Android 6.0.1) was used for this experiment. For the BLE proximity beacon data, the location of the beacon with the strongest signal was taken as the current location for two consecutive observations. For the GPS data, we used Android's basic Location Manager API, calling `requestLocationUpdates()` with the arguments shown in Table V. We also used the same API to obtain data from the network location provider, with the same `minTime` and `minDistance` values as in Table V. For the fused location provider, we used Android's new Fused Location Provider API. This combines position information from the GPS, network (wireless LAN, mobile phone base station), and sensors (e.g., acceleration). Table VI shows the methods used to access this API. Fig. 4 shows the results obtained by these four methods while walking near Omiya station's western entrance. In Fig. 4(a) (BLE beacons), although the position is only specified at wide intervals, it is always on the sidewalk, unlike in Figs. 4(b) and 4(d) (GPS and fused location providers, respectively), where there are significant

TABLE V

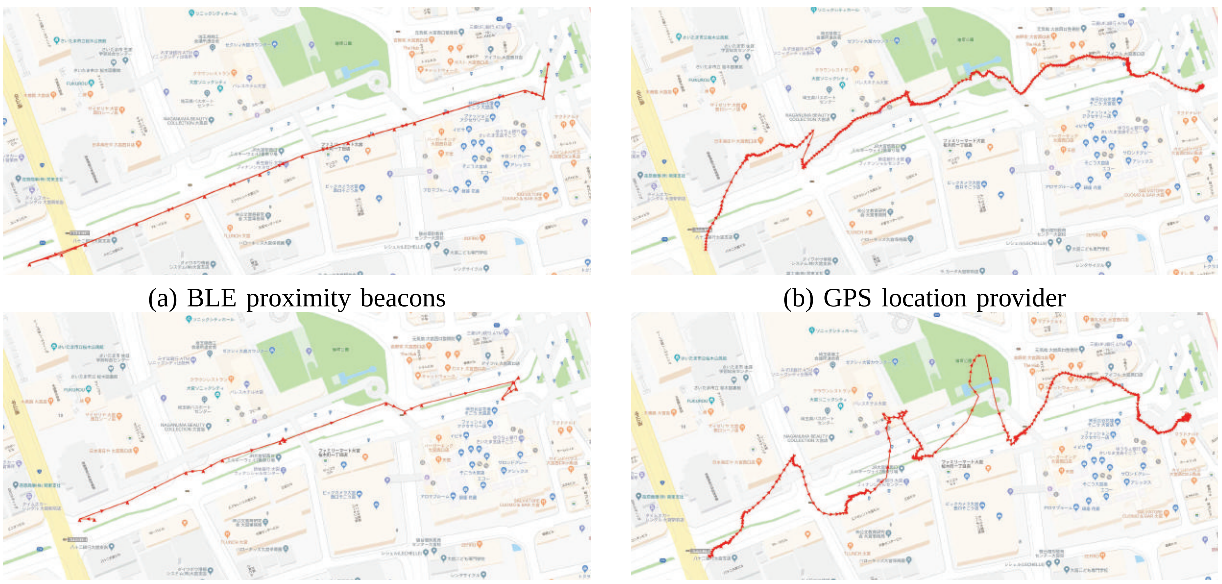
ARGUMENTS USED WITH REQUESTLOCATIONUPDATES()

Parameters	Description	Value
provider	Name of the provider with which to register	GPS_PROVIDER
minTime	Minimum time between location updates (milliseconds)	0
minDistance	Minimum distance between location updates (meters)	0

TABLE VI

PARAMETERS USED WITH ANDROID'S FUSED LOCATION PROVIDER API

Method	Description	Value
setPriority()	Set the request priority	PRIORITY_HIGH_ACCURACY
setInterval()	Set the desired active location update interval (milliseconds)	1000
setFastestInterval()	Set the fastest possible location update interval (milliseconds)	16



(a) BLE proximity beacons (b) GPS location provider

(c) Network location provider (d) Fused location provider

Fig. 4. Positioning performance results for different location providers in the experimental area.

deviations into the road and buildings. In Fig. 4(c) (network location provider) the position deviates, but always into the road. These results indicate that the BLE beacons adopted in this paper generate accurate locations (always on the sidewalk), but only at widely-spaced intervals.

We also assessed the positioning performance subjectively by asking users about their experience with the system using a questionnaire. We asked 46 users (a mix of male and female, in their 20s to 40s) the following questions.

- Q1: Did you feel that you did not know your current location while heading to your destination during the experiment? (In response, 85% of the users said never or almost never.)
- Q2: Did you feel that you did not know where to go while heading to your destination during the experiment? (In response, 93% of the users said never or almost never.)

In addition, we asked 37 users, who had used existing navigation application on smartphones in everyday life among the above users, the following question.

- Q3: Have you ever felt that you do not know where to go while heading to your destination where there are many high-rise buildings like Omiya station's western entrance? (In response, 76% of the users answered often or sometimes.)

The above results show that the BLE beacons adopted in this system gave satisfactory results, both in terms of objective positioning performance and users' subjective impressions.

B. System usability

We also asked users to assess the system's subjective usability. As above, 46 users (male and female, in their 20s to 40s) were asked to fill out the questionnaire shown in Table VII. This covered six areas: operability, responsiveness, information display, reliability, overall impressions, and usefulness. The results are shown in Fig. 5, and indicate that at least two-thirds (67%) of the users felt that the system was good or very good in all areas.

TABLE IV

ELEMENTAL TECHNOLOGY LAYER REQUIREMENTS

Requirement	Value
(1) Positioning	
Available area	*
Accuracy	Precise and stable
Type	*
Base	*
Location information acquisition method	*
Acquisition	User-side
Location information display format	Latitude/longitude
Direction information acquisition method	*
(2) Information communication	
Accuracy	Precise and stable
Transmission speed	*
Number of transmission	*
Transmission time	*
Traffic	*
Link up time	*
Casting	*
Content	Transportation information, software
Machine-machine interface (MMI)	Not present
(3) Human-machine interface	
Input destination	Machine's tactile (touch panel)
Quantity of information that can be input	*
Input method flexibility	*
Input information flexibility	*
Input rate	*
Output destination	Human's visual (visual display)
Quantity of information that can be output	*
Information output area	*
Output information portability	High
Interactivity	*
Touch panel display	Depends on the user's smartphone
Resolution of on touch panel	Depends on the user's smartphone
(4) Spatial information database and route-planning	
Size of road map database	*
Size of pedestrian map database	*
Size of transfer information database	*
Size of destination area information database	*
Database structure	*
Database management method	*
Route-planning function	Present
(5) Sensing	
Ability to sense user's surroundings	*

VI. CONCLUSION

In this paper, we have designed a new pedestrian navigation system using a comprehensive framework called the PNCRM. We have implemented this system as a publicly-available smartphone application and evaluated its positioning performance near Omiya station's western entrance. We have also evaluated users' subjective impressions of the system using a questionnaire. In both cases, promising results were obtained, showing that the PNCRM can be used as a tool for designing pedestrian navigation systems, allowing such systems to be created systematically.

TABLE VII

QUESTIONNAIRE

#	Questions	Category
Q1	Was the system's usage easy to understand?	Operability
Q2-1	Did the system respond quickly?	Responsiveness
Q2-2	Was the system stable?	
Q3-1	Was the screen layout easy to understand?	Information display
Q3-2	Was the arrow icon easy to understand?	
Q3-3	Were the letters easy to read?	
Q4-1	Was the information displayed properly?	Reliability
Q4-2	Was the displayed information reliable?	
Q5-1	Did you have a positive experience with the system?	Overall impressions
Q5-2	Was the system stressful to use?	
Q6-1	Was the system intuitive?	Usefulness
Q6-2	Would you use the system again in the future?	

Our future work will include the creation of different types of pedestrian navigation system, such as kiosk terminals.

APPENDIX

All components and values of the PNCRM [11] are shown in Table VIII.

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TABLE VIII

COMPONENTS AND VALUES OF THE PNCRM

(a) Service layer

Component	Value
(1) Target users	
Physical traits	Non-handicapped ↔ Physically-handicapped
Movement	Pedestrian, Passenger
Purpose	Trip, Tour, Shopping
(2) Functions	
Navigation type	Destination location, Destination information
Navigation range	Present-location-oriented, Whole-route-oriented, Final-destination-oriented
Physical support	Required, Not-required
(3) Coverrage	
Available area	Outdoor ↔ Indoor
Range	Local ↔ Global
(4) Information provided	
Information acquision method	Pull, Push
Number of operations to get information	Many ↔ Few
Information reliability	High ↔ Low
Freshness degree	High ↔ Low
Personalization degree	High ↔ Low
Number of languages	One, Two or more

(b) System layer

Component	Value
(1) User devices	
Necessity	Needed, Unneeded
Type	Device, e-tag/ICcard(active type), e-tag/ICcard(passive type), card
Size	Big ↔ Small
Weight	Heavy ↔ Light
Purpose	Input to machine, Output from machine, Communication with the system
Input recording and output display methods	Read-only, Rewritable
(2) Fundamental architecture	
Utility form	Commodity ↔ Exclusive goods
Network type	Non-network, Ad-hoc network, Central network
Infrastructure depenance	Heavy ↔ Light
(3) System behavior	
Operation schedule	Event-driven ↔ Time-driven
Response	Quick ↔ Slow
(4) System expansibility	
Ease of migration	Easy ↔ Difficult
Degree of platform	System-by-System ⇔ Platform-oriented

(c) Elemental technology layer

Component	Value
(1) Positioning	
Available area	Accurate(precise) and stable, Inaccurate(imprecise) or unstable, Not work
Accuracy	High ↔ Low
Type	Analog ↔ Digital
Base	SBP (space-based positioning), GBP-T (ground-based positioning (terrestrial)), GBP-G (ground-based positioning (gounrd))
Location information acquisition method	Direct, Indirect(calculation), Indirect(cumulation)
Acquisition	User-side, System-side
Location information display format	Latitude/longitude, Others
Direction information acquisition method	Equipped, Not-equipped
(2) Information communication	
Accuracy	Accurate and stable, Inaccurate or unstable, Not work
Transmission speed	High ↔ Slow
Number of transmission	Many ↔ Few
Transmission time	Long ↔ Short
Traffic	High ↔ Low
Link up time	Long ↔ Short
Casting	Unicast, Multicast, Broadcast
Content	User's intention, Location information, Transportation information, Destination and its suburbs information, Software
Machine-machine interface (MMI)	Equipped(contact), Equipped(contactless), Not-equipped
Medium of MMI	Light, Radio wave (inc. magnetic coupling)
Wavelength of optical medium	Visible light, Near infrared light
Frequency band of radio wave	VLF, LF, MF, HF, VHF, UHF, SHF, EHF
(3) Human-machine interface	
Input destination	(Machine's) tactile, auditory, visual
Quantity of information that can be input	Large ↔ Small
Input method flexibility	High ↔ Low
Input information flexibility	High ↔ Low
Input rate	Fast ↔ Slow
Output destination	(Human's) tactile, auditory, visual
Quantity of information that can be output	Large ↔ Small
Information output area	Large ↔ Small
Output information portability	High ↔ Low
Interactivity	High ↔ Low
Touch panel display	Equipped, Not-equipped
Resolution of on touch panel	One, Two or more
(4) Spatial information database and route-planning	
Size of road map database	Large ↔ Small
Size of pedestrian map database	Large ↔ Small
Size of transfer information database	Large ↔ Small
Size of destination area information database	Large ↔ Small
Database structure	Hierachical, Networked, Relational, Object-type
Database management method	Distributed ↔ Centralized
Route-planning function	Equipped, Not-equipped
(5) Sensing	
Ability to sense user's surroundings	Equipped, Not-equipped