Design and Evaluation of a Location-Based Virtual City System for Mobile Phones

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Abstract

We are developing a virtual city system with a model that consists of virtual architectural objects and virtual creatures, geographically overlaid onto the real world. People who have mobile terminals with location sensors like GPS can visit the virtual city when walking about in a real city. The most important aspect of our research is that we have adopted current market mobile phones. In this paper we describe a prototype of virtual city system and its evaluation. The result of evaluation suggests that subjects were very much interested in the virtual city system. Technical problems have been revealed by the evaluation but most of them will be solved or minimized if we use the next generation of mobile phones.

1. Introduction

Mobile phones are getting more and more popular in many countries. In recent years, location sensors like GPS are optionally attached to them. In some countries, location sensing is planned to be a mandatory function. For example, in the United States, the enhanced 911 (E911) phase II rules require location information. Also in Japan, similar rules are now being established. So far, about 10 million phones with GPS have been shipped to the market in Japan.

With internet accessing methods, cameras, higher resolution displays, higher-speed communication capabilities, etc., mobile phones are not just communication tools, but general purpose multimedia terminals. Popularity and light weight are important advantages of mobile phones, compared with other mobile multimedia terminals like PDA or laptop PC. Even people who are not interested in IT have mobile phones, now. Hence we think current mobile phones and their future models should be the main target of public multimedia infrastructure.

We are developing and evaluating mixed reality systems for mobile phones. Here, by *mixed reality* we generally mean a mixture of real and virtual objects, including those cases where real and virtual things are not graphically overlapped on one screen (e.g. [1]). Our goal is to develop and popularize a system with which people can experience virtual worlds using their mobile phones. Each virtual world has a same geographical structure (latitude and longitude) with the real world. In other words, we can create various virtual worlds that have the same geographical structure, and they are overlaid onto the real world. We call it the *overlaid virtual model* (Figure 1 [2]). A user can select and visit one (or even more) virtual world 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

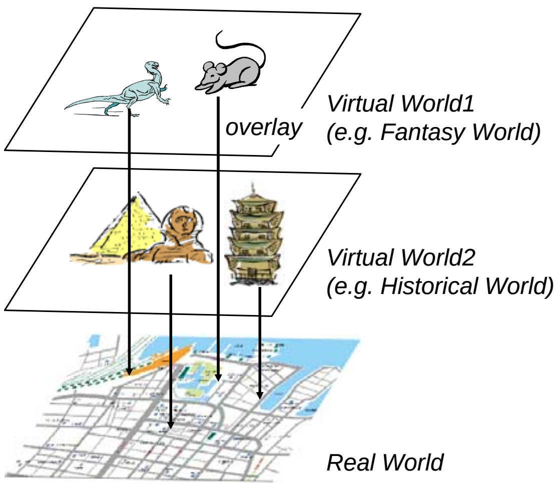

Figure 1. Overlaid virtual model

[1] Currently, Synform, Co., Ltd.
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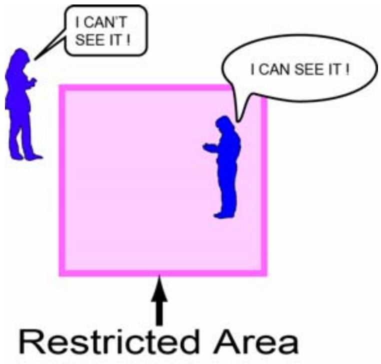

Figure 2. SpaceTag's access restriction

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 uttering words to the user. They can also exchange messages with other agents. Sometimes we call virtual creatures just as "agents".

The virtual city system is an expansion of the SpaceTag system [2,3,4], which gives information objects to mobile terminals so that only limited users can see them. The access restriction is defined by location and time. Each SpaceTag object has a particular geographical area where users can see the object (Figure 2).

The virtual city system described in this paper is a development from the SpaceTag system. It allows 3D data as objects, while the original SpaceTag system only permitted text or image objects. 3D data are handled as follows. A far 3D object appears to be small to users, and a near one appears to be large. If a user can see the front face of an object from the north, she can see its back side from the south. A display of mobile terminal is like a window opened to the virtual world. In this paper, we will describe the system's configuration and evaluation.

Another interesting aspect of the original SpaceTag system is that it is bi-directional. Users can create new objects and put them into a virtual world. This feature will allow entertainment application designers to design more exciting application on the virtual city system. For example, a user can leave a notepad to a particular place so that another user can find it. As another example, if it is applied to a game application, a game player would be able to create new creatures.

There are other research activities that give users a mixture of real and virtual things in outdoor environments using sensors and image recognition techniques [1,5,6,7]. However, none of them adopted current mobile phones. By adopting them, we can avoid the problems of terminal costs, terminal distribution, usability for wide range of people, and the necessary building of a new communication infrastructure that should be available everywhere.

2. Virtual City Project

Our final goal is to provide virtual city systems available to people all over Japan and other countries. For the first step, we are building a prototype system giving a small virtual world overlaid onto our university campus. We have evaluated it from the usability and performance aspects.

One of the target applications of the system is a sightseeing support system. For example, we can give historical buildings that do not exist today, as virtual architectural objects. Visitors to a city can see them using their own mobile terminals. Agents (i.e. virtual creatures) will help visitors by giving information of the city. Even historical episodes could be played by virtual creatures.

As other applications, we are investigating entertainment systems like games. For example, urban simulation could be implemented in a more realistic way. Role playing games would be implemented with virtual creatures moving about in a real city.

We are also supposing virtual presentation to the public, including advertisements and digital arts, as possible applications.

3. Prototype System

Figure 3 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 (Qualcomm's gpsOne) and internet accessibility. Terminals we used then were A5303H II, A5401CA, and A5501T provided by KDDI with "au" brand (http://www.au.kddi.com/), but other types of terminals could be used if they support GPS.

Most of the required functions were implemented at the server side. We did not provide any special software for terminals. Only a web browser was required for terminal's software. The reason why we did not implement terminal-side programming was that GPS functions could not be controlled from user's software on the terminal, at the time when we designed it. The next version will adopt terminal side programming using the *Brew* architecture, which will be described in section 5. Fortunately, the system we evaluated in the evaluation sessions did not need special software on the client.

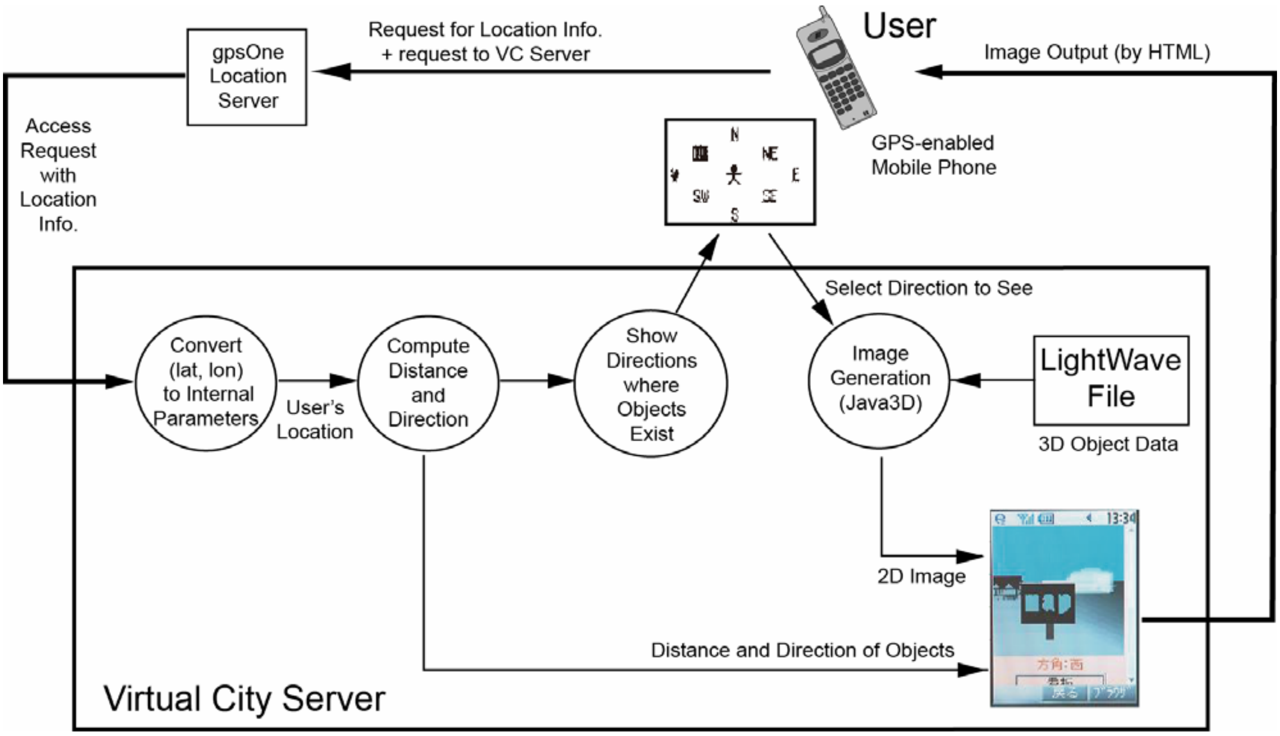

Figure 3. System configuration

The server's main function was to generate a static image of virtual city for each user. When a user accessed to the server, location parameters were attached to the request message by the gpsOne server. The virtual city server could then detect the location of user by latitude and longitude values. These location parameters were converted to the internal coordinates, and distance and direction of virtual objects were computed.

We had to design the system with a function detecting the direction in which the user was facing. When we designed it, no terminals supported orientation sensors like an electronic compass. A possible approach was to adopt an independent electronic compass to attach a terminal. However, our main goal was not to implement a perfect system immediately, but to utilize popular mobile phones on the market and to let as many people as possible take part in the virtual city. Hence manual input of orientation parameter was required instead of orientation sensors. A user was asked by the server about the direction he/she wanted to see. The user should have selected one of the eight directions: N, NW, W, SW, S, SE, E, or NE. The direction was passed to the server and the server generated a still image of the virtual city that was supposed to be a view from the given location into the given direction.

Data of virtual objects were stored as LightWave 3D data files at the server side. A LightWave file was loaded to an image generation module written by Java using Java3D package, and was converted to a 2D image (120 x 120 pixels). An image generation process was invoked by the servlet mechanism triggered from a user's request. By adopting a popular tool like LightWave, many people would have chances to take part in the activities of authoring virtual city objects. However, we could not take full advantage of LightWave, because complex objects with many polygons or fine textures could not be handled by Java3D and phone terminals.

Finally, the generated image was sent to the user's terminal as an HTML file, with distance and direction parameters as texts. Note that the output could not be updated automatically because the terminal was not able to send a GPS request without a manual operation.

On this version, the system did not support dynamic behavior of virtual creatures. Hence virtual creatures could not move or interact with others; they were just standing still in the virtual world.

4. Evaluation Sessions

We took three types of evaluation sessions. The first one was conducted on August 10th, 2003. It was just a pre-test for the succeeding evaluation. Subjects were guests of our open campus event. The second one was our main evaluation session taken place from January 11th to January 20th, 2004. The number of subjects was 49. The third one was a reference session using large-sized display, instead of mobile phones. 24 subjects were involved.

4.1. First Session.

We put four virtual buildings, one virtual signboard, and three virtual creatures overlaid onto our university campus. The area of our virtual city was about 150m x 150m. Subjects were guests of our open campus event, ranged from 10 to 43 years old. Eleven of them were male and seven were female. We asked them to walk in the virtual city area east to west (150m long). We asked questions to them after their experiences. The result was as follows.

Subjects did not well recognize their position in the virtual world. This problem was mainly because the GPS function had errors. Since our campus is located in the suburban area of Takamatsu city, there are few tall buildings that hide GPS satellites. However, our campus has two tower buildings, one of which is about 52 meters tall. In our campus, GPS errors were typically about 10 to 20 meters, but sometimes more than 50 meters. Hence subjects lost their positions in the virtual city due to the location error. Especially, if a virtual building was placed close to a real building, subjects were troubled with more GPS errors when they approached to a virtual building, since the real building hides GPS satellites.

In order to compensate GPS errors, one approach is to adopt other devices or infrastructure for location sensing. However, this approach is not consistent with our goal. Hence we took an approach to show real world objects with virtual objects on a same display. We developed a set of LightWave data for real buildings in our campus. On the version for the second session, they are shown as semitransparent objects. We expected that users would be able to find their own position by referencing real buildings shown on the terminal display.

Another problem found during the first session was the brightness of virtual objects; they were too dark. This problem was solved easily by changing LightWave's light parameters.

4.2. Second Session

For the second session, we recruited totally 49 students of our university as subjects. 28 of them were male and 21 were female. 35 belonged to faculty of engineering; others were students majoring law, economics, or pedagogy.

We have created additional virtual architectural objects for this session, including popular ones like the Arc de triomphe of Paris and the Leaning Tower of Pisa. They were arranged as shown in figure 4. In Figure 4, thick lines represent real buildings of our university, and illustrated (colored) objects are virtual ones. The area of experiment was almost same as the first session.

Figure 5 shows a sample of user's terminal display. In this case, two virtual objects (a signboard and a house) and one real object (a building) are shown. The direction into which the user is looking is shown with text.

The session was controlled as follows, for each subject.

1. We explained the model of virtual city overlaid onto the real university campus.
2. We explained what the semitransparent objects meant.

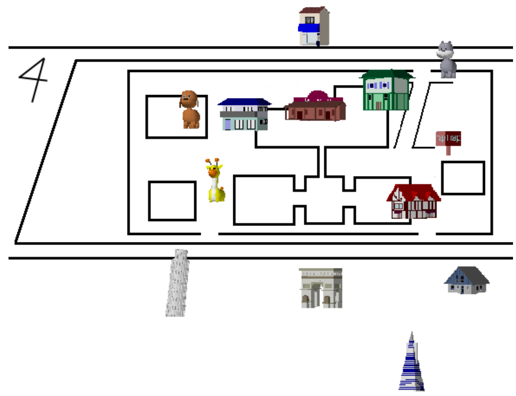

Figure 4. A virtual city map for the second session

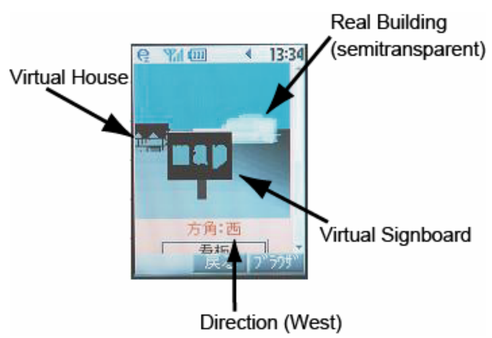

Figure 5. An example of mobile phone's display

3. We lent each subject a mobile terminal prepared by us, and instructed him/her how to use the terminal.
4. Each subject was asked to walk around the upper-half area of figure 4, for about 30 minutes and try to access the virtual city system.
5. After the experience, each subject was given a questionnaire.
6. Based on the result of questionnaire, we asked further questions to each subject.

For questions “Did you feel it interesting to visit a virtual city with a mobile phone?” and “Would you like to visit here again after we create more virtual buildings?” the average score was 4.35 and 4.20, where the range of score was 1 (worst) to 5 (best). From these results, we can say that subjects were interested in the virtual city concept.

For a question “Did you feel that the virtual buildings really existed there?” the average score was not good. It was 2.9. We asked further questions with regard to this point. The reasons subjects pointed out were:

a) They had to select a direction and create a mental model of city by their own efforts.
b) The image was not updated automatically.
c) Size of generated images was small.
d) Background information (e.g. mountains behind real buildings) was not given.
e) GPS error.

For problems a) and b), we can solve them by adopting one of the newest types of mobile terminal. We will mention it in section 5. Problem c) will also be solved immediately because new types of mobile phones have wider screens. Problem d) is expected to be fixed or minimized by solving other problems or giving 3D data of mountains. We still have problem e). It cannot be easily solved in a short time, but some new phone terminals already have Bluetooth transmitter/receiver or printed code (e.g. QR code) readers, which will be able to be used as location sensors with physical tags placed in real cities. As a whole, we can say that technologies to clear up these difficulties are becoming available one by one. Virtual cities will be more realistic in near future using these devices that improve the precision of location information.

For the question “Were you satisfied with the system response?”, we got 3.3 as the average score. Results of a further interview to subjects suggested that most of the reason of this score was the time required for the location detection by gpsOne (about 15 seconds). The response will be very much improved if we adopt terminal side rendering and automatic GPS updating. It will also be mentioned in section 5.

Semitransparent representation of real buildings did not yield clear benefits. The main reason of its undesirable effects was that virtual objects behind a semitransparent object were visible to subjects. They were confused since they could not tell which object was closer.

Another problem caused by the real objects was that they sometimes gave a scene that seemed to be unusual. For example, in figure 7 (shown as an example of the third session but it also happened on the screens of mobile terminals) a virtual creature like giraffe was contained within a real building shown as a semitransparent object. Real and virtual things logically existed in different worlds as we have shown in figure 1 and as we explained to the subjects, but subjects could not distinguish the two worlds easily. Moreover, people know that a real building has a floor at the bottom of each story. Hence subjects could not understand a giraffe whose neck broke the second floor! It was very much confusing.

On the next version, graphical representation of semitransparent real objects will be able to be switched on and off on the display.

We have analyzed the result of questionnaire, but we could not find any statistically significant difference between genders and majors of subject students. For the question “Did you feel it interesting to visit virtual city with a mobile phone interface?”, answers from male and female students were very similar. We gave a t-test for the difference of genders on this question, and found that we could say that male and female students were both interested in the system without difference, with a probability of 0.92.

4.3. Third Session

We developed a virtual city viewer (figure 6) with a tablet PC (running Windows XP) and an attached GPS receiver with an electronic compass function. The attached GPS device was Garmin’s eTrex Summit, which had an embedded electronic compass and could be connected to the PC via a USB port. The viewer ran as a standalone system.

Figure 6. Virtual city viewer with a tablet PC

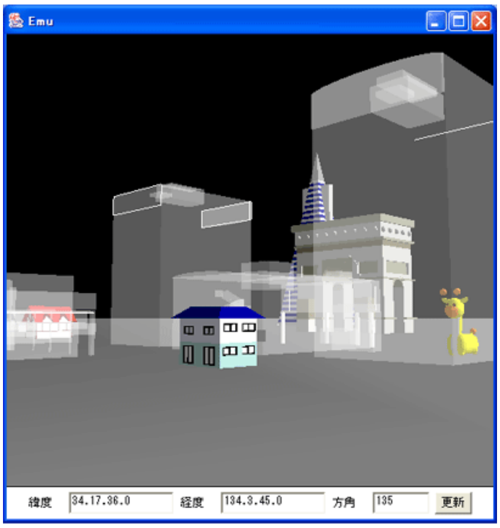

Figure 7. An example of tablet PC interface

We did not use a network connection to the server because only slow wireless network (64kbps PHS) was available. All virtual city data were preloaded to the viewer, and the rendering program by Java installed in the tablet PC dynamically rendered object on the screen according to the location and orientation data given from the eTrex Summit. The rendered scene was updated automatically. The standalone design was aimed at simulating a future environment where automatic updating function would be available for popular mobile phones and they would have wider screens.

Figure 7 is a sample of its screenshot. As is the case of the second session, semitransparent objects are real buildings and colored ones are virtual architectural objects or creatures.

Twenty-four subjects were asked to walk straight to a virtual building, and to take a 360 degree turn at least once. We gave questionnaire to subjects and interviewed them. They were also asked to draw a map of the virtual world, after their experience.

The most interesting result of this session was the map they drew. In case of the Garmin GPS, its correctness strongly depends on the weather and other environmental conditions, since it does not cooperate with other location sensing services like gpsOne location server. Because the session took several days for many subjects, GPS error rate much differed among subjects. When the condition of GPS was good, the maps they drew were relatively better. However, when GPS had more errors, subjects felt that all virtual objects existed at a same location. They were confused then.

The viewer was higher evaluated than mobile phones because it had a wider screen and automatic updating function. With this result, we can expect a better result than the second session, if we use new types of mobile terminals described in the next section.

5. Next Version

We are now developing a revised system, reflecting the evaluation study. In this section, we will describe some crucial points of interest in the next system.

5.1 Brew-based Terminal

Brew (http://brew.qualcomm.com/brew/) is a software platform for mobile terminals designed by Quallcomm, Inc. In Japan, some of “au” brand mobile phones released from KDDI support the technology. With Brew, we can develop terminal-side software with C or C++ language that is faster than Java programs. Also, rich API is supported to control mobile phone hardware, including GPS or electronic compass, if they are embedded in the terminal.

Especially, in case of some terminals, each has an autonomous GPS receiver, an electronic compass, and also a QVGA (320 x 240 pixels) wide display. For these devices, we have developed a terminal side program supporting real-time tracking of location and orientation [8]. Figure 8 shows a sample usage on a W21S type terminal.

5.2 Q-based Agents

On the prototype system used for the evaluation session mentioned in section 4, virtual creatures were not really supported in the sense that they could not move or interact with other virtual objects or users. For our next version, we have designed and prototyped mechanisms of interaction between a user and a virtual creature and for active behavior of virtual creature.

We have adopted Q language to control virtual creatures. Q [9] is a scenario description language for multi-agent systems. It is based on the Scheme language and supports scenario description, including event-driven actions. On our system, virtual creatures are agents in terms of Q system.

The Q engine is installed at the server side, and invoked by HTTP requests from the terminal. The invocation mechanism is implemented with the servlet technique. Actions, like moving or interaction with the user, are also supported. For example, a virtual creature (= a Q agent) may go away from the user, as an action triggered by a particular word from the user.

Figure 8. A Brew-based system on W21S

Figure 9. Q-based interaction with a virtual creature

Figure 9 is a simple example of interaction between a user and a virtual creature, supported by our current prototype. In this case, the agent (dog) is saying "Hello" as a response to words from the user.

6. Conclusion

We have developed a prototype system of virtual city for currently available mobile phones as user's terminals. We are trying to design a low cost and realistic system to be used as a public platform of mixed reality in the wider sense.

Evaluation sessions have shown that subjects were well interested in the virtual city system, which means that virtual city would have chances to be a popular information service in near future. Some problems were pointed out in the evaluation sessions, but most of them are now being or will shortly be improved by state-of-the-art technologies.

We have developed a prototype of the next version with Brew and Q technologies, with which we can expect improved functions for our virtual city.

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References

[1] Schnadelbach, H., et al..: The Augurscope: A Mixed Reality Interface for Outdoors, *Proceedings of CHI 2002*, ACM, pp.9-16. 2002.

[2] Tarumi, H., Morishita, K., Nakao, M., and Kambayashi, Y.: SpaceTag: An Overlaid Virtual System and its Application, *Proceedings of International Conference on Multimedia Computing and Systems (ICMCS'99)*, Vol. 1, pp. 207-212, 1999.

[3] Tarumi, H., Morishita, K., Ito, Y., and Kambayashi, Y.: Communication through Virtual Active Objects Overlaid onto the Real World, *Proceedings of The 3rd International Conference on Collaborative Virtual Environments (CVE 2000)*, ACM, pp. 155-164, 2000.

[4] Tarumi, H., Morishita, K., and Kambayashi, Y.: Public Applications of SpaceTag and their Impacts, *Digital Cities: Technologies, Experiences and Future Perspectives*, T. Ishida and K. Isbister (Eds.), Lecture Notes in Computer Science, Vol. 1765, pp.350-363, 2000.

[5] Feiner, S., et al..: A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment, *Proceedings of 1st International Symposium on Wearable Computers (ISWC '97)*, IEEE, pp.74-83, 1997.

[6] Pyssysalo, T., et al.: CyPhone -- Bringing Augmented Reality to Next Generation Mobile Phones, *Proceedings of Designing Augmented Reality Environments 2000*, ACM, pp.11-21, 2000.

[7] Satoh, K., Anabuki, M., Yamamoto, H., and Tamura. H.: A Hybrid Registration Method for Outdoor Augmented Reality, *Proceedings of IEEE and ACM International Symposium on Augmented Reality*, pp.67-76, 2001.

[8] Tarumi, T., Matsubara, K., and Yano, M.: Implementations and Evaluations of Location-Based Virtual City System for Mobile Phones, *Proceedings of the 1st IEEE International Workshop on Networking Issues in Multimedia Entertainment*, Nov. 2004 (in printing).

[9] Ishida, T.: Q: A Scenario Description Language for Interactive Agents. *IEEE Computer*, Vol.35, No. 11, pp. 42-47, 2002.