# Indoor Localization for an Augmented Reality-Aided Operation and Maintenance System based on Sensor Data Integration*)

Tomohiro UMETANI, Susumu YAMANE and Yuichi TAMURA

*Konan University, 8-9-1 Okamoto, Higashinada, Kobe 658-8501, Japan*

(Received 10 December 2013 / Accepted 27 February 2014)

We propose a method for determining the location of a mobile client for augmented reality (AR) aided maintenance and operation systems using the data integration of localization results from wireless LAN signals and three-dimensional camera image sequences. The AR technology is used to enhance real information by adding virtual objects, images, and sounds through camera images. To apply the AR system to maintenance and operation tasks in large structures, a data management system for localization is crucial because of the cost for searching for real-location information. We propose a sensor data integration scheme for the localization of a mobile client the indoor structure using the localization results from camera image sequences and the results using the wireless LAN signal strength. The data integration scheme provides an area selection method using the estimation result of the location in the structure using wireless LAN signals and the precise location estimation using camera image sequences. The experimental results confirm the feasibility of the proposed method.



Keywords: augmented reality, visualization, self localization, wireless LAN signals, RGBD camera, sensor data integration

DOI: 10.1585/pfr.9.3406054

## 1. Introduction

Data on the physical location of mobile agents, such as workers with personal electronic devices and mobile robots, are important for surveillance and maintenance of the condition of plants in a large indoor environments [1]. Recently, an augmented reality (AR) system for indoor operation and maintenance tasks was proposed [2, 3]. The AR technology enhances real information by adding virtual objects, images, and sounds to a camera images. To apply the AR system to maintenance and operation tasks in large structures, a data management system for location estimation (localization) is crucial because of the associated search cost for the information related to the real location.

This study proposes a localization method for a mobile client for AR-aided maintenance and operation systems integrating wireless LAN signals [4] and three-dimensional (3-D) camera image sequences [5,6]. Figure 1 shows the overview of the proposed method. In indoor environment, visual localization using a one-shot measurement from camera images is not effective because of the symmetry of the building's structure. On the other hand, there is also uncertainty in the localization results when using wireless LAN signals because of the uncertainties in the signal strength caused by the reflections and multipath fading.

We propose a data integration scheme for the localization of a mobile client in indoor structures using localization results from camera-image sequences and wireless LAN signals strengths [7]. The selection of the area, such as floor number in the buildings and rough localization of the mobile client, are determined using a stochastic localization system and the signal strength from wireless LAN access points in the buildings [8]. Then, the precise location of the client is estimated by the matching of the local feature points in the camera images and stored in advance map of feature points.

The goal of this study is to construct an information aid system for helping indoor operation and maintenance tasks such as a nuclear fusion reactors and associate buildings. The experimental test bed is a laboratory building with long corridors and the multistoried structure—most nuclear fusion reactors are large, and their buildings are also large and multi-storied. The experimental results confirmed the feasibility of the proposed method.

## 2. Research Methodology

### 2.1 System configuration

We constructed a mobile client consisting of a notebook PC, a red-green-blue-depth (RGBD) camera and a wireless LAN client. The mobile client obtains camera images, depth data, and signal strength from the wireless LAN access points. The depth data correspond to the pixels of the camera image. We used an ASUS Xtion PRO live as the RGBD camera device, which is a 3-D image acquisition system. The Xtion device and PC are placed on a cardboard box on a mobile carriage. The height of the Xtion device is 780 mm, and the moving direction of the

*author's e-mail: umetani@konan-u.ac.jp*

*) This article is based on the presentation at the 23rd International Toki Conference (ITC23).

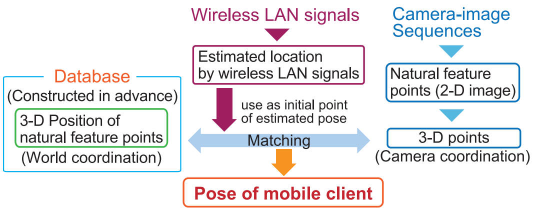


Fig. 1 Localization of mobile client using data integration of wireless LAN signals and camera-image sequences.

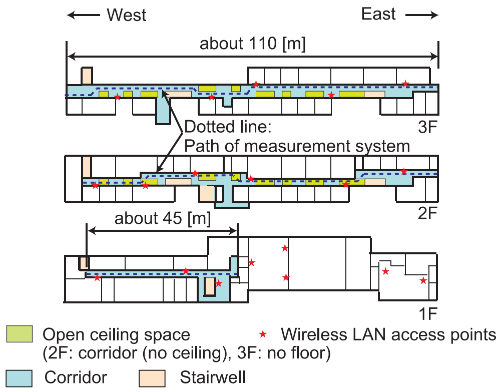


Fig. 2 Experimenal environment.

imaging sensor is at the horizontal plane.

We used an ICOM SU-50 W, which supports the IEEE 802.11a, 802.11b, and 802.11 g standards, as the wireless LAN client. The location estimation system for the wireless LAN signals is of the fingerprinting-type, which uses the relation between the position of the wireless LAN client in the building and the corresponding strength of the signals received from the wireless LAN access points in advance.

## 2.2 Experimental environment

The experimental test bed is a three-storied laboratory building. Figure 2 shows the building layout. The dotted lines mark the paths along which the mobile client moved. The corridor runs from east to west and is about 110-m long on the second and third floors and about 45-m long on the first floor. There are numerous open-ceiling and stairwell spaces, which are commonly observed in factories and large structures.

The wireless LAN access points (Cisco Aironet 1210) were located in the corridors and large rooms. There were 19 access points: eight, six, and five on the first, second, and third floors, respectively. In total, 38 signals were detected. The wireless LAN access points use the IEEE 802.11a, 802.11b, and 802.11 g standards. We distinguished the access points for public use from those located in each laboratory, with extended service identifiers (ESSIDs). We also used the strengths of the received signals from the public wireless LAN access points.

## 2.3 Localization model using wireless LAN signals

We estimated the location of the mobile client using a probabilistic model [8]. Let $K$ be the total number of floors in the building. Let $\mathcal{I}$ be the input vector of the estimation system; that is the received signal strength from the wireless LAN access points. Let $\boldsymbol{y}$ be the output of the estimation system; $\boldsymbol{y}$ consists of the distance from the eastern edge of the building $y_l$, and the floor number $\boldsymbol{y}_f$. We set the floor number $\boldsymbol{y}_f$ as a vector of length $K$, such that if the floor number is $j$, then all elements $y_f^{(k)}$ of $\boldsymbol{y}_f$ are zero, except for element $y_f^{(j)}$. The element $y_f^{(j)}$ is set to 1.

The probabilistic model is described by

$$p\left(\boldsymbol{y}|\mathcal{I}\right) = p\left(y_l|\mathcal{I}, \boldsymbol{y}_f\right) p\left(\boldsymbol{y}_f|\mathcal{I}\right). \qquad (1)$$

The floor number is expressed by using multinominal logistic regression. On the other hand, the location of the mobile client is expressed by a normal distribution, and the output value is the location of the mobile client and its variances. The estimation parameters are obtained using the training data set in advance [8].

## 2.4 Localization of mobile client using wireless LAN and camera images

This section describes the localization scheme for the mobile client based on data integration from wireless LAN signals and camera-image sequences, as shown as Fig. 1. The localization procedures are as follows:

1. The mobile client estimates its location in the buildings using the strength of the wireless LAN signals and the location estimation system constructed in advance. The client obtains signal strengths from wireless LAN access points. The client requests for the signal strengths from the wireless LAN access points to construct a wireless communication between the client and the access points.
2. The mobile client obtains a camera images and 3-D points with respect to the camera coordination frame using an attached vision system. The natural features suitable for detection and tracking image sequences in the two-dimensional (2-D) camera image and their 3-D positions are then obtained. We apply the scale invariant feature transform (SIFT) features to the natural features in the camera images [9] because the SIFT features are robust against the change of scale, rotation and change of illumination in the camera image.
3. The obtained natural feature points and those stored in the database are matched using the iterative closest point (ICP) algorithm for pattern matching [10]. The candidate feature points in the database are selected based on the localization estimation provided by the wireless signal strength (procedure 1) and the matching of the identifier of the SIFT features of the camera images. The 3-D positions of the natural feature points in the world coordination frame are obtained

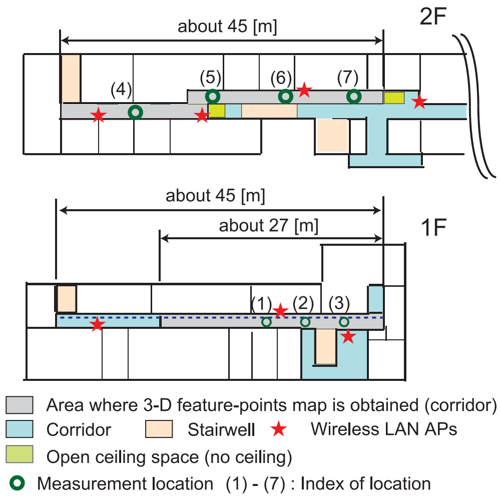


Fig. 3 Layout of experimental environment. We conducted the experiment at the part of the building.

using this procedure. The mobile client position is then estimated.

Note that the global position of the mobile client is obtained by using procedures 1 and 3. To construct the database of the natural feature points in camera images, their 3-D positions are stored in advance. The wireless LAN localization system is needed to select the 3-D feature points' map in the structure and the rough localization in the buildings for the initial solution of the matching algorithm of the procedure 3.

## 3. Experiment

This section describes the localization experiment in the laboratory building. We introduce the experimental setting for localization of the mobile client using wireless LAN signals and camera image sequences. Then, the experimental results and discussions are illustrated.

### 3.1 Experimental conditions

We applied an estimation system using wireless LAN signals constructed in a former study [8]. The localization experiment was conducted on the first and second floors of the building, where the 3-D feature points map are constructed, as shown in Fig. 3. We estimated the location of the mobile client at seven locations, as shown in Fig. 3. The mobile client faces the western edge of the building on each floor.

### 3.2 Results and discussions

First, we evaluated the errors in the location estimation using the 3-D feature-points map for the case where the estimation result using wireless signals was correct. The estimation result using the wireless signals were used as the initial solution in the ICP algorithm. The Xtion device was facing west.

Table 1 Estimation error for location estimation in case the estimation result using wireless signals is correct.

| Condition | Estimation error [m] | Pose |
|---|---|---|
| (1) | +1.29 | OK |
| (2) | -0.29 | OK |
| (3) | -0.05 | OK |
| (4) | -14.56 | NG |
| (5) | +3.04 | NG |
| (6) | -1.80 | OK |
| (7) | -0.56 | NG |

Table 2 Estimation error for location estimation using 3-D features' map and the wireless LAN signals (estimation error using wireless LAN signals is small).

| Condition | Estimation Error using signals [m] | Estimation error [m] | Pose |
|---|---|---|---|
| (1) | -0.50 | +0.19 | OK |
| (2) | -0.03 | -0.29 | OK |
| (3) | +0.90 | -0.31 | OK |
| (4) | +0.54 | -9.46 | NG |
| (5) | -0.85 | +0.18 | NG |
| (6) | +1.12 | +1.06 | NG |
| (7) | -5.12 | -6.18 | NG |

Table 1 shows the estimation error for each condition. Conditions (1)–(7) indicate the locations of the mobile client shown in Fig. 3. The error of the estimated location is the difference between the real and estimated location of the mobile client with respect to displacement from the eastern edge of the building. If the value is positive, the estimated location is the west side of the real location. The element "Pose" indicates the 3-D position and rotation of the mobile client. If the "Pose" is "OK," both the rotational and vertical translational error of the mobile client are small. The horizontal and vertical translational errors are smaller than 0.5 m. The rotational error is smaller than 20°. On the other hand, "NG" means that the rotational or vertical translational error of the mobile client is large.

From Table 1, we can infer that if the estimation results using the wireless LAN were correct, then the location estimation results using the 3-D feature points would also be correct.

Next, we evaluated the errors in location estimation using the 3-D feature-points map and wireless LAN signals. Tables 2 and 3 show the estimation error for each condition. The Xtion device was again facing west. The details of the location estimation method using the wireless LAN signals are described in [8]. The "Estimation error using signals" indicates the error of the location using the wireless LAN signals. If the value is positive, the estimated location is the west side of the real location. For

Table 3 Estimation error for location estimation using 3-D features' map and the wireless LAN signals (estimation error using wireless LAN signals is large).

| Condition | Estimation error using signals [m] | Estimation error [m] | Pose |
|---|---|---|---|
| (1) | -5.02 | -5.78 | OK |
| (2) | +5.86 | +3.42 | OK |
| (3) | +11.46 | +13.38 | OK |
| (4) | -19.93 | -20.20 | NG |
| (5) | -21.57 | +21.35 | NG |
| (6) | +32.03 | +33.21 | NG |
| (7) | -9.44 | -13.11 | NG |

the location process using wireless LAN signals, the floor number estimation at all conditions was successful. The result for the floor estimation shows the feasibility of the selection of the database for the precise location estimation.

From Table 2, when the estimation error using wireless LAN signals is small, the total estimation error for the mobile client on the first floor is small. On the other hand, from Tables 2 and 3, when the estimation error of the location using wireless LAN signals is large and the mobile client is on the second floor, then the total estimation error is considerably large. One of the reasons for the large estimation error is the error in the feature points' map for the second floor of the building. The improvement in the construction of the 3-D feature points' map and matching method for the feature points will be addressed in the future.

Moreover, the error and uncertainty of the location estimation using wireless LAN signals is considerably large for the initial solution using the 3-D feature points from the experimental results. The accuracy of the location estimation using wireless LAN signals is influenced by the symmetry of the buildings structure such as the open-ceiling and stairwell spaces. This influence depends on the experimental environment.

To apply the entire system to visualization applications, the mobile client moves throughout the buildings and the locations of the mobile client are continuously estimated using wireless LAN signals. In this case, the estimated localization results are smoothed by using the motion of the mobile clients and the estimation results using wireless LAN signals using the Gaussian filter, such as a Kalman filter [11].

We will develop more accurate and robust methods for indoor location determination based on wireless LAN systems in the future. The probabilistic location estimation model needs to be improved by using one-shot measurements. The evaluation of the system using the entire system will be addressed in the future.

## 4. Conclusion

We described a method for the localization of a mobile client for AR-aided maintenance and operation systems integrating localization data from wireless LAN signals and 3-D camera image sequences. We selected areas, such as floor number in the buildings, to roughly establish the localization of the mobile client using a stochastic localization system that considers the signal strength from wireless LAN access points in the buildings. Then, the precise location of the client is estimated by the matching of the local feature points in the camera images and the feature points' map stored in advance.

The experimental results showed the feasibility of the proposed method; however, the estimation results needs to improve with respect to the accuracy of the estimated locations and robustness of the uncertainty of the location estimation using wireless LAN signals. The accuracy of the location estimation using wireless LAN signals is influenced by the structure of the buildings such as the open-ceiling and stairwell spaces.

In the future, we will address the development of more accurate and robust methods for establishing the indoor location based on wireless LAN systems; moreover, the use of the entire system will be addressed.

## Acknowledgments

This work was supported in part by the Japan Society of Promotion of Science under a Grant-in-Aid for Scientific Research (#22500114 and #24500288), and MEXT.

[1] J. Hightower and G. Borriello, Computer **34**, 57 (2001).
[2] Y. Tamura, T. Umetani and S. Kubo, Plasma Fusion Res. **8**, 2506102 (2013).
[3] N. Mizuguchi, Y. Tamura, S. Imagawa, A. Sagara and T. Hayashi, Fusion Eng. Des. **81**, 2755 (2006).
[4] P. Bahl and V.N. Padmanabhan, Proc. IEEE Infocom 2000 **2**, 775 (2000).
[5] Y. Tamura, Y. Takabatake, N. Kashima and T. Umetani, Plasma Fusion Res. **7**, 2406036 (2012).
[6] T. Sato, H. Koshizawa and N. Yokoya, Int. J. Virtual Reality **9**, 37 (2010).
[7] T. Umetani, S. Yamane and T. Tamura, Proc. Int. Conf. Ubiquitous Robots and Ambient Intelligence 240 (2012).
[8] T. Umetani, T. Yamashita and Y. Tamura, J. Robot. Mechatronics **23**, 475 (2011).
[9] D.G. Lowe, Int. J. Comput. Vision **60**, 91 (2004).
[10] P.J. Bsel and N.D. McKey, IEEE Trans. Pattern Anal. Mach. Intell. **14**, 239 (1992).
[11] T. Umetani, S. Yamane, T. Yamashita and Y. Tamura, Trans. Inst. Syst. Control Inf. Eng. **25**, 316 (2012).