Towards Mobility Oriented Interaction Design: Experiments in Pedestrian Navigation on Mobile Devices

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ABSTRACT

Current mobile interaction is not well designed with considering mobility. Usability of a mobile service is degraded while on the move, since users can not pay enough attention to the service in such a dynamic and complicated mobile context. In this paper, we propose the mobile service design framework, which improves the mobility by decreasing the user's cognitive load. Our approach provides two interaction modes (i.e. simple interaction mode and normal interaction mode) to mobile services so that the user can retrieve important information with less attention. Moreover, the service's events are simplified to support several modalities, and thus the user can be notified in the most suitable way according to the situation. In order to evaluate the feasibility of our approach through field experiments, we have developed a pedestrian navigation service as a part of the framework. The results showed that the simple interaction mode successfully decreased the user's attention to the service. Also, future directions for further improvements are discussed based on feedbacks from subjective comments.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: Interaction styles, Prototyping, User-centered design

General Terms

Experimentation, Human Factors, Performance, Design

Keywords

mobile computers, interaction style, interface design, pedestrian navigation

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1. INTRODUCTION

The rapid progress of mobile computing in this decade has drastically improved user experience on mobile services [9]. Today we have smart software keyboards on touch screens, high resolution displays and reliable networks for mobile devices. The growth and maturity of the Internet have accelerated the progress - various attractive services and contents provide rich user experiences to mobile users. Moreover, context-awareness (e.g. location-awareness with GPS, posture-awareness with 3D accelerometer) has partially been realized with sensor equipped devices [24].

However, the mobile services still frustrate mobile users while on the move. To fix the position of a small mobile user interface, users are forced to stop walking and pause frequently in order to access information. Moreover, mobile users are often situated in multitask contexts [20] and the user's cognitive performance would be drastically degraded when frequent interrupts and task switching occur. Even though problems of mobile interaction have been addressed in previous research [6], the mobile service design is still pursuing desktop-miniaturization trend and has not been adapted to the real mobile computing environment. Most of the services are designed on the assumption that they are used in stationary situations, so *mobility* becomes restricted as a consequence.

In this paper, we propose a dual-mode approach to mobile service design. The dual-mode approach provides a simplified interaction style (named *simple interaction mode*) to a mobile service, in addition to a conventional user interface (named *normal interaction mode*). Our approach aims to decrease the user's cognitive load with the simple interaction mode so that he/she can retrieve important information with less attention while on the move. While some of the research activities aim to realize unobtrusive user interfaces for moving users [18], their advantages from conventional user interfaces have not been evaluated sufficiently. Therefore, we prototyped a mobile pedestrian navigation service and performed field experiments in order to clarify feasibility of our approach. Below list summarizes main contributions of our work:

- Design issues of mobile services were discussed and identified from a human factor aspect.
- The advantage of the dual-mode approach was then evaluated. The simple interaction mode successfully decreased the user's cognitive load to the service in the field experiments, compared to a conventional user

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interface. Also, the dual-mode approach enabled all users to complete tasks, even though some users could complete only with the simple interaction mode.

- Valuable findings for further improvements are finally summarized from the experiments and feedbacks.

In the next section, we focus on the cognitive perspective and discuss how usability degradation is caused in the mobile computing environment. Also, related works are introduced in Section 3. In Section 4, we propose a mobile service design framework based on the discussion in Section 2. A prototyped mobile pedestrian navigation service is introduced in Section 5, and experimental results of the fieldwork is shown in Section 6. In Section 7, we discuss future directions based on some findings and given feedbacks. Finally, we conclude this paper in Section 8.

2. USABILITY DEGRADATION WHILE ON THE MOVE

User attention is one of the important factors to design user interfaces. Fine usability allows users to perform a task with less attention. For example, if a mouse cursor creeps by itself or is not calibrated appropriately, the user becomes frustrated as he/she must take care of fixing the position while manipulating. User interfaces should require minimum attention to allow the user to concentrate on the task (e.g. elaborate sentences in a mail, browse web sites).

Since mobile devices are not statically placed on a desk as ordinary desktop PCs, application scenarios vary tremendously. Mobile users and their attention could be affected by more kinds of factors than with desktop PC environments. In [6], Johnson presented three scenarios and addressed problems of usability caused by mobility. He focused on the complexity of mobile users' activities and pointed out the difficulties of mobile-world modeling in interaction design. For example, the user using a mobile guide service would be in a multitask environment and how much he/she can pay attention to the interface changes according to the tasks (e.g. crossing a busy intersection, browsing dresses through glass windows). Mobility breaks the traditional interaction model and degrades the usability of mobile services.

Current mobile service design is too attention-consuming for moving users to perform their tasks. For example, most of the existing researches aim to improve information retrieval efficiency by changing the layout and size of user interface components [1]. They assume the device to be operated in stationary situations (e.g. "sitting on a chair", "standing on the street"), and thus it needs to keep the user's attention all the time. They are not truly helpful in real mobile environments, since such situations are ideal and most of the time mobile users are performing action.

We have analyzed how the user's attention is affected in the mobile computing environment, and identified two important issues: *Situational Disabilities* and *Fragmentation of Attention*. Below sections give detailed explanation about each issue.

2.1 Situational Disabilities

Due to the user's postural and environmental changes, sometimes the physical condition makes it hard to perform interaction. Usually, users can set up or adjust the working environment in stationary situations (e.g. adjust light position in a room). However, in mobile computing scenarios, users move around and the surrounding environment dynamically changes accordingly. For instance, the display of a mobile device is frequently shaken in walking motion and text messages on the display can not be recognized well from the user's eye. Also, ring tone notification from a cell phone can not be heard in noisy places. In such situations, users have to pay more attention to sense the information or to catch missed information.

Regarding visual tasks, Mustonen et al. studied legibility of texts on a cell phone display while walking [16]. They found that walking condition affects processing speed significantly in text reading tasks and the performance suffers from increasing walking speed. Also, the walking effects differ between pseudo(random)-text and real(normal)-text cases. Mizobuchi et al. studied the effect of key size on text entry on a handheld device while walking in [15]. They found that text input speed while standing is faster than in walking situations, even though they did not find any evidence that walking speed can be used as a way of assessing the difficulty.

2.2 Fragmentation of Attention

Mobile users are often placed into a multitask environment, because the moving activity is a task by itself. Unlike stationary situations, users have to interact with mobile devices while performing their main tasks (e.g. move their legs to walk and look around to evade roadblocks). For instance, some mobile services (e.g. route navigation service) aim to interactively support the user on the move, but he/she can not or should not look at the display carefully. Also, mobile services tend to interfere with main tasks, since users can access information or can be accessed by others anytime and anywhere. When the user is performing prior tasks, the degree of attention to the service can be decreased due to the capacity limitation and frequent interrupt handling.

In [20], Tamminen et al. monitored human actions in social life and discussed how mobile contexts are characterized for context-aware interaction design. They found that navigating through an urban environment requires paying constant attention to surroundings and limits attentional resources available for interacting with a device. Also, they pointed out the fluctuation in importance of time and place that is called *temporal tensions* affects task scheduling strategy for occupying the user's attention. When people are hastened, they have to perform multiple tasks more or less simultaneously. The priority of the tasks changes and some of the pre-scheduled tasks become impossible at that moment. Instead, they start to direct their attention to space and time in order to perform urgent tasks.

As shown above, these two issues are related to each other and not clearly separated. Even though these issues are not major concerns in stationary situations, mobile services should be designed to handle them appropriately in order to provide fine usability. In the next section, missing points in related works are discussed, and then we introduce our mobile service design framework in Section 4.

3. RELATED WORK

Kristoffersen and Ljungberg are the early researchers who addressed shortcomings of traditional mobile user interfaces

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[9]. They argued that direct manipulation interaction style is unsuitable for mobile work contexts, since small keyboards and screens require a high level of visual attention. Therefore, they proposed MOTILE interaction system for operating mobile devices. MOTILE requires less or no visual attention (e.g. rely on only four buttons for user input and audio output for feedback) so that the user can concentrate on performing main tasks.

Their works well pointed out practical issues of mobile interaction. However, they mainly focus on decreasing user's cognitive load by replacing visual modalities with audio. As discussed in Section 2.1, situational disability is a possible problem for all modalities, so appropriate modalities should be selected according to the situation. Furthermore, how MOTILE has an advantage over conventional user interfaces was not sufficiently evaluated in the paper.

In [17], Pascoe et al. identified four requirements in extremely mobile and dynamic work places: *Dynamic User Configuration*, *Limited Attention Capacity*, *High−Speed Interaction*, and *Context Dependency*. They proposed Minimal Attention User Interface (MAUI) for fieldworks in Kenya. MAUI realized one-handed operation to allow the user to keep watching animals while recording logs on a mobile device. Moreover, context-awareness supports instant input by automatically filling fields (e.g. put GPS location information to the "recording point" field).

In their works, the user's input was mainly discussed rather than output, since main tasks were animal observation and data recording. MAUI was designed based on modeled operation sequence of tasks so that the user can manipulate the device with eyes-free. In this sense, more or less the user has to keep attention to the service, but it is difficult in most of cases due to the fragmentation of attention as discussed in Section 2.2. Users should be able to distract the attention and be notified when interesting events occur.

Sawhney and Schmandt presented their work, Nomadic Radio in [18]. They implemented audio interface on a wearable device to allow the user to access information services by speech and audio while on the move. Scalable auditory presentation mechanism allows for change in abstraction level of incoming messages so that Nomadic Radio can provide enough information to the user with minimum interruption. Also, Nomadic Radio can catch the user's attention or interests to a message by monitoring actions to adapt notification weights.

However, in some cases, interaction on single modality requires more attention and cognitive load to users. For example, with only audio interaction, sometimes the user loses where him/herself in a message space. Visual representation is required to understand currently pointing message. In addition to the issue, the single modality approach is susceptible to the situational disabilities. Therefore, multimodal interaction style is needed to realize robust interaction.

4. DESIGN ISSUES

In Section 2, we have pointed out that the user's attention to mobile services is not stable in a mobile computing environment. Therefore, we propose a mobile interaction design principle as follows:

Keep it simple, to not require too much of the user's attention while on the move.

Our approach aims to minimize interaction cost (i.e. required attention) by simplifying the interaction method and maximizing the benefit of mobility. While moving, users have to handle multiple information and events, so they can not or should not actively interact with mobile services. On the other hand, users should be interrupted when important events are monitored by the service. For example, a pedestrian navigation service should guide the user to the destination without frequent manipulation. Once the destination is set, the users should be freed from operation and concentrate on walking, enjoying the sight, chatting with friends, and so on. Only when important events are detected (e.g. "the user is following a wrong way", "the user should turn right this corner"), the user should be notified in an appropriate way.

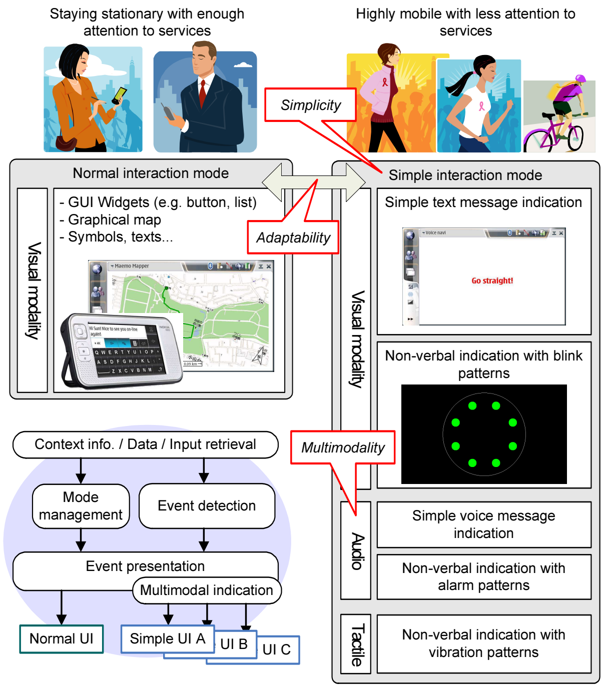

Figure 1: Overview of the mobile service design framework

To realize this concept, mobile services should represent minimum, but important information effectively. In Figure 1, an overview of the design framework is shown with a pedestrian navigation service as an example. Logical service components are identified at the lower left of the figure. Also, we point out three important characteristics from the discussion above and explain details of each in the below sections.

4.1 Simplicity

Our framework makes the mobile services non-interactive to decrease the number of interaction cycles. In the framework, mobile services provide a *simple interaction mode* in addition to the conventional user interface, named *normal interaction mode* in the figure. In the example, the pedestrian navigation service provides five kinds of user interfaces in the simple interaction mode. Like status indicators, the simple user interface allows users to check status of the service and him/herself at a glance. Duration of an interruption

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caused by the service is minimized, and thus the service can work even if the user's attention is fragmented in a multitask environment.

In the simple interaction mode, the mobile service mainly focuses on tasks that do not require complex interaction for the user. This means that the mobile service should be designed to keep its semantics as simple as possible in the simple interaction mode. In the example, one essential point of the route navigation service is "to guide a user to the destination". Needless to say, most of the information that the map includes is excluded from the simple user interface. However, it still aims to achieve the same task without explicit inputs from the user. (If the user would like to operate the service, the mode can be switched to the normal one.)

Also, the interaction style changes to an event-driven model in order to achieve the task with minimum interaction. This means that the mobile service should be designed to detect important events for the user and notify them in a smart way. In the figure, the event detection component retrieves context information (e.g. location data), several kinds of service-related data (e.g. route information) and the user's input to detect events. Detected events are represented by the event presentation component.

In the simple interaction mode, information is mainly pushed from the mobile service to the user. Therefore, to not disturb the user, only necessary information should be sent at the right timing. Usually mobile devices can not perform complex interaction due to its tiny display and keypads. Therefore, this push-type service may fit to mobile devices.

4.2 Multimodality

To perform efficient event notification, multimodality is important for moving users. As discussed in Section 2.1, the user's perceptual ability could be limited according to physical limitations. To notify events, mobile services should select the appropriate modality that can reach the user's perception. In Figure 1, the multimodal indication component selects an appropriate modality channel and assigns a corresponding simple user interface. Availability of modalities is managed in the mode management component and is determined based on the input (e.g. context information of the surrounding environment).

As explained above, this service design framework forces services to be simple and task oriented. Instead of limiting freedom of interaction, information important to the user can be determined and simplified. The simplified information is easy to convert, and it can be represented on various modalities. In the example, three kinds of modalities are shown: visual modality, audio modality and tactile modality. Also, even in the same modality, the representation method varies according to the abstraction level of the information. In the example, two types of indication methods (simple text message indication and non-verbal indication with blinking patterns) are represented in the visual modality.

The simplicity and multimodality allow information to appear on various types of devices by changing its form. For example, a simple text message can be shown in the sub LCD on a cell phone. Also, it can be shown as a ticker tape message flowing on a part of LCD, while other services occupy most of available display area. Non-verbal information does not require rich display devices and it allows various forms and shapes in the device design. If a wrist-watch-type device is equipped with eight LEDs in the frame, it could be used as an event indicator of the route navigation service on our framework. Also, tactile modality based route guiding with waist-belt-type devices were introduced in previous research [2, 21]. Wearable devices are important actuators to effectively notify events to a user. Since our framework supports multimodality based on the event simplification, coordination with such devices could be realized easily.

This design approach is a kind of modality abstraction, which is a concept proposed by Gellersen in [4]. He defined modality abstraction as a concept for capturing parts of the user interface that abstracts its appearance into logical interaction. Thus, modality abstraction provides a common ground for user interfaces that may differ according to used representational media. Our approach also abstracts output to the user, and the modality adaptation is realized in this sense.

4.3 Adaptability

Since the framework provides two kinds of interaction styles and multimodal input/output, adaptability is required to control the modes [10]. As discussed in Section 4.1, mobile services should occupy the user's attention as short periods as possible. Otherwise the fragmentation of attention may get worse. To decrease unnecessary interaction, the service should autonomously change the mode or modality according to the situation.

Several approaches could be considered by varying the intelligence level. For example, time-out is one basic approach to switch the interaction mode [14]. In this case, user interface changes from the normal interaction mode to the simple interaction mode when the specified time has passed (like a screen saver). This approach enables mobile services to show the simple user interface to the moving user without explicit operation.

As shown in authors' previous work [25], smarter adaptation can be implemented based on context-awareness [19, 24]. Since the simple interaction mode aims to be used while moving, context information which relates to the user's moving status (e.g. whether walking or standing, moving speed) is an important element for this framework. Also, *attentive user interfaces* (AUI) technologies can be applied to acquire the user's interests from his/her behavior (e.g. eye movements, hand gestures) [13, 23]. For example, if the user starts to look at the display for a while, the service notices that the user has lost the way and switches to the normal interaction mode in order to show detailed information.

In this paper, we mainly focused on the simplicity, since we have to evaluate how our dual-mode approach affects the user's behavior as the first step. Some simple user interfaces, the event detection component and the event presentation component are implemented for a pedestrian navigation service (even though they are not clearly separated as components). Detailed explanations about our prototype are presented in the next section.

5. PROTOTYPING

To evaluate the feasibility of our approach, we chose pedestrian navigation as the mobile service to be implemented on our framework. Our brain can not store complete maps, and we can not find fine routes to a destination immediately in unfamiliar places [8]. The digital route guide assists us

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in finding the route by accessing enormous digitally stored knowledge. This is one of the location-aware services which are successfully realized and deployed in the market. However, further improvements are still required as described in Section 2. Also, we believe that empirical studies on the service could be a basis for other mobile services for moving users.

We prototyped the pedestrian navigation service as an extension to Maemo Mapper that is a geographical mapping visualization software on the Maemo application development platform [11, 12]. A route matching algorithm is newly developed and the simple interaction mode is added to the Maemo Mapper. In Figure 2, service flow of the pedestrian navigation and examples of event indication patterns are presented.

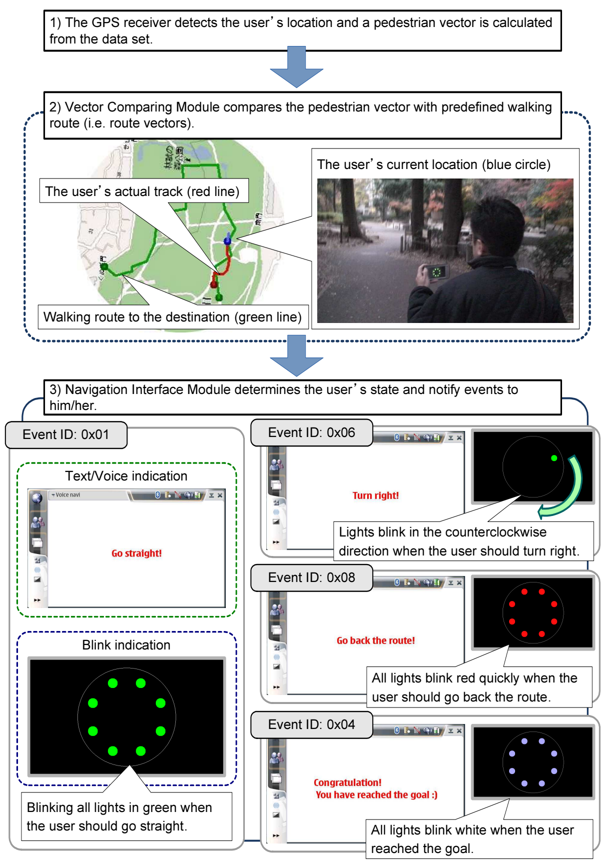

Figure 2: Service flow of the mobile pedestrian navigation and event indication pattern examples

The pedestrian navigation service consists of two modules, *Vector Comparing Module* and *Navigation Interface Module*. The Vector Comparing Module retrieves the user's location information and calculates moving direction so that the service can handle events by comparing the user's track and predefined routes. The Navigation Interface Module receives parameterized context information (i.e. angle and distance between the user's track and the route) from the Vector Comparing Module. The module determines the user's current status according to the state calculation rule and makes events according to the results. Detected events are notified to the user with pre-configured modality. Detailed explanations about these modules are given in below sections.

5.1 Vector Comparing Module

Two kinds of vectors are defined in the Vector Comparing Module. *Pedestrian vector* represents the user's current location and the moving direction, which is calculated from time-series of GPS data. *Route vector* represents the predefined route information which the user should follow.

5.1.1 Pedestrian Vector

To calculate the pedestrian vector, the method of least squares is applied to the most recent GPS data set (e.g. a series of the most recent five GPS data). Figure 3 illustrates the calculation method of the pedestrian vector. The number of data could be flexibly configured according to GPS sampling rate and acceptable delay.

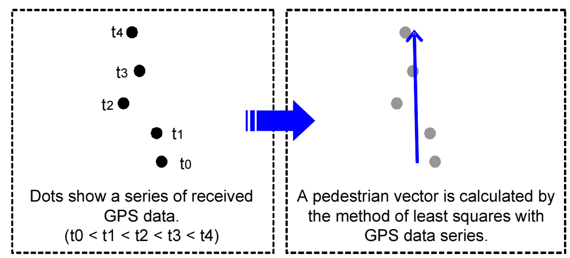

Figure 3: Pedestrian vector calculation

5.1.2 Route Vector

The route information includes multiple geographical coordinate values from a starting point to a destination. Entire route information is divided into the route vectors, which connect adjacent two coordinate values, so that the service can simplify vector comparing process.

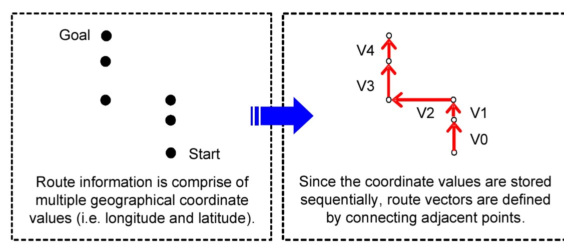

Figure 4: Route vector calculation

Figure 4 illustrates an example of five route vectors calculation. In a set of route vectors, sequential ID numbers are assigned to each vector. When the set is composed of N vectors, numbers from 0 to N-1 are assigned (e.g. numbers from 0 to 4 are assigned in the figure). The vector comparing process would be performed to one route vector, which is identified as the nearest to the pedestrian vector. As shown in Figure 5, candidate vectors are defined by checking whether the route vector crosses a circle drawn with radius R from the user's location or not. If only one route vector is found in this process, the vector is identified as the nearest route vector.

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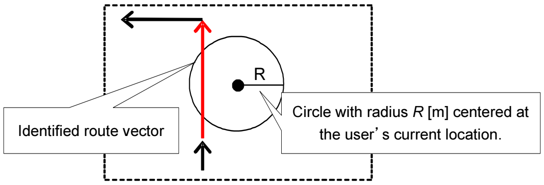

Figure 5: Route vector selection

If multiple vectors are found, the below equation is applied to calculate the vector's ID ($Vidx$):

$Vidx = Vid_{min} + \lceil(Vid_{max} - Vid_{min})/2\rceil$.

The Vid_{min} represents the smallest ID number and the Vid_{max} represents the largest ID number among the candidate vectors. If no route vector is newly identified, the Vector Comparing Module will keep the current vector as the nearest one.

5.1.3 *Parameterization Method*

After one route vector is identified, the vector comparing process is performed to calculate contextual parameters. In this implementation, angle θ and distance λ between the pedestrian vector and the route vector are sent to the Navigation Interface Module as parameters. In order to simplify the explanation, we define P as a pedestrian vector and V as a route vector as shown in Figure 6.

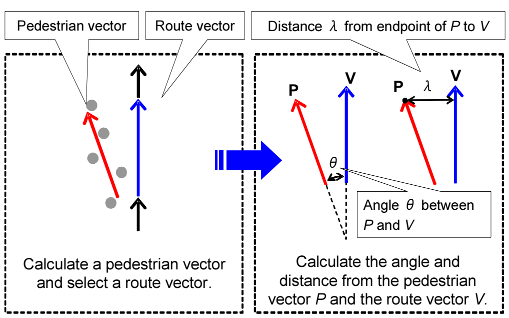

Figure 6: Parameter calculation from the vectors

To calculate the *theta*, an inverse function of tangent with an inner product and outer product between these two vectors is applied:

$\theta = arctan2(x, y)$.

The x represents outer product of P and V, and the y represents inner product of P and V. To calculate a distance λ, whether a perpendicular line can be dropped from the endpoint of P to V is checked. If possible, length of the perpendicular line would be calculated as the distance. If impossible, distance between the endpoint of P and the endpoint of V will be used.

When the user reaches the destination, the service will be terminated. The termination condition is defined as "when the user gets within R distance of the destination". Distance R should be set with an appropriate length (e.g. 10m), since GPS data could contain some errors in general.

5.2 Navigation Interface Module

Calculated parameters are used to define the user's current state in the Navigation Interface Module. Table 1 shows the user's state and distance level calculation rule. In this implementation, nine kinds of user's states ($state\_*$) and four kinds of distance levels ($dist\_*$) are defined. For instance, where the distance d is less than 10m, the user's state would be defined as shown in Figure 7.

Table 1: User's state and distance level calculation rule (x[degree]: Angle between the pedestrian vector and the nearest route vector, d[m]: Distance from the user's current position to the destination)

User's state			
	$d < 10$	$10 \leq d < 20$	$20 \leq d$
$0 \leq x < 30$	state_0	state_0	state_1
$30 \leq x < 60$	state_1	state_2	state_3
$60 \leq x < 100$	state_2	state_3	state_4
$100 \leq x$	state_3	state_4	state_4
$0 > x > -30$	state_0	state_0	state_M1
$-30 \geq x > -60$	state_M1	state_M2	state_M3
$-60 \geq x > -100$	state_M2	state_M3	state_M4
$-100 \geq x$	state_M3	state_M4	state_M4

Distance level			
$d < 10$	$10 \leq d < 50$	$50 \leq d < 100$	$100 \leq d$
dist_0	dist_1	dist_2	dist_3

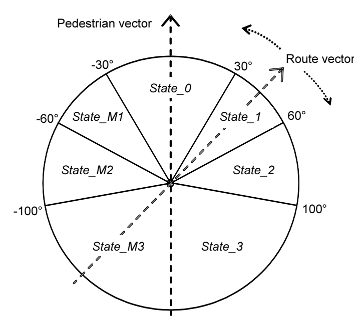

Figure 7: User's state definition where the distance d is less than 10m. (In this case, the user's pedestrian state is defined as $State\_1$ according to angle of the route vector)

Event type is determined according to the combination of the user's state and the distance level as shown in Table 2. The table also shows how the events are handled and indicated in each modality. Our prototype provides three kinds of indication methods: simple text messages, simple audio messages, graphical signals with blinking circles on a display. The simple audio messages are generated from the simple text messages by text-to-speech (TTS) engine [3], and thus the same information is given to the user. Blink indication pattens are defined subjectively in this experiment. In the next section, evaluation method for our prototype and results are shown.

6. EVALUATION

To evaluate the feasibility and usability of our prototype, we performed a field experiment. This experiment aims to observe how the dual-mode approach works and affects to

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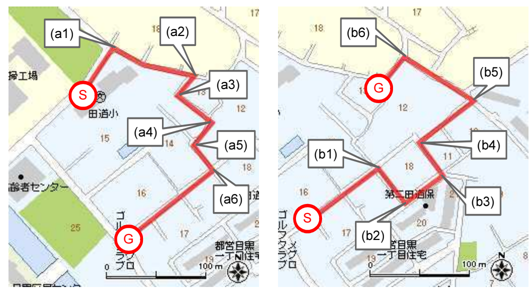
Table 2: Event types and corresponding indication patterns (Asterisk "*" represents a wildcard character)

ID	Condition (*state*, *distance*)	Text/Voice indication	Blink indication
0x01	(state_0, dist_3)	"Go straight!"	All lights blink green slowly.
0x02	(state_0, dist_2)	"Go straight!"	All lights blink green.
0x03	(state_0, dist_1)	"Go straight!"	All lights blink green quickly.
0x04	(*, dist_0))	"Congratulations! You have reached the goal!"	All lights blink white.
0x05	(state_1, *)	"Go forward left"	Lights blink green slowly in the counterclockwise direction.
0x06	(state_2, *)	"Turn left"	Lights blink green slowly in the counterclockwise direction.
0x07	(state_3, *)	"Go backward left"	Lights blink yellow quickly in the counterclockwise direction.
0x08	(state_4, *)	"Go back the route"	All lights blink red quickly.
0x09	(state_M1, *)	"Go forward right"	Lights blink green green slowly in the clockwise direction.
0x0a	(state_M2, *)	"Turn right"	Lights blink green slowly in the clockwise direction.
0x0b	(state_M3, *)	"Go backward right"	Lights blink yellow quickly in the clockwise direction.
0x0c	(state_M4, *)	"Go back the route"	All lights blink red quickly.

Table 3: Distance between each corners in the routes

Route A		Route B	
Start - a1	72m	Start - b1	79m
a1 - a2	81m	b1 - b2	43m
a2 - a3	20m	b2 - b3	47m
a3 - a4	38m	b3 - b4	39m
a4 - a5	32m	b4 - b5	66m
a5 - a6	33m	b5 - b6	81m
a6 - Goal	109m	b6 - Goal	29m
Total	385m	Total	384m



Route A Route B

Figure 8: Routes and corners in the field experiments

the user's behavior while on the move. Therefore, we compared the normal interaction mode and the simple interaction mode with the same modality (i.e. visual modality). The below section explains the experiment method and derived results.

6.1 Method

Two different tasks are given to participants and each task is performed once.

TaskA : Participants are instructed to walk a route only with the normal interaction mode (i.e. Maemo Mapper). The normal interaction mode shows the user's current location and route to the destination. The user can reach the destination by following the route, but the shown area on the display is small enough so that the user can not remember the entire route. Users are not allowed to manipulate the device to scroll and zoom in/out the map.

TaskB : Participants are instructed to walk another route with a combination of the simple interaction mode (i.e. blink indication) and the normal interaction mode. In this case, the simple interaction mode has to be mainly used and the normal interaction mode is used auxiliary when the user has lost his/her way. Users can switch modes by manually pushing a hardware key.

Figure 8 shows the routes which we used for this experiment. Route A is used for task A and route B is for task B. Course length and the number of corners are almost the same and it takes about 5 or 6 minutes to reach the goal by walking as shown in Table 3.

5 participants from Nokia Research Center Tokyo joined this fieldwork (male:4, female:1) and 2 observers followed the participants. The participants were not familiar with the area where this experiment took place. In the tasks, participants hold an N800 Nokia Internet Tablet with the hands and wore a GPS receiver attached helmet on their head. Observers monitored and recorded participants' behavior with two video cameras as shown in Figure 9. Observer A recorded a participant's face to analyze whether he/she pays attention to the display or surrounding environments. Observer B monitored observer A and the participant from behind so that situational information (e.g. walking time, obstacles) could be recorded. After the fieldwork, we asked the participants to answer some questions.

6.2 Experimental Results

6.2.1 System Performance

To evaluate the system performance, we measured execution time of the Vector Comparing Module and the Navigation Interface Module. N800 Nokia Internet Tablet was used as the evaluation platform (CPU: TI OMAP2420 330MHz, RAM: DDR 128MB), and we calculated the values using actual samples acquired from the fieldwork (1816 samples of data). Table 4 shows the results of mean execution time (*MET*) and standard deviation (*SD*). Our navigation ser-

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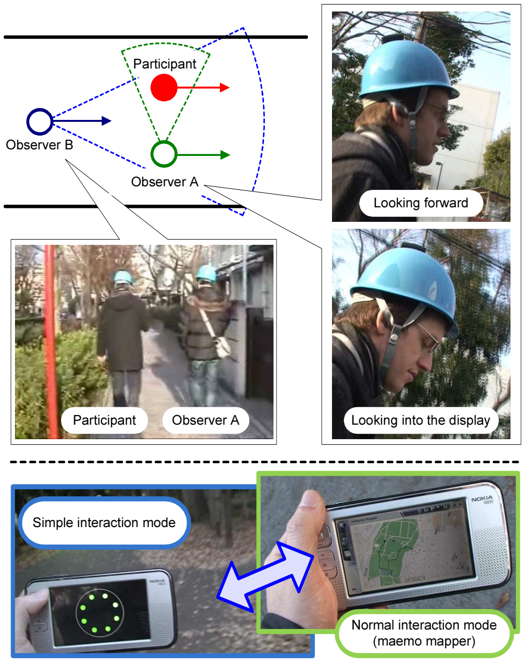

Figure 9: Two observers recorded the participants' behavior with video cameras (above). Interaction modes used in the Task B (below)

Table 4: Execution time and standard deviation (sample data = 1816). Parameter calculation function including location data retrieval is measured in the Vector Comparing Module. Also, event determination function is measured in the Navigation Interface Module (event indication on user interfaces is not included).

	MET	*SD*
Vector Comparing Module	376usec	134usec
Navigation Interface Module	16usec	17usec

vice is driven by GPS data input and measured overhead is added for every updates. However, the overhead was quite small and thus our algorithm did not critically affect the system performance.

6.2.2 *Route Navigation Results*

From the recorded videos, we measured and analyzed the below factors for each tasks: *TT* [sec]: Total time spent to reach the destination, *ST* [sec]: Total time of stationary state (i.e. just standing without walking), *LT* [sec]: Total (loss) time spent for walking incorrect route, *LD* [m]: Total (loss) distance of incorrect route walking, *SP* [km/h]: Average speed, *GR* [%]: Proportion of time that the participant paid attention to the display to *TT*, *MT* [sec]: Total time of the normal interaction mode (i.e. Maemo Mapper). Table 5 summarizes the analysis results.

TaskA : As shown in *LT* and *LD*, even though the map information is provided, 4 participants followed a wrong route. This is due to both individual map reading ability and fluctuation of GPS data. However, soon afterwords

Table 5: Experimental results from the five participants' trial

Task A	*TT*	*ST*	*LT*	*LD*	*SP*	*GR*	*MT*
User A	276	26	27	24	5.33	52.17	-
User B	303	0	18	16	4.76	44.55	-
User C	283	0	0	0	4.89	62.19	-
User D	308	4	30	24	4.78	38.96	-
User E	233	0	41	70	6.13	46.78	-

Task B	*TT*	*ST*	*LT*	*LD*	*SP*	*GR*	*MT*
User A	258	7	0	0	5.35	50.00	0
User B	381	53	150	124	4.80	33.07	39
User C	267	9	0	0	5.17	62.17	12
User D	266	9	0	0	5.19	32.70	0
User E	274	57	141	168	6.07	22.26	54

they noticed the situation and went back to the original route. Indeed, all participants reached the destination.

TaskB : As for Task A, 2 participants lost the way and asked the normal interaction mode to help. This is due to notification delay caused from the fluctuation of GPS data and lack of attention. Contrary to Task A, the fail was critical since the participant could not understand the situation without graphical map information. Moreover, our prototype does not support rerouting features that updates and rearranges the route with the user's current location information. Our prototype continued to guide even though the participant left away from the route, and it resulted in greater loss than Task A as shown in *LT* and *LD*. However, at last, they could reach the goal with checking the map in the normal interaction mode.

On the other hand, 3 participants could perform the task without time losses. The user C checked the map information once, since the system behavior seemed to be incorrect. However, other 2 participants reached the goal only with the simple interaction mode.

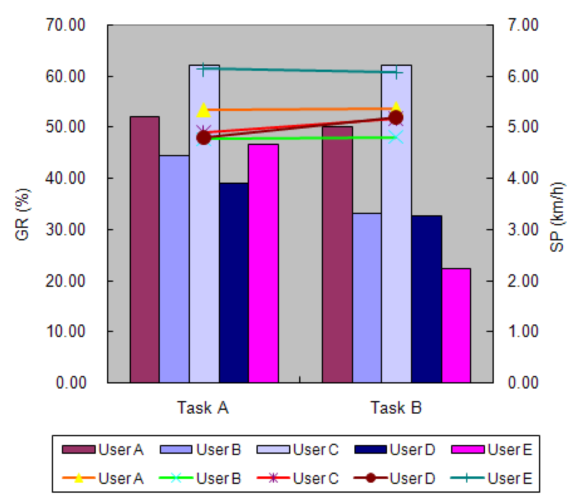

Figure 10: Chart of *SP* and *GR* value comparison

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Also we found two important factors SP and GR, which tightly relate to a user's cognitive load, show interesting trends in the results. As shown in Figure 10, most of participants' GR value decreases in Task B. This means the participants paid less attention to the display than Task A case. On the other hand, some of SP slightly increases and it indicates participants could walk faster than Task A case. We acquired some of the reasons from questionnaires. In the next section, we discuss future directions for further improvements based on participants' comments and our findings.

7. DISCUSSION AND IMPLICATIONS FOR FUTURE WORK

Table 6 shows questions given to the participants and subjective scores on the evaluation. The subjective scores show that the simple interaction mode could keep service semantics useful enough to complete tasks.

Also, we acquired useful comments for further improvements. Below, we discuss about identified issues and possible solutions to them.

- Users would expect the next event and attempt to know when it will occur. For example, users can recognize the next corner to turn from map information. It seems that users temporary remember route information with point of interests (e.g. landmarks, corners). Actually, in some cases, GR decreased for a while after checking map information when the participant lost the way. It can be said that the participant remembered the next corner and used the simple interaction mode to check whether the memory was correct. In the navigation service case, the timing of next event can be estimated according to the pedestrian's moving speed and direction. If such information (e.g. time bar which indicates when the next event will occur) could be added, users do not have to wait the indication carefully, and usability might be improved as a result.
- Some events and indications seem to be unnecessary. In our prototype, the "Go backward left/right" indication was a bit confusing and the yellow light indication was not appropriate to the meaning. Also, timing to show the indication was slightly inadequate due to fluctuation of GPS data. Since the simple interaction mode does not provide any further information, unnecessary or incorrect warnings are critical. Service designers should consider possible errors and allow the system to propose to check the status with the normal interaction mode, when handled events seems to be doubtful.
- The blinking pattern was comprehensible, but no indication seems to be needed while the user is walking on the right route. Also, this indication pattern does not support stationary situations. Once the user stops, he/she could not recognize the right route since the indication remains green blinking. The simple interaction mode should indicate the direction to go when the user stops.
- Some users commented that audio indication is preferred while on the move. In the experiment, we did not allow to use the audio modality, since this experiment aims to simply evaluate whether the simple interaction mode decreases the user's cognitive load. Also, it is obvious that audio indication has advantage in terms of decreasing visual attention. However, current implementation does not support some of proposed important features including the multimodality management. The modality management feature is also needed in order to coordinate with wearable devices, so we will implement them in the future work.
- Since the user interface on the simple user interaction mode was not interesting, users started to look the scenery. This is an interesting point, since the simple user interface affected users and motivated them to pay attention to the surrounding environment.

Also, we have found that sometimes the user has strong confidence or relies on the service too much. However, such users tend to be stuck and be thrown into utter chaos when the service behaves in an unexpected way. Therefore, recovery methods should be provided to the user, even in the simple interaction mode. This issue was also pointed out by Jones et al. [7]. Their system named ONTRACK guides a pedestrian to the destination by continuously adapting the spatial qualities of listening music. ONTRACK is similar to our work in terms of the simplicity, since it uses only audio modality with non-verbal information. They experienced that sometimes visual landmark became a stronger attractor than the audio cues and misled users.

FInally, the user's input should be allowed even in the simple interaction mode, in order to provide feedbacks to mobile services [5, 22]. One reason for this is that explicit commands from the user is useful to detect the user's attention in addition to implicit information (e.g. eye movement, ambient noise).

8. CONCLUSION

We have proposed a mobile service design framework that aims to improve usability of mobile services on the move. Main causes of usability degradation have been discussed and we took an approach that allows users to perform interaction with less attention. We have implemented the simple interaction mode on a pedestrian navigation service and evaluated its feasibility through field experiments. The result has shown that we have successfully decreased the users' cognitive load by adding a simple interaction mode. Also, we have proved that the service semantics was successfully kept even in the simple interaction mode, and users could perform tasks with it. Even though there is room for further improvements, we received positive feedbacks and identified feasibility of our approach. As shown in future directions, we will improve the system based on the comments and discussions, in order to realize the complete picture of the proposed design framework.

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Table 6: Mean subjective scores for the simple interaction mode

	Question	Score (MAX: 5 - MIN: 1)	Standard deviation
Q1	Compared to map UI, did simple UI lighten the load to be guided by the navigation service?	4 (better than map UI)	0.63
Q2	Is the variation of shown information (blinking pattern) enough to be guided?	2.6 (almost enough)	0.48
Q3	Is the meaning of shown information (blinking pattern) intuitive and comprehensible?	4 (comprehensible)	0
Q4	Is the information shown at the right timing?	2.6 (slightly inadequate)	0.8

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