KOTOHIRAGU NAVIGATOR: An Open Experiment of Location-Aware Service for Popular Mobile Phones

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Abstract. We have developed a location-aware sightseeing support system for visitors to KOTOHIRAGU Shrine, using only popular mobile phones employing the gpsOne system. Its design is not a map-based navigation system, but a shared virtual world system like multi-player online role-playing games. We conducted an experiment recruiting 29 subjects from *real* tourists visiting the shrine, who had their own compatible GPS-phones. From the survey, we have found that location-aware sightseeing support system using mobile phones can be accepted by young people, but the generation gap is wider than expected.

1. Introduction

As many of the readers know, Japan is in a special situation in the deployment of mobile phones. GSM is not available but the third generation phones are widely used. Au[1], one of the three major mobile phone companies in Japan, employs CDMA 1X or CDMA WIN system and many of its terminals are equipped with the GPS function based on the gpsOne system[2] by Qualcomm. More than 15 million GPS phones have already been shipped out in Japan.

Au also provides some flat-rate packages for data packet communication. This means that many Japanese people can enjoy GPS-based applications without paying extra costs. Au is actually offering some pedestrian navigation systems and location tracking services for parents and their children.

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[1] A brand name provided by KDDI. (http://au.kddi.com/)

[2] As well known, gpsOne uses location information of cellular base stations, as well as GPS. However, we do not pay attention to this issue in this paper.

On the other hand, there are some research projects developing virtual world model for mobile users [1-8]. However, they adopted PDA (with an attached GPS antenna) or larger terminals that are not appropriate for real business. Since they are relatively costly and heavy, it is difficult to expect many consumers to buy such terminals and walk with them. PDA is rather popular but we cannot expect that it has a GPS antenna.

The difference between PDA and phones are not only in the hardware resources such as CPU or memory. There are more restrictions on user interfaces of phones, including the size of display. Application programming interfaces (API) and peripheral devices for phones also put restrictions on programming. For example, location values from GPS cannot be obtained as frequently as in the cases of PDA or laptop PCs. Hence we needed to develop and evaluate a system with mobile phones, though there have already been several evaluation results using PDA or laptop PCs by other researchers.

Recently some techniques using GPS (or GSM) and other sensing technologies like WiFi are actively researched (e.g., [9]). However, we avoid it because WiFi is not available everywhere, especially in many tourists' destinations.

For such reasons, we started to develop a virtual world service for popular mobile phones in Japan, so that Japanese users can enjoy virtual world service without buying extra devices or paying extra costs if they already have any GPS-phone.

According to this design policy, we have succeeded to develop a location-aware virtual world system "KOTOHIRAGU NAVIGATOR" to guide tourist visiting the KOTOHIRAGU Shrine. We have asked real tourists (not a priori recruited subjects) who have their own GPS-phones to use the system and collected their reaction. In this paper, we will describe the system outline and the evaluation by real tourists.

2. Virtual World System based on SpaceTag

The outdoor shared virtual world developed by us is based on our concept of SpaceTag [10-13]. Our goal is to develop and deploy a system with which people can experience virtual worlds using their mobile phones. Each virtual world has the same geographical structure (with respect to latitude and longitude) with the real world. In other words, we can create various virtual worlds that have same geographical structure, and they can be overlaid onto the real world. We call it the overlaid virtual model (Fig. 1 [10]). A user can select and visit one (or even more) virtual worlds with his/her mobile terminal.

A virtual world consists of virtual architectural objects and virtual creatures. Virtual architectural objects are static objects like buildings, houses, and bridges. Virtual creatures are dynamic objects that can move or interact with other objects, or with users visiting the virtual world. In other words, a virtual creature is an active agent that can react to stimuli from the environment and dynamically execute methods like giving messages to the user. They can also exchange messages with other agents. Sometimes we call virtual creatures just agents.

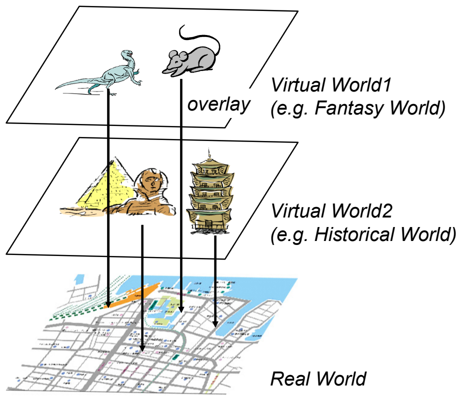

Fig. 1. Overlaid Virtual Model

From a user with a mobile phone, a virtual world can be seen with a perspective view. A far object is drawn as a small image, whereas a closer object is shown as a larger image. If a face of a virtual creature can be seen from the north side of the virtual animal, its back can be seen from its south side. Location of a user can be detected by the GPS embedded on the mobile phone. Hence a user can walk in the virtual world while he/she walks in the real world. The correspondence between the two worlds is based on location.

We have two versions of the virtual world system: a *browser-based* version and a *Brew-based* version.

The browser-based version does not need any special software on a mobile phone. Only a built-in browser is used. All the necessary processing for the virtual world system is performed at the server side. However, it is a *pull* information system, so a user should manually send a request to the server whenever he/she has moved to a new location, to download a new description or an image of the virtual world,.

On the other hand, the Brew-based version needs special software based on Brew, at the terminal side. Brew (http://brew.qualcomm.com/brew/) is a software platform for mobile terminals designed by Qualcomm, Inc. With the Brew-based version, the graphics is dynamically redrawn [11]. It gives more satisfying user interfaces than the browser-based version. However, since it needs an electronic compass that is not popular among phones on the current market, we used the browser-based version.

Fig. 2 shows the configuration of our virtual city system prototype. It is basically a client-server system. Clients are mobile phones on the Japanese market with a GPS function and internet accessibility.

In Fig. 2, the server is drawn as one block, but it consists of two computers. Because the graphics processing needs computer power, one machine is used only for drawing.

The server's main function is to generate a static image of virtual world for each user. When a user accesses to the server, location parameters are attached to the request message by the gpsOne location server. The virtual city server can then detect the location of user by latitude and longitude values ("Convert (Lat, Lon) to Internal Parameters" module). These location parameters are converted to the internal

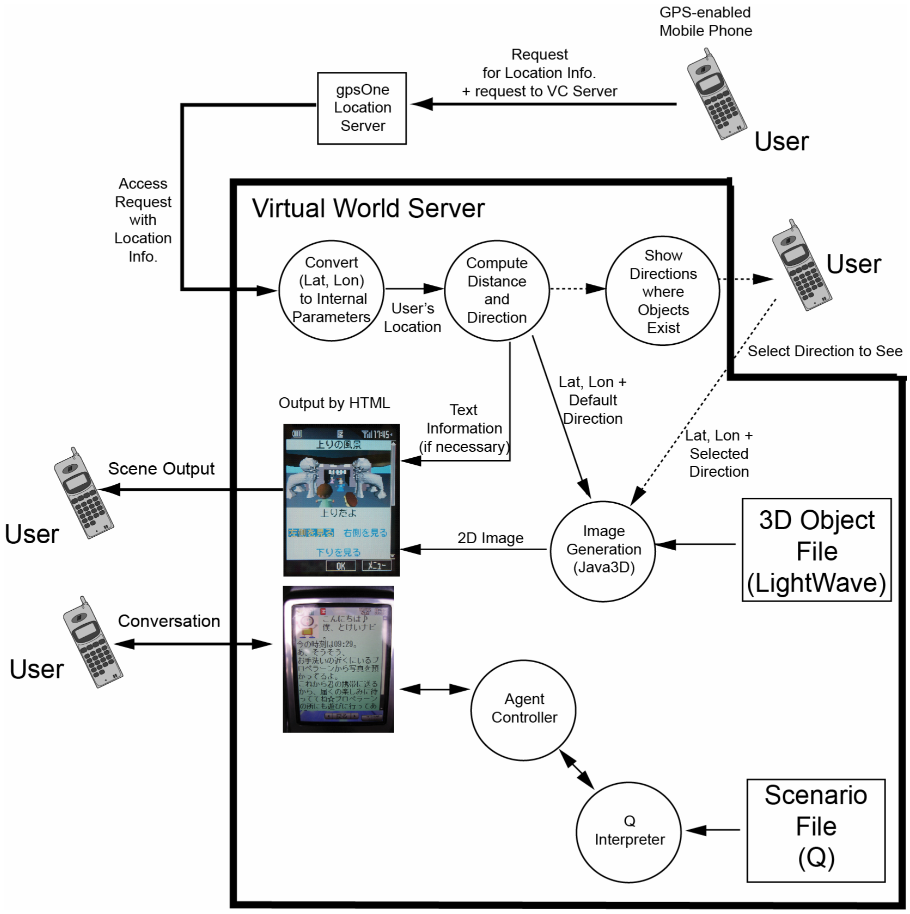

Fig. 2. System Configuration (Browser-based Version)

coordinates, and the distance and direction of virtual objects are computed ("Compute Distance and Direction" module).

The "Compute Distance and Direction" module gives a default direction to the "Image Generation" module. A default direction is defined as the direction in which the closest object exists. The user can look into another direction by selecting from a direction list (its flow is shown as broken arrows). In this case, a user is asked by the server about the direction he/she wants to see.

Data of virtual objects are stored as LightWave 3D data files on the server. A LightWave file is loaded to an image generation module written by Java using Java3D package, and is converted to a 2D image. An image generation process is invoked by the servlet mechanism triggered by the user's request. By adopting a popular tool like LightWave, many people will have chances to take part in the activities of authoring virtual city objects. However, we cannot take full advantage of LightWave, because complex objects with many polygons or fine textures cannot be handled by Java3D and phone terminals.

In Fig. 2, two images are shown. The upper image is an example of the viewing mode. In this case, the generated page in HTML format containing an image of scenery is just sent to the user's terminal.

The lower image in Fig. 2 is an example of the conversation mode. A user is in this mode when talking with an agent. Conversation by an agent is controlled by the "Agent Controller" module. This module uses the Q interpreter to control the conversation. Q is a language developed by the Q consortium [14], which is a scenario-description language based on the Scheme language. With Q, we can easily define the behavior of agents. A more detailed description of the agent control mechanism is given in [12].

3. KOTOHIRAGU NAVIGATOR

3.1 The KOTOHIRAGU Shrine

The KOTOHIRAGU Shrine (in Kagawa Prefecture, Japan) is one of the most famous old shrines in Japan. It is well known with its long approaching way of stone steps. It has totally more than 1300 steps, but the main shrine building (HONGU) is at the 785th step. Many of the tourists stop climbing at the main shrine building and returns. Tourists are coming from all over Japan and also from other countries.

At the 365th step, there is a big gate (OOMON). Along the approaching way beneath the big gate there are many souvenir shops. The approaching way after the big gate is the official territory of the shrine, where no shops are allowed and many points of interest exist. We have developed to design a virtual world system between the big gate and the main shrine building.

3.2 Design Concept

The most important point is the balance between the virtual and the real world. If a tourist is absorbed into the virtual world, it would not be worth visiting the real shrine. If a tourist rarely accesses the virtual world, the virtual world service would be unnecessary.

The virtual world we have designed was a partial set of copies of the real buildings, monuments, and trees (Fig. 3.). Users can see virtual copies on the phone's display. We have totally 22 virtual copies; four of them can introduce themselves in the virtual world. (Fig. 4.)

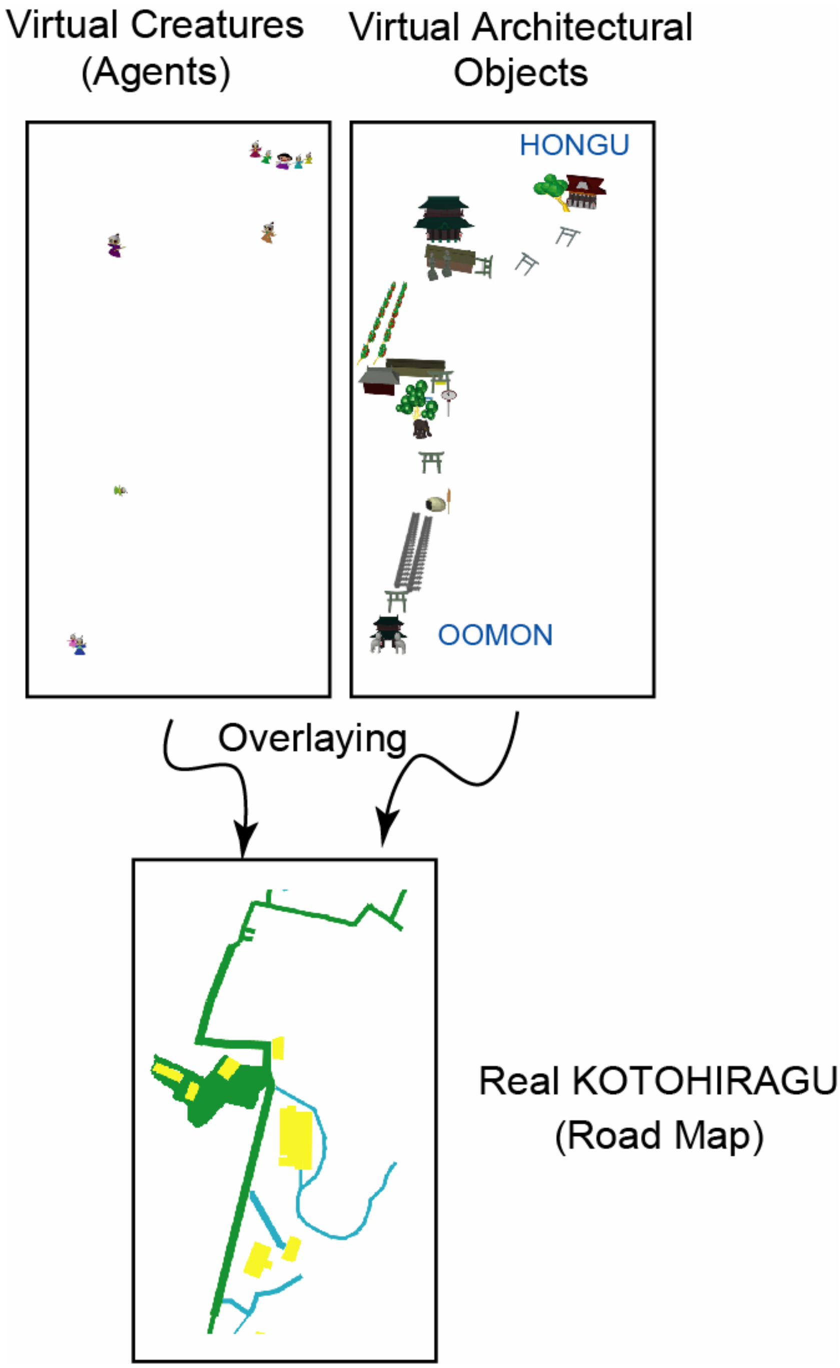

Fig. 3. Real KOTOHIRAGU Map and Overlaid Virtual Objects

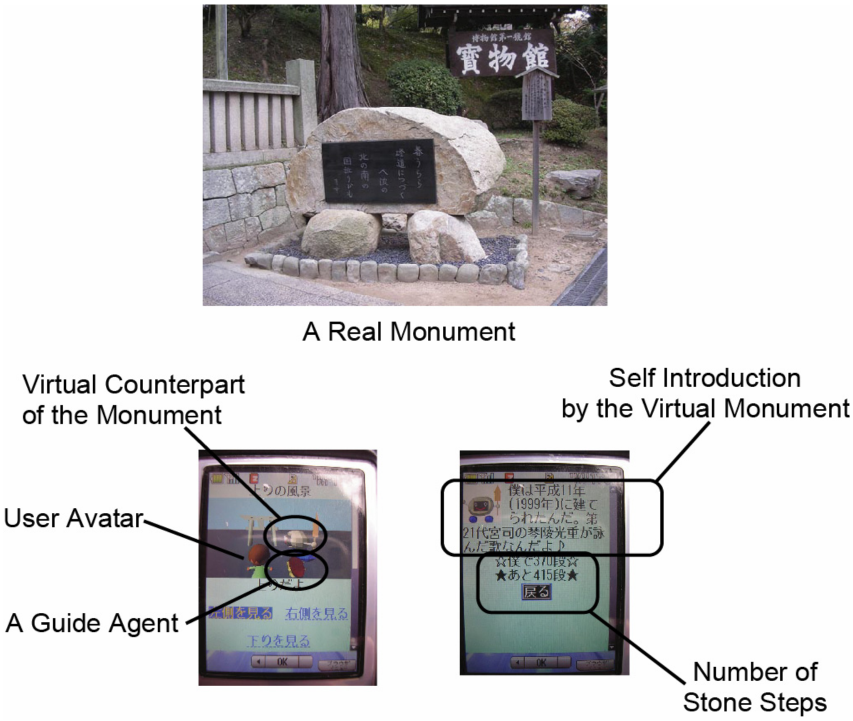

Fig. 4. A Real Monument and Its Virtual Counterpart

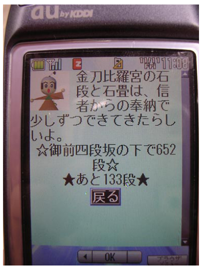

Fig. 5. A SAMURAI Agent Explaining the History of Shrine

A user is accompanied by a guide agent. A guide agent is a virtual character, who gives a short message to the user whenever the user requests. We have defined three areas within the total experiment space and ten to eleven prepared sentences for each area. Each sentence is an area-dependent description of the shrine, or sometimes just an encouraging comment to the user climbing the mountain. One of the sentences is randomly selected and shown as the guide agent's message.

On the other hand, there are eleven location-dependent guide agents that look like SAMURAI (Japanese old soldiers) as shown in Fig. 5. They give (narrow) location-

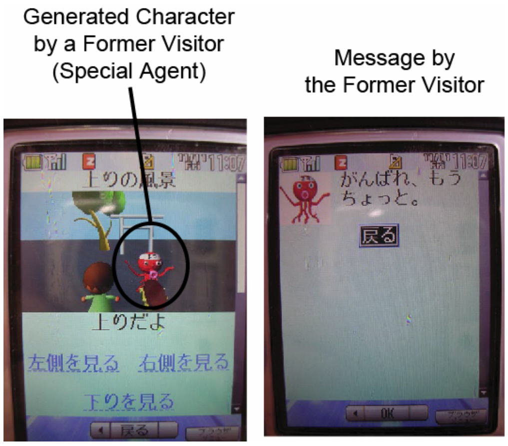

Fig. 6. A Generated Character and Its Message

dependent comments to tourists. For example, a SAMURAI agent gives a description of the nearest building.

To encourage users, some of the location-dependent comments given by virtual monuments and SAMURAI agents include the number of steps to the main shrine building. Since they should climb up a large number of stone steps, they are strongly interested in the number of steps. By giving the number of remaining steps to the user, we expect frequent accesses to the server (Fig. 4, right.).

With these agents and messages, we expect balanced interest of users to the real and virtual worlds.

Another challenge for us was to encourage users to enjoy the shared virtual world among users. To accomplish this goal, we have designed a *generation* function. A user can generate one special agent whenever he/she likes. A special agent can be given a message from the user and stays at the location where it is born. This can be done easily by clicking “leave comment” button, selecting one of the appearances of the special agent, and typing a comment to leave. We designed nine kinds of appearances for them, each of which is an animal in the sea, like an octopus, a turtle, etc. This is just because KOTOHIRAGU enshrines the God of marine transportation. A special agent will give the comment from its creator to other guests it encounters. Hence tourists can see how other people feel at the place by the shared comment given from a special agent. In Fig.6 (left), a user is finding a octopus that is a special agent; in Fig. 6 (right), the octopus is showing a message given by a former visitor.

3.3 Interface Design

The most difficult problem for the interface is how to represent orientation and how to make users to input it. If a phone has an electronic compass that can be sensed by our software, we can use it. However, only a few types of GPS-phones have compasses. As shown in Fig. 2, a user has to select a direction in order to change the virtual view to another direction.

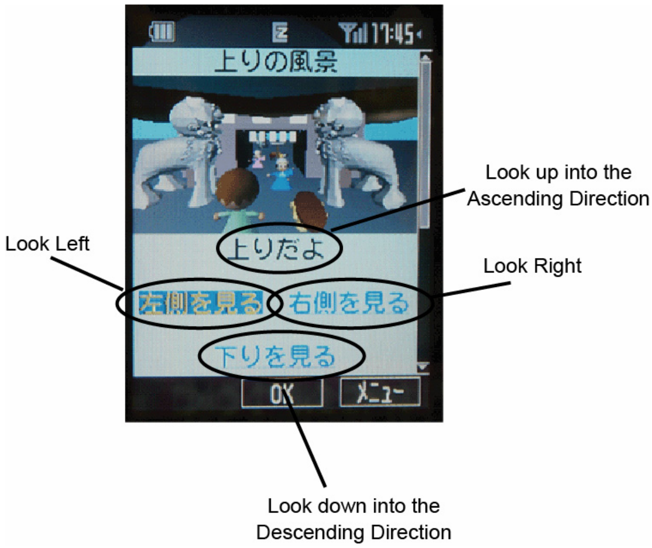

Fig. 7. User Interface for Directions

On past systems [11-13], "north", "east", "west", etc. (eight or four directions) were used to indicate directions on the user interface[3]. On KOTOHIRAGU Navigator, however, we employed another set of expression, up, down, left, and right. "Up" means, of course, the climbing-up direction; other directions can be naturally understood (Fig. 7). This design is possible since all users are always climbing up. (This system is only for the climbing up situation.)

4. Development Process

4.1 The Previous Experiment at Takamatsu Port

In January 2005, we had another experiment that recruited 20 student subjects for evaluation [13]. The evaluated system was also a sightseeing-support system using the same concept of virtual world. The system was highly evaluated as an entertainment system, but we had two problems left.

One was the balance of the virtual and the real worlds. The system rather gave story-following type of experiences like role-playing games, and was mostly focused on the virtual world. In order to challenge this problem, we have designed the current system as we described in section 3.2.

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[3] We had permitted to select one of eight directions in an earlier version, but we re-designed it since users preferred a simpler interface.

Another problem was the GPS inaccuracies. As we just used the raw location data obtained from the gpsOne system, we sometimes had GPS errors of more than 10m, which confused users to find agents or buildings in the virtual world.

On the current system, we need a more accurate location system because we have copies of real buildings or monuments in the virtual world that should be at the same location of the real ones, while only truly virtual buildings (we mean non-existing buildings in the real world) were given in the experiment in January.

4.2 GPS Error Compensation

After the January's experiment, we conducted another experiment recruiting ten student subjects. We developed five location compensation algorithms and input real location data obtained by popular GPS-phones to each algorithm. Using modified location data output from each algorithm, simulated virtual scenes were computed and shown to the subjects. The algorithms were map-matching, moving-average, avoiding big jumps, etc. We have found that we need the strongest algorithm, map-matching, for our purpose of virtual world navigation.

Fortunately, as the walking path of visitors to the KOTOHIRAGU Shrine is limited to the stone steps, map-matching can be easily implemented to the KOTOHIRAGU Navigator. There is only one path from the start to the goal, except the square in the middle and some very short branches. Thick lines in Fig. 8 are possible walking paths defined in the system. This data is given in the system by a bitmap image. Raw location data are also mapped on the same surface and modified to the nearest black dot in the bitmap image of possible paths.

At the places where the path is straight, near OOMON for example, we are free from the location error in the orthogonal direction against the path, with this method. However, we still have an inaccuracy of five to ten meters in the direction of the path.

There is a square in the middle of OOMON and HONGU. In the square, the walking path is less restricted, but not perfectly free due to some monuments and trees. Of course in this square and near the square, the compensation effect is weak. Also, if the path has a corner, the compensation result is sometimes confusing near the corner. We also have some places of bad condition. Fig. 9 is the worst place at the 652nd step, where leafy trees block off radio waves from satellites and we could not give correct location data.

Despite the imperfectness of compensation, we can still say that the service quality has been much improved compared to the January's system.

4.3 Development of Information Contents

3D graphics and messages to users were developed by three of the co-authors for about two months[4]. They were novice users of LightWave 3D, but could successfully create fantastic objects. In order to use Java 3D, we needed to limit the number of polygons for each 3D object: to 5000 or less.

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[4] We are not trying to evaluate the human power for the development. Their time was not 100% devoted to the task.

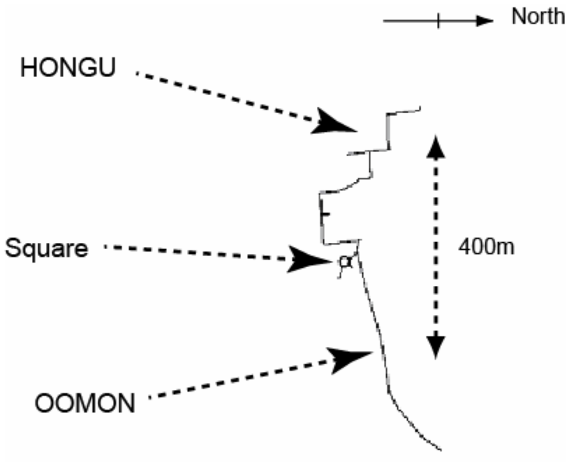

Fig. 8. A Map for GPS Error Compensation

Fig. 9. The Worst Place for GPS

For the development, we also needed to visit KOTOHIRAGU several times, to measure location values, to check GPS condition, to find interesting monuments to deal with in the KOTOHIRAGU Navigator, to find tourists' typical walking paths, and to confirm that our system would not cause any troubles to the souvenir shops or other visitors. In order to develop high-quality location-oriented services, we should also take into account such investigation cost.

5. Experiment with Real Tourists

5.1 Evaluation Method

From November 9th to 15th, 2005, totally seven days, we were staying at the entrance of the approaching way, which was below the first stone step. We caught tourists walking along the way and asked them to join our experiment. We offered them a book coupon of 500 yen for their cooperation. It was a hard task to find tourists who could accept our offer, because more than 70% of them did not have compatible phones and many tourists just did not like to cooperate. As KOTOHIRAGU visitors are mostly in senior generation, such visitors often had never used the GPS function nor the Internet access function, even if they had a GPS-phone.

If a tourist accepted our offer, we gave him/her a card that only shows the URL for the service and some legal notices. We explained that the service area is between OOMON and HONGU and that the tourist could enjoy a sightseeing-guide service, take an accompanying agent, and talk with it. Other detailed description of the system was given by the system itself. Receiving little information before using the system is a natural situation if the service is really intended for the public. Also we needed to avoid taking long time for explanation before the experiment, in order to make the tourist agree with our sudden offer.

Scenes in the trial sessions are shown in Fig. 10. In these photographs, models are not real tourists but recruited students who were asked to try this system during the same period of experiment. We avoided neither taking photographs of real tourists nor following them in order to let them use it in a natural situation. One difference between real tourists' usage and Fig. 10 would be that real tourists were often in a group of two to five people and only one of them had a compatible phone to use our system.

After 90 minutes or so, the tourists came back to us. We asked them to fill a survey form (two pages). We gave a book coupon to each tourist and also obtained a sequence of access log for each user.

5.2 Results

During the seven days experiment, totally 29 tourists (21 men and 8 women) agreed to participate. Twelve of them were between 25 and 30 years old, which was the most frequent age. Thirteen of them visited KOTOHIRAGU for the first time.

They accessed the system 24.2 times in average, including 5.8 times of location acquisition. They talked with agents 7.7 times in average.

Analysis by Age. Table 1 shows some results of survey in a four-grade scale, where 1 is the worst and 4 is the best score. The most highly evaluated function was the indication of remaining steps to HONGU (question (6)). This is because there are no real signboards along the steps showing the number of remaining steps, although most climbers would like to know it.

Location-aware description of monuments (question (1)) scored 3.18, which is not very good. However, its S.D. is rather large and some subjects appreciate it in their free comments, explicitly. This evaluation of the system varies by generation. If we observe only young tourists under 30 years old (17 subjects), the score is much better, 3.56. On the other hand, tourists over 30 years old gave average score of 2.67. Surprisingly, the difference between generations is much wider than other

Fig. 10. Scenes in the Trials**.** (left: beneath OOMON, right: in front of HONGU)

Table 1. Results from the Survey Sheets (by Age)

Question or Evaluation Target	Total Average (N=29)	Young Users' Average (age <=30, N=17)	Senior Users' Average (age >30, N=12)	Total S.D. (N=29)
(1) Location-aware description of monuments	3.18	3.56	2.67	0.86
(2) Is it better than guidebooks or brochures?	2.86	3.00	2.64	0.66
(3) Did you understand how to use it?	3.17	3.29	3.00	0.85
(4) To leave shared comments	3.10	3.21	2.86	0.62
(5) To read shared comments	3.19	3.21	3.14	0.51
(6) Indication of the number of remaining steps	3.59	3.69	3.44	0.59
(7) Do you like to use a similar system again at other sightseeing destinations?	3.28	3.47	3.00	0.53

Score range: 1-4, 1 is worst, 4 is best.

evaluations, for example, usage understandability (question (3)). The difference is proved to be statistically significant by a t-test ($p<0.01$). On the other hand, answers to questions (2) to (6) did not show statistically significant difference between generations. Question (7) was given to obtain the total evaluation of the system. Answers to this question is also different between generations (statistically significant, $p<0.01$).

The comments-sharing function was not used by all subjects because we did not have enough time for explanation of this function. This function was only described in the function description message that was shown to the user at the beginning, and also in the help file. Only six subjects left their comment using this function. However, this function was fairly well evaluated among users who experienced it. Example comments they left were "I have been exhausted by climbing," and "You can find a stamp at the rest house." These types of messages are what we expected.

Look at the results of questions (4) and (5). The average evaluations were not so different, but the generation gap was wider in question (4) than question (5). The gap in question (4) was not statistically significant, but we can assume that younger people are more willing to actively communicate with others in a shared virtual world.

Analysis by Visitor's Experience. Table 2 shows the evaluation by visitors who visited KOTOHIRAGU for the first time and for the second or more times, based on the same data as Table 1. We could not find any statistically significant differences between the two groups. However, there are some interesting suggestions.

Question (6) is supported by both groups. The number of stone steps is important information for visitors. From question (1), we can assume that the first-time visitors need more descriptions of monuments than the repeaters. On the other hand, from questions (4) and (5), we can assume that communication with other visitors was more accepted by the repeaters than the first-time visitors. These assumptions can be naturally understood. We can consider that repeaters need another kind of entertainment other than just to know the shrine itself. We assume that the repeaters evaluated questions (2) and (7) better than the first-time visitors, because the system provides a communication function. However, it is still an assumption that should be confirmed by using much bigger number of visitors, though it is difficult to conduct such a large-scale survey.

We believe that different service designs for first-time visitors and for repeaters should be considered.

GPS Accuracy. Subjective evaluation of GPS accuracy was 2.37 in total average, which had not been improved from the January's experiment, although it became much better in our own evaluation. We consider that this is because the subjects did not know the former system and it was no comparative evaluation between the two experiments. Subjects are always requiring more accurate location-based system.

In order to understand the bad effects of GPS inaccuracy on the service, we have calculated correlation coefficients of the evaluation data. All absolute values of coefficients are less than 0.4. This shows that subjects recognized the GPS inaccuracy as an independent problem from the system's value.

Table 2. Results from the Survey Sheets (by Experience)

Question or Evaluation Target	Total Average (N=29)	Average of First-Time Visitors (N=13)	Average of Repeaters (N=16)	Total S.D. (N=29)
(1) Location-aware description of monuments	3.18	3.33	3.06	0.86
(2) Is it better than guidebooks or brochures?	2.86	2.75	2.94	0.66
(4) To leave shared comments	3.10	3.00	3.15	0.62
(5) To read shared comments	3.19	3.00	3.31	0.51
(6) Indication of the number of remaining steps	3.59	3.56	3.62	0.59
(7) Do you like to use a similar system again at other sightseeing destinations?	3.28	3.15	3.37	0.53

Score range: 1-4, 1 is worst, 4 is best.

Free Comments. In the free description on the survey sheet, they also gave negative comments. A popular comment was on the battery, as the GPS-related functions consumed energy.

Another popular comment was that they preferred a map on the display. In our case, we avoided using a map to focus on the virtual world model, and also due to the copyright problem. This problem should simply be solved by adopting map interfaces in the future system.

Some people pointed out that they felt it dangerous to use this system when they were on the stairways, especially when they were going down (though this system was just for the situation of climbing up). One of the subjects claimed that when he was using this system he was almost left alone from his friends. These facts suggested that the service was attractive enough.

The function of showing the number of stone steps was also appreciated in their free comments. Some subjects appreciated that this system gave some information that they did not know. From these comments, we can conclude that one of the most important functions is to provide information that is not on the guidebooks, brochures, or signboards. It seems to be a paradox, because this system would become of no value if such real information sources were very rich. However, handy guidebooks cannot be too thick. Many signboards cannot be set up, because they would spoil the scenery. As a conclusion, we should design the service to well balance the real and virtual information sources.

6. Conclusion

In this paper, we have introduced our location-aware system with the virtual world metaphor, and one of its applications, the KOTOHIRAGU Navigator. The most important feature of our system is that it employs only popular mobile GPS-phones on the market. Due to this fact, we succeeded to recruit 29 real tourists, whose motivation was not the evaluation of our system but sightseeing, to participate in the evaluation sessions.

According to the survey, we have found that the location-aware sightseeing support service was accepted and appreciated by young people, in particular. The generation gap between senior and young people was wider than other evaluation points like usability.

Virtual world functions like comments-sharing were not fully enjoyed by visitors because of the nature of this experiment with real tourists, i.e. very novice users, but were accepted by at least some of the subjects, especially visitors who visited there for a second or more times.

Although our GPS error compensation mechanism was successful, the remaining GPS inaccuracy was still a problem. However, tourists could recognize it as a different problem from the information service quality.

We have also described the development experience of ours. It should be noted that deep investigation of the site was necessary to develop such kind of location-aware information service, in order to adjust location parameters and error compensation functions, to find a better representation to fit the visitors' requirements, etc. An appropriate balance between the real and the virtual information sources is the most important point in the information service design.

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