Position Tracking System for Commodities in an Indoor Environment

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***Abstract*— We propose an object tracking system for a service robot working in an everyday indoor 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 object tracking system is successfully demonstrated through experiments.**

I. Introduction

Daily life support work in a care house for elderly persons is a promissing 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. The position measurement of objects is necessary for this application.

Mori et al. [1] 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. [2] 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. [3] 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 [4]. 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.

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Many papers on the position tracking system have been written however they 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.

We propose an object tracking system which uses sensors embedded in 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 commodities

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. 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.

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. 1.

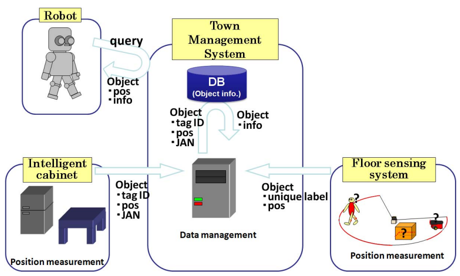

Fig. 1. Data flow of object tracking system.

A. Intelligent Cabinet

We use a loadcell and a RFID reader to develop the intelligent cabinet. The loadcell measures the weight of objects on a shelf of the cabinet. The RFID reader recognizes a RFID tag with a radio wave. Loadcells are installed to the bottom of an acrylic plate. The plate is supported by the loadcells. The plate with loadcells are placed on a shelf of the cabinet. The position of the object on the plate is calculated as the center of gravity of the outputs of the 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.

We developed the intelligent cabinet. 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. The experimental result is shown in Figs. 2 to 3. Occlusion of bottles occurs in Fig. 2. Two bottles are piled and stuck in Fig. 3. 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.

Fig. 2. Position measurement of objects.

Fig. 3. Position measurement of piled objects.

B. Floor Sensing System

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.

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.
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.

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 [5].

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. 4. Two pedestrians are successfully tracked while they move along a different trajectory.

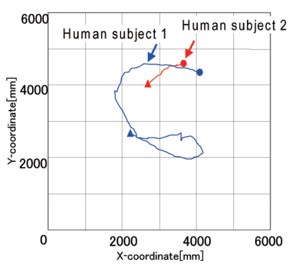

Fig. 4. Tracking result of two pedestrians.

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 intelligent cabinet can recognize the object which is placed in itself, because a RFID tag is attached to the object. In contrast, the floor sensing system can not recognize the object which is placed on the floor, because a RFID reader is not installed to the floor. However 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. When an object on the floor is picked up, the floor sensing system identifies the person who is closest to the object. The object is related to the person.

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. 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. The position information measured by the intelligent cabinets and the floor sensing system is integrated in TMS.

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. 5 and 6. 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. 6. 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.

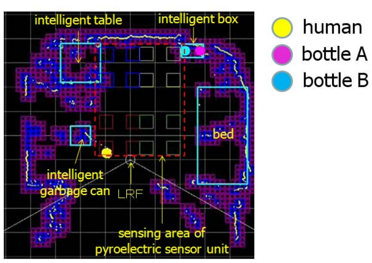

Fig. 5. Experimental result.

V. Conclusion

We developed the object tracking system in an indoor environment. 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 tracks objects. The object tracking system is successfully demonstrated in the experiment.

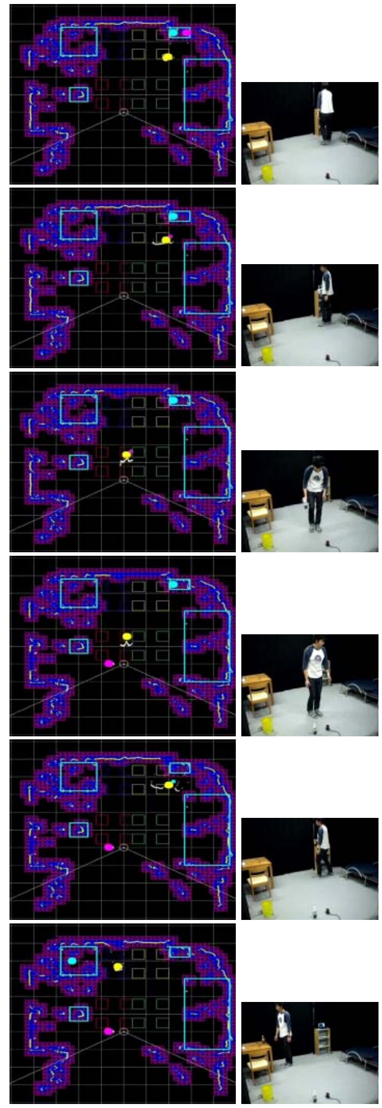

Fig. 6. Result of object tracking.

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