The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

Position Tracking System of Everyday Objects in an Everyday Environment

Kouji Murakami, Tsutomu Hasegawa, Kousuke Shigematsu, Fumichika Sueyasu, Yasunobu Nohara, Byong Won Ahn, Ryo Kurazume

***Abstract*— We propose an object tracking system for a service robot working in an everyday environment. The system is composed of an intelligent cabinet, a floor sensing system and a data management system. The position of an object can be classified into three areas: 1) in/on furniture, 2) on the floor, 3) held by a human or a robot. Being equipped with a RFID reader and loadcells, the intelligent cabinet measures the position of an object in/on itself. The floor sensing system which uses a laser range finder, measures the position of an object on the floor and the position of a human walking in a room. The data management system integrates the position data of the intelligent cabinets and the floor sensing system, and it performs position measurement of an object carried by a human. The data management system provides robots with position information to support robot activities.**

I. INTRODUCTION

Daily life support work in a care house for elderly persons is a promising application of a service robot. Most work includes a go-and-fetch task of objects. If the robot can perform the go-and-fetch task of objects specified by an elderly person at the care house, the burden on health care workers is reduced. However, an everyday environment is a dynamically changing 3D real space because there are human beings walking and working around, and the placement of objects will change frequently. Although it may be a simple and well-ordered environment for human beings, it is too complex to recognize changes for a conventional self-contained autonomous robot equipped with as many sensors as possible within its limited body. We will not be able to expect a capable robot to execute various tasks in the everyday environment in the near future. An alternative approach to the realization of a service robot working in the everyday environment is to structure the environment in an informative way [1][2][3][4][5]. Instead of solely relying on the sensors on the robots themselves, we distribute laser range finders, pressure sensors and other sensors embedded in the environment and connected to a computer network to support autonomous robotic activities.

We are currently developing technologies to implement such a structured environment platform: Robot Town [6][7] (Fig. 1). In this platform, a data management system called Town management system (TMS) collects data from embedded sensors and integrates them to establish a real time database of the environment. TMS supports the robotic activities by providing information of the environment. This paper describes a position tracking system of everyday objects in an everyday environment. The system has been developed as one component in the informationally structured environment, the RobotTown.

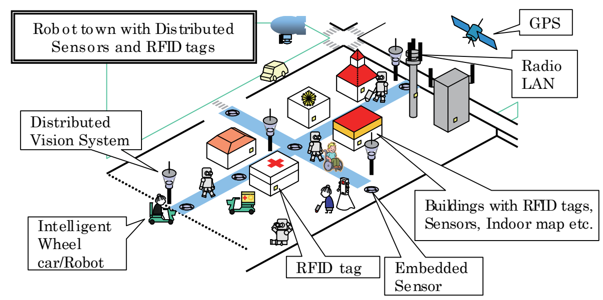


Fig. 1. Concept of RobotTown.

Mori et al. [8] proposed a position management system in which the positions of objects with RFID tags are measured by using a RFID reader attached to a cabinet; however, the system cannot track an object when the object is out of the cabinet. Deyle et al. [9] reported a position search scheme by moving a directional antenna and receiving the signal from a RFID tag attached to an object; however, the position resolution of the scheme is low. Nishida et al. [10] used an ultrasonic sensor for position measurement. The positions of objects with ultrasonic tags are measured by using ultrasonic receivers placed on the ceiling. However it is difficult to attach the ultrasonic tags to many objects due to the cost and the size of the tag. Pressure sensors embedded on the floor has been introduced to track human activities [11]. However, this method cannot detect the positions of lightweight objects. A vision sensor is often used for position tracking. But the vision system will often fail to track objects due to occlusion, lighting conditions, and complex backgrounds. Moreover constant surveillance by using vision sensors causes an invasion of privacy.

Many papers on the position tracking system have been written however these have reported on a human tracking sytem rather than an object tracking system. An object is smaller than a human, and the object is taken in and out of a small space such as a cabinet. Therefore previous work can not be directly applied to the object tracking sytem.

This work is supported by NEDO (New Energy and Industrial Technology Development Organization, Japan) project 'Intelligent RT Software Project'.

K. Murakami, T. Hasegawa, K. Shigematsu, F. Sueyasu, Y. Nohara, and R. Kurazume are with Graduate School of Information Science and Electrical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Japan (e-mail: mkouji@ait.kyushu-u.ac.jp).

B.W. Ahn is with Division of Marine Engineering, Mokpo Maritime University, 571 Jukgyo-dong, Mokpo-si, Jeollanam-do, Republic of Korea.

We propose an object tracking system which is based on the structurization of an everyday environment. The features of the object tracking system are as follows.

1) position tracking of objects which are smaller than a human
2) position tracking of objects in an everyday environment
3) position tracking of objects carried by human

II. Position tracking of everyday objects

The placement of an object can be classified into three areas as follows.

1) in/on a cabinet,
2) on the floor,
3) held by a human or a robot

We develop an object tracking system which is applicable to these three cases. In the case of 1), information structurization of a cabinet is implemented by installing a RFID reader, a loadcell etc. to the cabinet. In the case of 2), we consider information structurization by using an laser range finder(LRF) which has wide sensing area. There are not only objects but also persons on the floor. So they have to be distinguished. We use supplementarily a pyroelectric sensor for this distinction. In the case of 3), it is difficult to directly track objects carried by a human. We assume that the movement of an object is caused by human beings. So position tracking of an object carried by a human can be replaced by human tracking while the human carries the object. In order to implement this replacement, the system has to decide whether a human has an object or not. This decision is achieved by data integration between the information of an object taken out of a cabinet and the position of the human. When the object is taken out of the cabinet, the object is related to the human who is closest to the cabinet. While the human carries the object, the position of the object is replaced by the position of the human.

Based on the considerations mentioned above, we arranged the requirements for the object tracking system as follows.

1) position measurement of objects in a cabinet
2) position measurement of objects and humans on the floor
3) recognition of an object type(object or human) on the floor
4) integration and management of position data of objects and humans

A function of providing a robot with the information of objects via a network is also needed. So we add the following requirement.

5) provision of the information of objects to a robot

The developed system satisfies all the requirements. There are some reports on object tracking. Each of them satisfies some requirements mentioned above. However no measurement system which satisfies all the requirements has been reported in previous work.

III. System Structure

The object tracking system is composed of three components as follows.

A) an intelligent cabinet
B) a floor sensing system
C) a data management system

The intelligent cabinet recognizes objects stored in it. It detects objects taken in and out, and measures the positions and attributes of objects. The floor sensing system measures the positions of objects on the floor and the positions of humans walking in a room. The data management system has a database and a network interface. The data management system integrates the position data of the intelligent cabinet and the floor sensing system, and performs object tracking. The data management system provides a robot with the information of existing objects in the environment. The data flow of the object tracking system is shown in Fig. 2. Each component is explained in the following subsections.

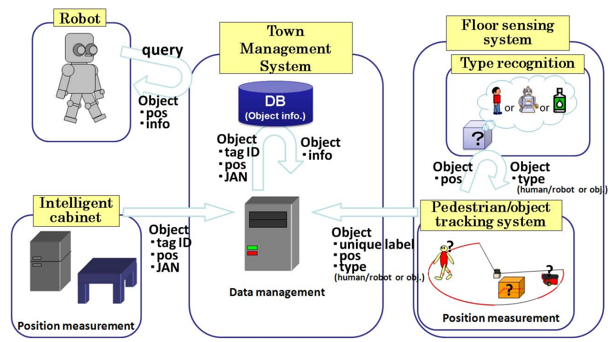


Fig. 2. Data flow of object tracking system.

A. Intelligent Cabinet

The intelligent cabinet recognizes the positions and attributes of objects stored in it. Objects are often placed closely to each other in the cabinet, therefore mutual occlusion of objects will often occur. A vision camera and a LRF are not suitable to the position measurement in the cabinet. In contrast, a loadcell and a RFID reader are not affected by occlusion. The loadcell measures the weight of objects on a shelf of the cabinet. The RFID reader recognizes a RFID tag with a radio wave. Therefore we use the loadcell and the RFID reader to develop the intelligent cabinet.

1) Design of Intelligent Cabinet: Four loadcells are installed to the bottom of an acrylic plate. The plate is supported by the four loadcells. The plate with loadcells are placed on a shelf of the cabinet. An object taken in and out of the cabinet is detected as the change of loads. The position of the object is also calculated from the outputs of the loadcells. The arrangement of four loadcells is shown in Fig. 3. Let the position of i th loadcell be $\vec{p}_i$. The weight of the object is the sum of the outputs of the four locadcells(eq. (1)).

$$f = f_1 + f_2 + f_3 + f_4 \tag{1}$$

The position $\vec{p}$ of the object on the plate is calculated as the center of gravity of the outputs of the loadcells (eq. (2)).

$$\vec{p} = \frac{f_1\vec{p}_1 + f_2\vec{p}_2 + f_3\vec{p}_3 + f_4\vec{p}_4}{f} \tag{2}$$

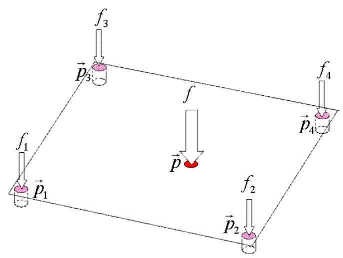


Fig. 3. Position measurement by using loadcells.

We use RFID to recognize attributes of objects. A RFID tag has a unique ID. By attaching RFID tags to the objects in an environment, the tag ID is used as the key to manage the positions and attributes of the objects in the data management system. The attributes such as name, weight, size are registered to the data management system in advance. The tag ID is used as the key for this registration.

The position of an object is related to its tag ID as follows. When an object is taken into the cabinet, its tag ID is newly recognized by the RFID reader. After the object is put on a shelf of the cabinet, the position of the object is calculated from the outputs of the loadcells. Finally its position is related to the tag ID which was previously recognized.

2) Intelligent Cabinet Implementation: The intelligent cabinet is shown in Fig.4. A rectangular RFID antenna is placed on a shelf of the cabinet. An acrylic plate with loadcells is placed over the RFID antenna. We used four loadcells(Measurement Specialties Inc., FC22), one RFID reader(TAKAYA Corp., TR3-LD003D-4), and one RFID antenna(TAKAYA Corp., TR3-SA101M). A passive RFID tag used is for the high frequency(HF) band at 13.56 MHz (Texas Instruments Incorporated: RI-I01-112A, ISO15693).

We conducted an experiment to measure the positions and attributes of objects in the intelligent cabinet. Three bottles with RFID tags were taken in and out of the cabinet (Fig. 5). The experimental result is shown in Figs. 6 to 7. Occlusion of bottles occurs in Fig. 6. Two bottles are piled and stuck in Fig. 7. In each figure, the right image shows the measured position and attributes. A green square indicates the position of a bottle. The bottle name as attribute is also shown near the square. The name was derived from the data management system by using the ID of the tag attached to the bottle. The measurement of the positions and attributes of objects is successfully demonstrated.

B. Floor Sensing System

The floor sensing system measures both the positions of humans walking in a room and the positions of objects on the floor. Moreover the system has to distinguish between objects and humans on the floor. We developed the floor sensing system by using a LRF and a pyroelectric sensor.

Fig. 4. Appearance of intelligent cabinet.

Fig. 5. Everyday objects with passive RFID tags.

1) Position Measurement of Objects using LRF: It is difficult to install many sensors densely on the floor which is spacious. A LRF has a wide sensing area, and it is robust against the lighting condition which is changed frequently in an everyday environment. Therefore we used a LRF for the position measurement on the floor.

The human/object tracking which uses a LRF, is performed in two steps: exclusion of stationary area in the range data, and then detection of blobs in the rest of the range data. These steps are implemented by using a simple background subtraction. Objects on the floor are identified in the range data out of stationary area by following procedures(Fig. 8).

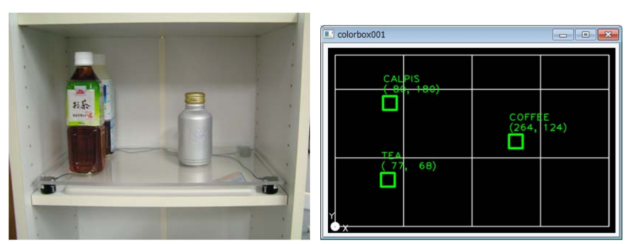


Fig. 6. Position measurement of objects.

Fig. 7. Position measurement of piled objects.

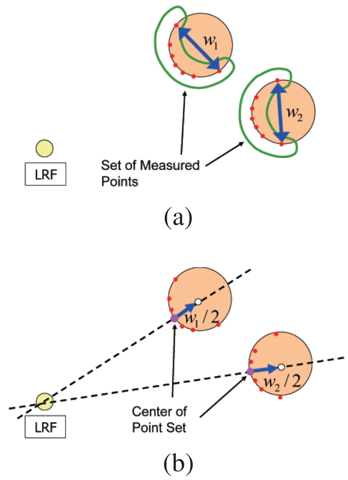


Fig. 8. Estimation of object position.

1) Points in the range data located within a certain threshold distance value are merged to be a profile of an object.
2) Width of a profile w is measured as the width of the object (Fig. 8(a)).
3) The center of the object profile is computed to be a point at distance $w/2$ on the extended line from the origin of LRF to the midpoint of the profile (Fig. 8(b)).

Tracking of a pedestrian is performed from a series of measured leg positions. Extracted legs are paired and tracked using the Kalman filter. The position of the human body is defined as the midpoint of the paired legs. The pair of legs has the following features.

1) Distance of the legs is shorter than a certain threshold value.
2) Traveling direction of the legs is almost the same.

The two legs satisfying these conditions in definite time period are paired. Consistent tracking of a pair of legs over a sequence of frames of range data is performed using the Kalman filter: the position of the paired legs in the next frame is estimated from the previous frames. Then the profiles of the paired legs are extracted in the range data of the next frame as the ones that are the closest to its estimated positions. Repeating the process, the legs are tracked. The Kalman filter is extended to use acceleration of the legs as the additional external input [12]. The acceleration of the leg is determined by using walking model(Fig. 9). In the model, the movement of the two legs is defined in four phases. The present phase is determined using past sequence of the velocity and acceleration of the leg. When the present phase is determined, the acceleration of the leg is determined accordingly.

We conducted an experiment to track two pedestrians. A LRF (Hokuyo Electronic Co. Ltd., UTM-30LX) was placed on the floor in an indoor environment of $6m \times 6m$. The system tracked the pedestrians by using the LRF. The tracking result is shown in Fig. 10. Two pedestrians are successfully tracked while they move along a different trajectory.

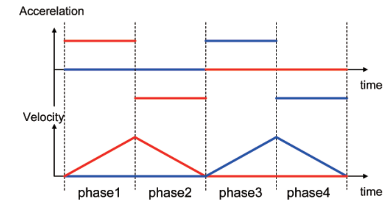


Fig. 9. Walking model (red : right leg, blue : left leg).

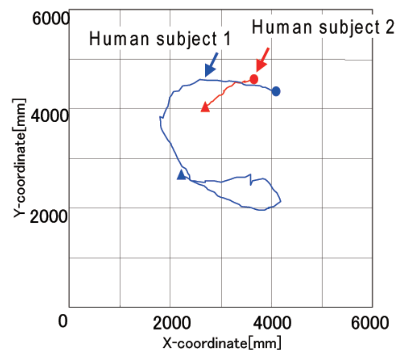
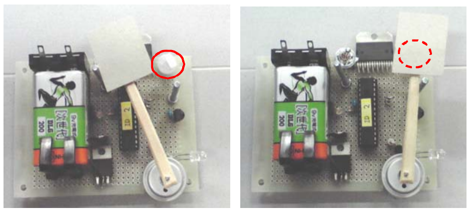


Fig. 10. Tracking result of two pedestrians.

2) distinction between pedestrian and object: The human/object tracking system can distinguish between humans and everyday objects if humans are walking. However if a human stands still, the system fails in this distinction. So we use a pyroelectric sensor to distinguish between a human and an object. This sensor detects changes of infrared radiation in its view area. The changes of infrared radiation occurs when something comes into the view area, because its temperature is different from the temperature of the background. The magnitude of the sensor output depends on the magnitude of the changes of infrared radiation. The temperatures of a human and an object are different. Therefore we can distinguish them by applying the threshold test to the sensor output.

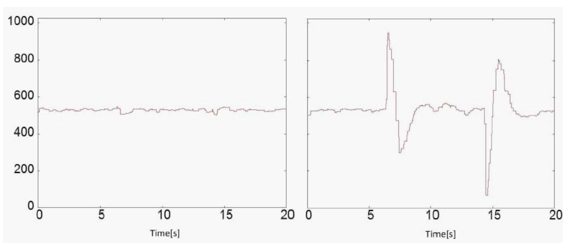
The pyroelectric sensor detects changes of infrared radiation at the current frame and infrared radiation in previous frames. If a human stands still, infrared radiation does not change. Then the sensor can not detect the human as changes of infrared radiation while the human does not move in the view area. We use a chopper to resolve this issue. This chopper masks a pyroelectric sensor periodically. When the sensor is unmasked, the sensor detects changes of infrared radiation even if the human does not move. The pyroelectric sensor unit with a chopper is shown in Fig. 11.

We conducted an experiment to distinguish between a human and an object. The pyroelectric sensor unit (Panasonic Corp, NaPiOn) [13] was installed to the ceiling. Fig. 12 shows the output of the sensor while each of them is in the sensing area. The vertical axis shows the sensor output. The horizontal axis shows elapsed time. The sensor is unmasked twice by a rotation of a chopper. In the case of the bottle, the output value is almost constant because its temperature is almost the same as the background. Thereofore when the position measurement system detects something new in the sensing area of the pyroelectric sensor unit, we can distinguish it by applying the threshold test.



(a) masked (b) unmasked

Fig. 11. Pyroelectric sensor unit with a chopper. A pyroelectric sensor is masked by a chopper in (a). The sensor is unmasked in (b).



(a) object (b) human

Fig. 12. Measurement result of a pyroelectric sensor unit with a chopper.

C. Town Management System : TMS

The position information measured by the intelligent cabinet and the floor sensing system is managed and robot interaction with the intelligent environment is ensured by Town Management System (TMS) as a data management system. TMS has the following functions:

1) Communication with robots and sensors embedded in an environment
2) Data storage, revision, and retrieval
3) Provision of the information related to the ID of a RFID tag attached to an object
4) Provision of the ID of a RFID tag related to specific data such as an object position and name

Network interface of TMS is implemented as Web service based on the Simple Object Access Protocol (SOAP). Then the adding of new sensors and the separating of installed sensors are easy. Database service of TMS is implemented by using MySQL. A tag ID is used for the key to update the position and attribute information of objects. Function programs we developed to enable robots and measurement systems to interact with TMS are provided in an application program interface (API) library. An example of API function is locating objects in the environment. Once the link to the API library is coded in a robot's control program, the robot obtains environment information from TMS by executing the API function at arbitrary timing.

D. Object Tracking System

When an object is taken out of an intelligent cabinet, the object is related to a person who is closest to the cabinet. The positions of pedestrians are tracked by the floor sensing system. It is difficult to directly track the small object carried by the person. However the object tracking system recognizes who has the tracked object by using the relation information between the object and the person. Therefore object tracking can be replaced by human tracking while the person carries it. TMS manages the position of the object held by the person as the position of the person. When the object is placed in the intelligent cabinet or is placed on the floor, the relation between the object and the person is released. The floor sensing system identifies the person who is closest to the object when the object is put on the floor. TMS has information of the object which the person held. Then the attributes of the object placed on the floor are recognized by using previously tracked information, though a RFID reader is not installed to the floor.

IV. Experiment

We conducted an experiment of tracking objects by the object tracking system which is composed of the intelligent cabinet, the floor sensing system and TMS.

A. Experimental setup

Three pieces of furniture were informationally structured. Loadcells and a RFID reader are installed to a box, this intelligent box measures the positions and tag IDs of objects stored in it. Loadcells are installed to a table, this intelligent table measures the positions of objects on it. A RFID reader is installed to a garbage can, this intelligent garbage can recognizes the tag IDs in it. We call them intelligent cabinets for the sake of convenience. The three intelligent cabinets and the floor sensing system were placed in an indoor environment. The arrangement of them is shown in Fig. 13. A laser range finder(Hokuyo Electronic Co. Ltd., UTM-30LX) was placed on the floor for the floor sensing system. Its scanning plane is parallel to the floor, and the height of the scanning plane is 60mm from the floor. Pyroelectric sensor units with a chopper were placed on the ceiling. The position information measured by the intelligent cabinets and the floor sensing system is integrated in TMS.

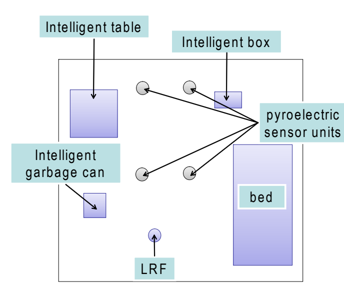


Fig. 13. Experimental setup.

Passive RFID tags are attached to all objects in the environment. A tag ID is used as the key to relate the attribute information with the position information of an object in TMS. The attribute information is registered to TMS in advance. The object tracking system is demonstrated after these preparations. We assume that the object tracking system will be used in a care house. So the preparations are made by care workers.

B. Object Tracking Result

In the experiment, the subject goes around in the environment. The subject handled two bottles. One of them was carried from the intelligent box onto the floor. The other was carried from the intelligent box onto the intelligent table. The positions of the bottles and the subject were tracked. The sequence of the experiment is as follows:

1) The subject moves to the front of the intelligent box.
2) The subject takes bottle A out of the intelligent box.
3) The subject carries bottle A.
4) The subject leaves bottle A on the floor.
5) The subject moves to the front of the intelligent box.
6) The subject takes bottle B out of the intelligent box.
7) The subject carries bottle B to the front of the intelligent table.
8) The subject puts bottle B on the intelligent table.

The tracking result is shown in Figs. 14 through 16. The yellow circle indicates the position of the subject. The purple circle and the blue circle indicate the positions of bottle A and bottle B respectively. bottle A and bottle B are shown as small circles while the subject carries them.

The system successfully tracks bottle A from the intelligent box onto the floor in Fig. 15. When bottle A is taken out of the intelligent box, it is related to the subject who has taken it. Object tracking can be replaced by human tracking while the subject carries it. When bottle A is put on the floor, its position is newly measured by the floor sensing system. The floor sensing system cannot recognize what the measured object is. However the floor sensing system identifies the subject who is closest to the object when the object is put on the floor. TMS has information of the object which the subject holds. Then the object is recognized as bottle A by using previously tracked information in TMS.

The system successfully tracks also bottle B from the intelligent box onto the intelligent table in a similar way in Fig. 16.

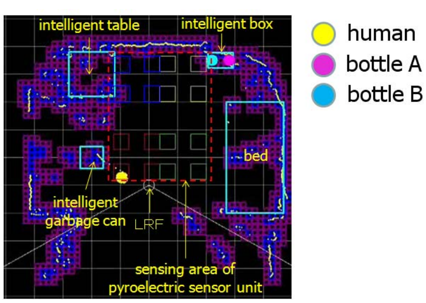


Fig. 14. Experimental result.

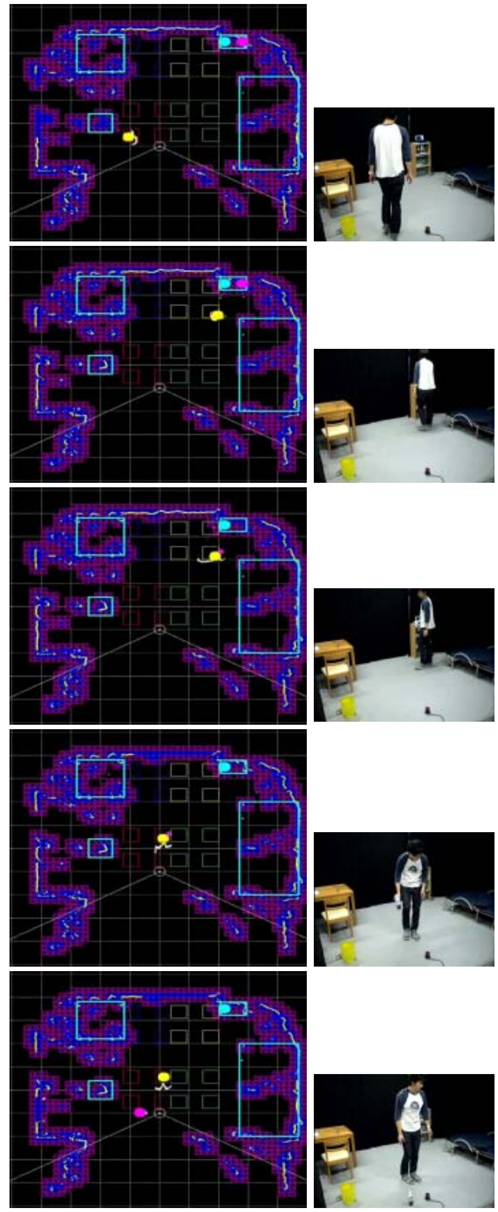


Fig. 15. Result of object tracking.

V. Conclusion

We developed the object tracking system. The system is composed of three components. The intelligent cabinet recognizes objects stored in it. The floor sensing system measures the position of an object on the floor and the position of a human walking in a room. TMS integrates the position data of the intelligent cabinet and the floor sensing system, and provides a robot with the position information. The object tracking system is successfully demonstrated.

If a person held several objects, the system cannot recognize which object was put on when the person put an object on the floor. In order to deal with this case, we will apply a probability model to the object tracking system in the future work.

This work is supported by NEDO (New Energy and Indus-

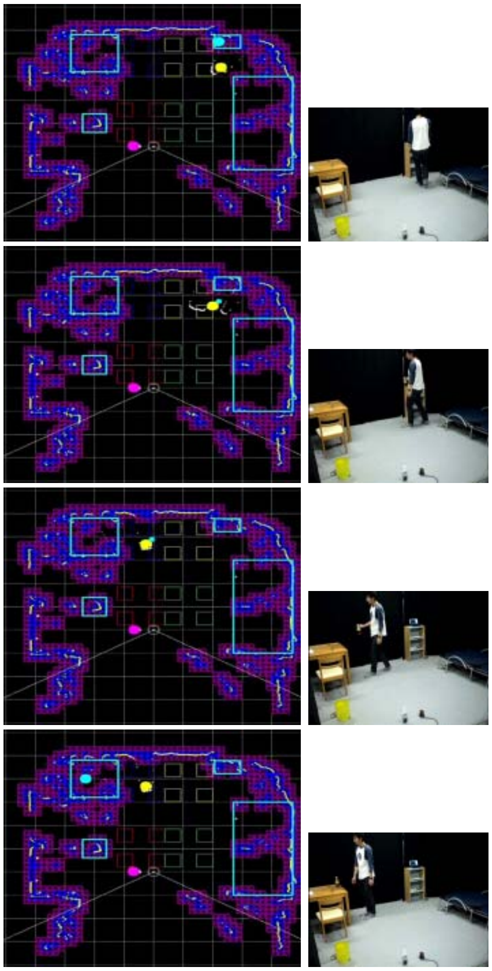


Fig. 16. Result of object tracking.

trial Technology Development Organization, Japan) project 'Intelligent RT Software Project'.

References

[1] Y. Nishida, T. Hori, T. Suehiro, and S. Hirai "Sensorized environment for self-communication based on observation of daily human behavior," *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp.1364-1372, 2000.

[2] J.H. Lee and H. Hashimoto, "Intelligent Space - concept and contents," *Advanced Robotics*, Vol.16, No.3, pp.265-280, 2002.

[3] Y. Nakauchi, K. Noguchi, P. Somwong, T. Matsubara, and A. Namatame, "Vivid Room: Human Intention Detection and Activity Support Environment for Ubiquitous Autonomy," *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp.773-778, 2003.

[4] K. Kogure, N. Hagita, Y. Sumi, N. Kuwahara, and H. Ishiguro, "Toward Ubiquitous Intelligent Robotics," *Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pp.1826-1831, 2003.

[5] C.D. Nugent, D.D. Finlay, P. Fiorini, Y. Tsumaki, and E. Prassler, "Home Automation as a Means of Independent Living," *IEEE Trans. Automation Science and Engineering*, Vol.5, No.1, pp.1-9, 2008.

[6] K. Murakami, T. Hasegawa, R. Kurazume, and Y. Kimuro, "A Structured Environment with Sensor Networks for Intelligent Robots," *Proc. of IEEE Int. Conf. on Sensors*, pp.705-708, 2008.

[7] K. Murakami, T. Hasegawa, R. Kurazume, and Y. Kimuro, "Supporting Robotic Activities in Informationally Structured Environment with Distributed Sensors and RFID Tags", Journal of Robotics and Mechatronics, Vol.21, No.4, pp.453-459, Aug. 2009

[8] R. Fukui, H. Morishita, T. Mori and T. Sato, "Development of a Home-use Automated Container Storage/Retrieval System", in Proceedings of IEEE International Conference on Intelligent Robots and Systems (IROS2008), pp.2875-2882, 2008.

[9] T. Deyle, H. Nguyen, M. Reynolds and C. Kemp, "RF Vision: RFID Receive Signal Strength Indicator (RSSI) Images for Sensor Fusion and Mobile Manipulation", in Proceedings of IEEE International Conference on Intelligent Robots and Systems , pp.5553-5560, 2009.

[10] Y. Nishida, H. Aizawa, T. Hori, N.H. Hoffman, T. Kanade and M. Kakikura, "3D Ultrasonic Tagging System for Observing Human Activity", in Proceedings of IEEE International Conference on Intelligent Robots and Systems, pp.785-791, 2003.

[11] T. Mori, T. Matsumoto, M. Shimosaka, H. Noguchi and T. Sato, "Multiple Persons Tracking with Data Fusion of Multiple Cameras and Floor Sensors Using Particle Filters", Workshop on Multi-camera and Multi-modal Sensor Fusion Algorithms and Applications (M2SFA2 2008), 2008.

[12] K.Nakamura, H.Zhao, and et al., "Tracking pedestrians using multiple single-row laser range scanners and its reliability evaluation", Systems and Computers in Japan, vol.37, no.7, pp.1-11, 2006.

[13] http://panasonic-denko.co.jp/ac/e/index.jsp