The International Conference on Soft Computing and Pattern Recognition
(SoCPaR 2009) in Malacca, Malaysia, pp.522-527 (2009)

Economic and Synergistic Pedestrian Tracking System for Indoor Environments

Tomoya Ishikawa, Masakatsu Kourogi, Takashi Okuma, Takeshi Kurata
Center for Service Research
National Institute of Advanced Industrial Science and Technology, AIST
Tsukuba, Japan
{tomoya-ishikawa, m.kourogi, takashi-okuma, t.kurata}@aist.go.jp

***Abstract*—We describe an indoor pedestrian tracking system that can economically improve the tracking performance and the quality and value of services by incorporating other services synergistically. Our tracking system utilizes existing infrastructures to be used for security services such as surveillance cameras and active RFID tags which are sparsely put in place and generally used in plants, offices, and commercial facilities for estimating user's walking parameters and correction of tracking errors without significantly increasing costs, and realizes the improvement of the tracking performance by them. Furthermore, by sharing not only surveillance videos and RFID signals from security services but also the tracking information and models from 3D environment modeling services among services, each service can enhance the quality and value of the service and relatively reduce the costs for creating the data and realizing functions.**

Keywords— service-engineering; human behavior; indoor environment; sensor fusion; pedestrian dead-reckoning; surveillance camera; RFID; map matching

I. INTRODUCTION

Tracking technology, which measures the location and orientation of a human, is one of the fundamental technologies for realizing location-aware services and for analyzing human behaviors induced by provided services by an objective indicator.

Previously, we have proposed an indoor/outdoor pedestrian tracking system [1] based on Pedestrian Dead-Reckoning (PDR) using wearable self-contained sensors for realizing location-aware services such as pedestrian navigation, and improvement of quality of services through analysis of pedestrian traffic and actions. We have also developed a museum guide system [2] that presents recommendation routes and content based on the location and orientation of the user from the tracking system in a large indoor environment (five floors, 2,500 to 2,700 [m^2] each). Over the past three years, we have carried out practical experiments and user studies of the museum guide and tracking systems in the actual field and have been improving the systems based on feedback from users who operated the systems in real-world environments.

For a navigation service, the service providers first create and place maps and annotations as content before operating the service, and then the navigation system presents them based on the location and orientation of the users. After the operation of the navigation, the service providers consider how to improve the service from subjective evaluations of the users by questionnaires and interviews and action analysis of the users based on the tracking logs. In each step of the service cycle, efficiently creating content, realizing good user experience and effectively analyzing user's actions have been desired. Actually, we have promoted efficiently providing the navigation service and have improved user experience based on feedback from the users by developing a 3D environment modeling system [3] which uses the pedestrian tracking system for efficiently creating maps and a lightweight client using iPhone 3G (Fig. 1)for displaying maps and content to the user.

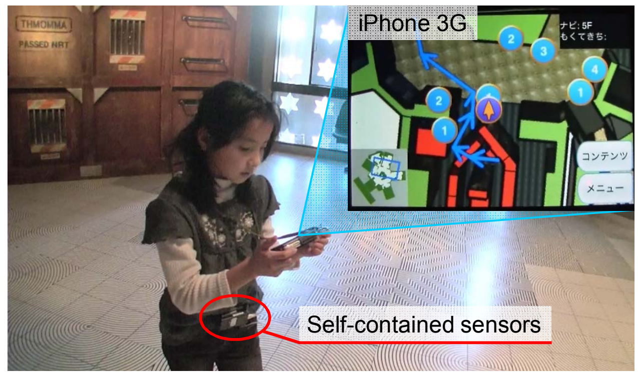

Figure 1. Museum guide system using self-contained sensors, sparse infrastructure, and iPhone3G.

However, we still have many issues. In particular, a calibration of human walking parameter for our pedestrian tracking system is a significant factor disturbing good user experience. The tracking system has to calibrate user's walking parameters which can be used to estimate walking velocity corresponding to the walking locomotion for estimating precise location of the user before using the system. For the calibration, the user has to walk several times at various walking speeds, and it is burdensome to the user. Moreover, parameters that are estimated in advance are not necessarily effective because the walking parameters change based on user activity. Therefore, it is necessary to estimate the walking parameters according to the present condition of the user without burdening the user.

Furthermore, the costs for introduction and improvement of the pedestrian tracking system have to be low and reasonable in order to apply the system to actual fields of services. The cost problems for operating services are well considered not only for the museum guide service but also for the other services.

We propose the following approaches for improving the tracking performance of the pedestrian tracking service and addressing the cost problem for the improvement.

- Dynamic walking parameter estimation and error correction of pedestrian tracking by utilizing existing infrastructure such as surveillance cameras and active RFID tags
- Enhancement of the quality and value of services by incorporating with other services, and reduction of overall introduction and running costs for the services

For estimating walking parameters of the user of the tracking service, our tracking system estimates the parameters dynamically using existing infrastructure, such as surveillance cameras and active RFID tags, which are used for security services while the user uses the tracking system. In addition, our system also corrects tracking errors by using the existing infrastructure. Using existing infrastructure, the tracking system can improve the tracking performance without additional introduction and running costs for infrastructure and burdening the user.

The dynamic walking parameter estimation and error correction using existing infrastructure are one of the examples which enhance the value of services at low-cost by service linkage between the tracking and security services. As well as that, we aim at enhancing the value of services and reducing overall costs for the services by prompting service linkages. Fig. 2 shows the overview of our service linkage. Our strategy for reducing costs for services is to share data created from each service among services and to enhance the value of the services by the data. By enhancing the values of services by the shared data, the cost for creating the data can be reduced relatively. In this paper, our system enhances services by sharing the tracking information estimated from our tracking system, 3D models created by 3D environment modeler for creating maps of navigation services, and surveillance videos and RFID signals from security services. These shared data enable each service to enhance the quality and value as follows.

- Pedestrian tracking service: dynamic walking parameter estimation, correction of tracking errors, and map matching
- 3D environment modeling service: efficient 3D modeling based on tracking information
- Security service: easy setup for surveillance cameras and active RFID tags and automatic video tagging
- Indoor navigation service: intuitive information presentation based on the location and orientation of the user by using photorealistic 3D environment models.
- Behavior analysis service: analysis of tracking logs by visual data mining

By above approaches, we realize not only improvement of user experience by improving the tracking performance but also efficiency improvements of 3D environment modeling and setup for infrastructure and effective behavior analysis, and we also realize overall cost reduction by such efficiency improvements and added values of services.

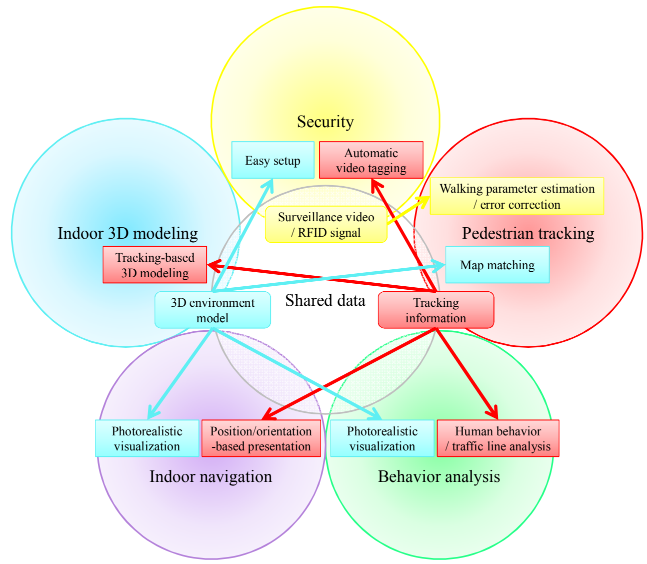

Figure 2. Overview of economic and synergistic service linkage.

The remainder of the present paper is organized as follows. Related work is described in Section II. Section III presents the proposed tracking system, which incorporates existing infrastructure and 3D modeling. Section IV introduces synergistic services by incorporating with our tracking service. Finally, Section V summarizes the paper.

II. RELATED WORKS

In the research fields of augmented / mixed reality, vision-based tracking methods using artificial markers and natural features in the scene have been actively investigated for estimating the location and orientation of the user in indoor environments such as museums and offices. The methods using artificial markers placed in the scene [4,5] can estimate the position and orientation of the camera relative to the markers by shooting them. In principle, the methods can support to track the user in large environments by placing large amount of markers in the scene. But, It is inefficient to place markers and to create the database of them only for the tracking. The method using natural features in the scene [6] does not need to place artificial markers, and can efficiently provide AR services by creating the database of the natural features and authoring AR content based on the tracking information simultaneously. These vision-based tracking methods can use cameras which are generally low cost, but the computational cost is expensive to run the tracking system for a long time, and the stability of the tracking still remains an issue.

Without adding new infrastructure for tracking services, signal-strength-based tracking systems using Wi-Fi and active RFID tags as existing infrastructure have been investigated [7,8]. These systems localize the position of the user based on the IDs and signal strengths from the access points or RFID tags by low-cost receivers and a usual PC.

However, they need another way for estimating the orientation of the user, and the access points and tags have to place densely for practical tracking. Besides, they also need additional costs to configure the positions of the access points and tags for the tracking purpose.

The tracking method [9] that probabilistically estimates the location and orientation of the user by fusing maps and information from existing infrastructure such as Wi-Fi, and RFID tags. The method tracks the user based on PDR from the measurements of the self-contained sensor module (accelerometers and gyro-sensors) mounted on the shoe of the user. Because of the measurements of the self-contained sensor module, the position and orientation can be estimated sustainably even if the user is in an environment with sparse infrastructure. Therefore, the provider of the tracking service can reduce the costs for installing and running the infrastructure. Our tracking system is based on PDR as well as the method [9], but it not only uses existing infrastructure simply but also is used for enhancing the existing services and the other services, and also realizes overall cost reduction.

III. Economic and Synergistic Pedestrian Tracking System

A. Overview

The proposed indoor pedestrian tracking system estimates the position and orientation of the user by sensor/data fusion of measurements from self-contained sensors worn by the user and sensors embedded in the environment together with constraints by maps generated from 3D environment models as content for the other services. Fig. 3 shows an overview of the proposed indoor pedestrian tracking system.

The tracking system estimates absolute velocity vector and orientation from PDR by the measurements of accelerometers, gyro-sensors, magnetometers, a barometer in the self-contained sensor module worn by the user. The PDR-based tracking can stably work by taking advantage of the highly regular nature and repeatability of human walking locomotion. However, the velocity vector and orientation estimated by PDR include errors derived from the errors of the walking parameter and velocity estimation corresponding to walking locomotion. Therefore, the position of the user has cumulative errors derived from the errors. In order to correct these cumulative errors and dynamically estimate walking parameters, the proposed system uses sensors that are embedded in the environment and 3D environment models.

Sensors that are part of the existing infrastructure in the environment include surveillance cameras, active RFID tags, and a reference barometer. The surveillance cameras and RFID tags to be used for security services must be placed at pivotal spots of human traffic evidently, and so they have the convenient features for applying to the tracking of humans. Furthermore, barometers are commonly inexpensive, but they can measure the change of atmospheric pressure stably. Surveillance videos are used for matching and identifying the user wearing the self-contained sensor module. When the

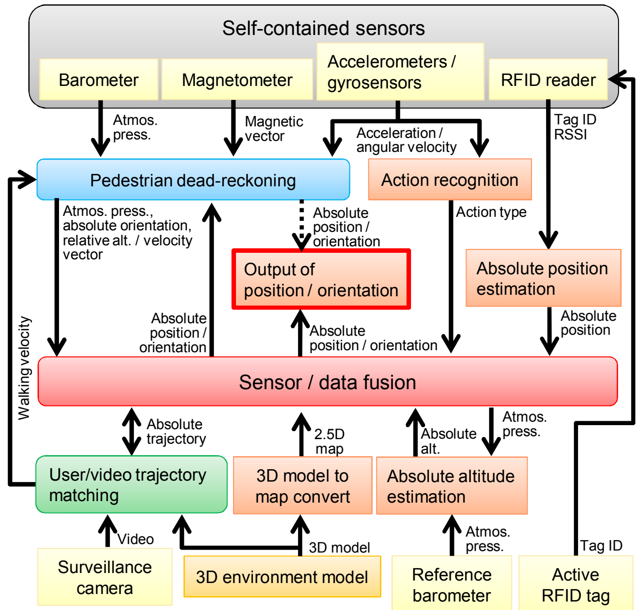

Figure 3. Overview of sensor/data fusion using existing infrastructure and 3D environment model for indoor pedestrian tracking.

system successfully identified the user, the trajectory of the user's movement estimated from the video can be used for dynamic walking parameter estimation and correction of tracking errors. Signals from active RFID tags are received by a RFID reader in the self-contained sensor module and used for localization based on the signal strength and the positions of the tags. Additionally, atmospheric pressure from the reference barometer in a site at a known absolute altitude and a barometer in the self-contained sensor module can be used for estimating absolute altitude of the user. The estimated location data from measurements are fused probabilistically in the sensor/data fusion unit.

Moreover, our tracking system can improve the tracking performance by map matching by using 3D environment models created as map content in the sensor/data fusion unit. The 3D models can help to configure the parameters such as camera parameters and positions for surveillance cameras and RFID tags.

We briefly describe about PDR, localization by sensors embedded in the environments, and the usage of 3D environment models in the following.

B. Pedestrian Dead-Reckoning

PDR estimates absolute velocity vector, absolute orientation, and relative altitude and recognizes actions of the user from the measurements by accelerometers, gyro-sensors, magnetometers (3-axis each), and a barometer in the sensor module.

Absolute velocity vector is estimated from the walking velocity corresponding to the absolute orientation tracked by gyro-sensors and magnetometers. In this process, the walking velocity can be estimated from walking parameters estimated by the process described in the next section and vertical acceleration amplitude while the user walks.

Relative altitude can be estimated by measuring temporal alteration of atmospheric pressure from the barometer in the sensor module and converting the alteration into the alteration of altitude. For converting the alteration of atmospheric pressure into the alteration of altitude, we employ the model of the standard atmosphere [11].

In indoor environments, pedestrians can move between floors by stairs, elevators, and escalators. Therefore, by recognizing the activities of walking up/down stairs and stepping into/out of an elevator and on/off of an escalator from the measurements of accelerometers and gyro-sensors, the tracking system can estimate the position and altitude of the user based on the probability that the user is near a staircase, an elevator, or an escalator [10].

The absolute velocity vector, absolute orientation, relative altitude, action types, and their uncertainties are sent to the sensor/data fusion unit.

C. *Tracking by Existing Infrastructure*

Our tracking system carries out dynamic walking parameter estimation and correction of tracking errors by the tracking information from the sensors embedded in the environment.

For the tracking system, surveillance cameras are used for realizing the following two functions.

- Correction of tracking errors
- Dynamic walking parameter estimation

Since cameras have high spatial resolution, time series measurement using cameras is effective for estimating the precise position of the user. In addition, cameras enable the proposed tracking system to estimate the walking velocity of the user from time series measurements. In order to realize the above functions, the tracking system needs to distinguish the user wearing the self-contained sensor module from other persons in the surveillance videos. Thus, the tracking system distinguishes the user by matching two types of 2.5D trajectories, namely, fusion-based trajectories estimated in the sensor/data fusion unit and video-based trajectories extracted from surveillance videos. The camera parameters to be used for converting 2D trajectories on videos into 2.5D trajectories can be estimated by our 3D modeler [3] from a video image easily without any special devices. When the system identified the user on the video, the walking velocity calculated from the video-based trajectory is transferred to the unit for walking parameter estimation in PDR, and the unit estimates the parameters from the velocity and acceleration amplitude at the walking (see [10] for more details).

RFID signals are received by a RFID reader in the sensor module, and they are used for estimating the absolute position of the user based on the positions and signal strengths of the tags. Generally, active RFID tags have directivity of the signal propagation. Therefore, in our tracking system, we use pairs of tags, and estimate the position of the user only if the signals of both tags are received by the RFID reader. In this way, the ambiguity of localization is reduced because the area sensed by the RFID reader becomes narrower. The signal power consumption can also be reduced by placing the tags on both sides of an entrance to a room.

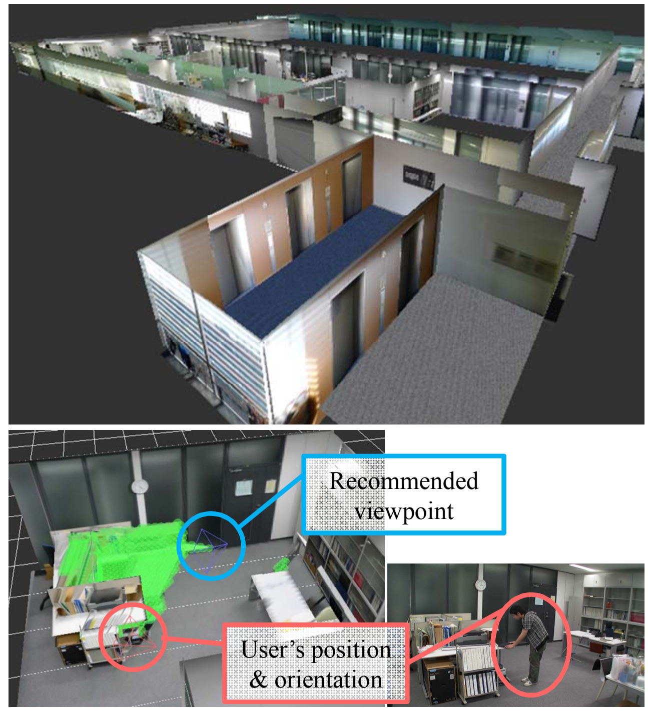

Figure 4. Example of 3D environment model (top) and location-based 3D modeling (bottom). A user can understand shooting position to capture untextured regions by visualization of the recommended viewpoint and own position and orientation. .

For a building and its surroundings, we can assume that the atmospheric pressure distribution is constant. Therefore, we can estimate the absolute altitude from the difference in the pressures detected by the barometer in the sensor module and the reference barometer by placing the reference barometer at a known altitude. As well as the relative altitude estimation, we employ the model of the standard atmosphere for converting the difference of pressures into the difference of altitudes.

The video-based trajectory extracted from surveillance video, the position estimated from RFID signals, the absolute altitude estimated by the barometers, and its uncertainties are transferred to the sensor/data fusion unit for correcting tracking errors.

D. *Map Generation from 3D Environment Model*

Our tracking system can improve the tracking performance by map matching by utilizing 3D environment models created as map content for navigation services. Furthermore, by incorporating with tracking and modeling services, we can create 3D environment models from multiple photos efficiently and prevent untextured regions by presenting the regions and the position and orientation of the user simultaneously. We use our interactive 3D modeler [3] and show an example of a 3D environment model and an appearance of 3D modeling based on tracking in Fig. 4.

Since the created 3D models, which consist of multiple polygons, require greater computational costs for map matching, the proposed system represents the maps as sets of 2.5D polygons and line segments, which include discrete altitudes, as well as the method of Woodman et al. [9]. Then, the polygons that can be walked on and that floor change will cause are assigned "Floor" and "Staircase/Elevator/Escalator" attributes. Line segments that intersect with polygons representing walls and floors are assigned "Wall" attributes.

The 2.5D map data are used to map matching for improving the tracking performance in the sensor/data fusion unit. In addition, the 3D environment models can be used for estimating camera parameters of surveillance videos and for positioning of active RFID tags. Thus, the models contributes to prompt efficient install and setup and to reduce costs for them.

E. Sensor / Data Fusion Based on Particle Filter

The sensor/data fusion unit estimates the position and orientation of the user by fusing the measurements from sensors and 2.5D maps generated form 3D environment models. The proposed tracking system realizes robust tracking by using the particle filter [12] to probabilistically fuse the data. The filter, which is a type of Bayesian filter, efficiently estimates the state of a system under the Markov assumption and Monte Carlo approximation of the probability distribution.

In the proposed system, we define the 4D state space consisting of 2D position, polygon ID in 2.5D maps, and absolute orientation for the particle filter. Then, the probability distribution of existence of the user at each time is estimated by the absolute velocity vectors, the positions estimated by sensors embedded in the environment, and their uncertainties and 2.5D maps. When the system predicts the probability distribution based on the absolute velocity vector from PDR, the samples which move to non floor areas or which intersect with line segments representing walls are disabled. Besides, the samples on the polygons representing "Staircase/Elevator/Escalator" are also disabled when altitude change is detected. By this map matching, we can realize more precise tracking (Fig. 5)

Figure 5. Map matching using a map converted from a 3D environment model (Left-column presents probability distributions of locations of the user shown in right-column. Bottom-row presents the state 1 second before top-row).

Figure 6. A user of an indoor navigation service (left) and an example of navigation information displayed onto a hand-held device (right).

IV. SYNERGISTIC SERVICES

In this section, we briefly introduce examples of applications for which the quality and value of services can be enhanced synergistically by the proposed tracking system.

A. Indoor Navigation

In indoor navigation services, our tracking system which precisely estimates the position and orientation of the user and efficiently created photorealistic 3D environment models realize superior user experience. Fig. 6 shows the user using an indoor navigation service and an example of the screenshot of the navigation system. By presenting photorealistic 3D environment models and an annotation based on the tracking information, the user can make correspondences between real and virtual world intuitively. Particularly, since there are not landmarks, which are clearly recognized, in indoor environments such as shapes of buildings and loads, presentation by the 3D environment models which can show the textures on the walls clearly is effective to understand the current position and orientation of the user.

B. Behavior Analysis

For analyzing behaviors of the users of services, tracking logs of the user and 3D environment models enable us to carry out valuable questionnaires and interviews and intuitive behavior analysis by visual data mining. While conducting questionnaires and interviews, it is important that the user remembers what the user considers at the moment. We can replay the views of the user who used the service approximately from the tracking logs and photorealistic 3D environment models, and make the user vividly imagine the considerations again by presenting the replayed views.

Furthermore, the behavior analyst is able to analysis the tracking logs intuitively by presenting human traffic lines of the users with the 3D environment models. Additionally, the analyst can also research the reason of the user's behaviors more precisely by experiencing the user's behaviors in a

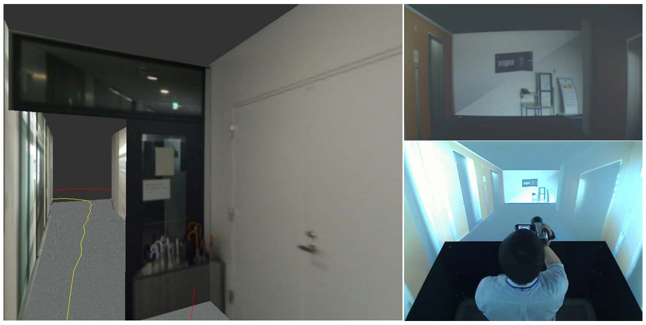

Figure 7. Replayed user's view based on tracking logs (left) and walk-through simulation using a 3D environment model and an immersive display (right-top: user's view, right-bottom: user in the simulator).

virtual environment presented by an immersive walkthrough simulator. Fig. 7 shows an example of the replayed user's view and the appearance of the analyst using an immersive walkthrough simulator. By such services for behavior analysis, the service provider can consider the way to improve the services.

C. *Security Service*

If security system can distinguish the person on surveillance videos, we can search a person from the videos easily, and the system can be used for managements of entrance and exit. Our tracking system matches and identifies the user and persons on surveillance videos when estimating walking parameters and correction of tracking errors. Based on the identification, we can add a new function, automatic video tagging to the security service like Fig. 8.

V. CONCLUSION

In this paper, we have proposed indoor pedestrian tracking system that can improve the tracking performance by dynamic walking parameter estimation and correction of tracking errors by using existing infrastructures, which are generally used in commercial facilities, such as surveillance cameras and active RFID tags without significantly increasing costs. Furthermore, we have shown examples of synergistic services that can enhance the quality and value of the services and reduce the costs for creating the data totally by sharing data among services.

In the near future, we will carry out experiments to evaluate the tracking performance of the proposed system with the infrastructure described in the present paper. We also plan to apply our system to actual fields of services and evaluate the effectiveness of service linkage. In addition, we will consider the other way and the other infrastructure for improving the tracking performance and enhancing the quality of services.

Figure 8. Automatic video tagging as an enhanced function of security service by cooperating with tracking service.

ACKNOWLEDGMENT

This research was entrusted by the Ministry of Economy, Trade and Industry (METI).

REFERENCES

[1] M. Kourogi, N. Sakata, T. Okuma, and T. Kurata, "Indoor/Outdoor Pedestrian Navigation with an Embedded GPS/RFID/Self-Contained Sensor System," In Proc. 16th Int. Conf. on Artificial Reality and Telexistence (ICAT2006), pp. 1310–1321, 2006.

[2] T. Okuma, M. Kourogi, N. Sakata, and T. Kurata, "A Pilot User Study on 3-D Museum Guide with Route Recommendation Using a Sustainable Positioning System", In Proc. Int. Conf. on Control, Automation and Systems (ICCAS2007), pp. 749-753, 2007.

[3] T. Ishikawa, K. Thangamani, M. Kourogi, A. P. Gee, W. Mayol-Cuevas, K. Jung, and T. Kurata, "In-Situ 3D Indoor Modeler with a Camera and Self-Contained Sensors", In Proc. 13th Int. Conf. on Human-Computer Interaction (HCII2009), pp. 454-464, 2009.

[4] D. Schmalstieg and D. Wagner, "Experiences with Handheld Augmented Reality", In Proc. 6th IEEE and ACM Int. Symp. on Mixed and Augmented Reality 2007 (ISMAR2007), pp. 3-18, 2007.

[5] E. Bruns, B. Brombach, T. Zeidler, and O. Bimber, "Enabling Mobile Phones To Support Large-Scale Museum Guidance", IEEE Multimedia, vol. 14, no. 2, pp. 16-25, 2007.

[6] R. O. Castle, G. Klein, and D. W. Murray, "Video-rate Localization in Multiple Maps for Wearable Augmented Reality", In Proc. 12th IEEE Int. Symp. on Wearable Computers, pp. 15-22, 2008.

[7] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-Based User Location and Tracking System", In Proc. IEEE INFOCOM2000, pp. 775-784, 2000.

[8] A. D. Koutsou, F. Seco, A. R. Jimenez, J. R. J. Ealo, C. Prieto, and J. Guevara, "Preliminary Localization Results with An RFID Based Indoor Guiding System", In Proc. IEEE Int. Symp. on Intelligent Signal Processing, pp. 917-922, 2007.

[9] O. Woodman and R. Harle, "Pedestrian Localisation for Indoor Environments", In Proc. 10th Int. Conf. on Ubiquitous Computing (UbiComp2008), pp. 114-123, 2008.

[10] M. Kourogi, and T. Kurata, "Personal Positioning Based on Walking Locomotion Analysis with Self-Contained Sensors and a Wearable Camera", In Proc. 2nd IEEE and ACM Int. Symp. on Mixed and Augmented Reality (ISMAR2003), pp. 103-112, 2003.

[11] National Oceanic and Atmospheric Administration, United States Air Force, "U. S. Standard Atmosphere, 1976", Washington D. C., 1976.

[12] N. J. Gordon, D. J. Salmond, and A. F. M. Smith, "Novel Approach to Non-Linear/Non-Gaussian Bayesian State Estimation", IEE Proceedings F, vol. 140, no. 2, pp. 107-113.