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Design of Ubiquitous Space for the Robotic Library System and Its Application

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Abstract: Visions of ubiquitous robotics and ambient intelligence involve distributing information, knowledge, computation over a wide range of servers and data storage devices located all over the world, and integrating tiny microprocessors, actuators, and sensors into everyday objects as well in order to make them smart. In this paper, we introduce our ongoing research effort aimed at realizing ambient intelligence in the ubiquitous robot technology space. For this, the ubiquitous space for the robotic library is introduced and an RFID technology based approach for the librarian robot is proposed.

1. INTRODUCTION

As technologies in the area of ubiquitous robotics, distributed computing and sensor network are evolving rapidly, the vision of ambient intelligence is positioning robot engineers' needs central to technology development. In the intelligent Systems Research Institute, National Institute of Advanced Industrial Science and Technology (AIST) in Japan where authors are working, We have been doing research on the knowledge distributed robot control system which connects distributed objects of physical space with the knowledge database of virtual space using an RFID tag as physical hyperlink (Miyazaki et al. [2004]). And also we have been developing a number of potential applications of ambient intelligence and the ubiquitous robot technology (u-RT) space (Ohara et al. [2005]) that interacts closely with human beings based on various sensors and the RFID technology. Recently there are two main issues in our research. The first is the ambient intelligence which provides information about human beings, robots, and objects using the embedded sensors in the daily living environments. The second is the robot middleware technology which is the basic software technology to connect robots and various module systems easily, to control the information flow, and to provide a variety of services. CORBA based RT Middleware (Ando et al. [2005]) and Web Services based Ubiquitous Function Services (Kim et al. [2005]) developed by AIST have been successfully applied as the middleware which defines and connects the hardware components of smart space and the software components to support these.

As one of the potential applications of ambient intelligence, we have designed and realized the robotic library system. The basic goal of the robotic library system is to arrange the books scattered on a table to the target place of the bookshelf as shown in Fig. 1. Hence, the robotic library system is composed of a mobile manipulator which has

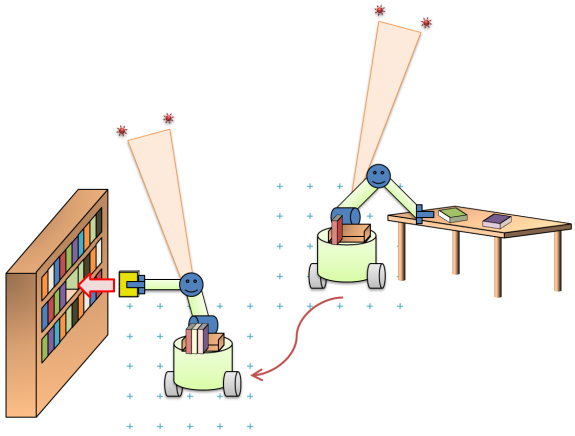


Fig. 1. The conceptual image of the proposed robotic library space.

ubiquitous functions to manipulate books, books which have RFID tags, the intelligent bookshelf which can recognize and localize books, the intelligent floor which provides the current robot position based on the passive RFID tags implanted under the floor, ambient localization sensors which enable the librarian robot to recognize the absolute position by itself, and the middleware which connects the whole system seamlessly. Various technologies related to the library robot system have been published in succession with this end in view. UJI librarian robot (del Pobil et al. [2005]), the robotic library system by CAPM project of the Johns Hopkins University (Suthakorn et al. [2002]), and the remote book browsing system (Tomizawa et al. [2002, 2003a,b]) are good examples. In our approach, we have applied the RFID technologies to the librarian robot system and designed and implemented *the Ubiquitous Robot Technology (u-RT) space* which has ambient intelligence. And we have developed a few kinds of ambient intelligent systems such as the intelligent table and the surveillance

system based on network cameras to support the proposed librarian robot. But, as a matter of fact, it is not so easy to build this kind of distributed system which has many kinds of sensors and actuators in the daily living environment, because of the complex network wiring and the complicated control programming. This is another issue of the proposed system. To cope with these problems, we have designed the proposed system using the network programming based on *RT Middleware* (Ando et al. [2005]) and *Web Services* (Kim et al. [2005]).

Section 2 illustrates the librarian robot system which has various ubiquitous functions and Section 3 illustrates the intelligent bookshelf developed based on the RFID technologies. Section 4 introduces u-RT space and the localization systems for the librarian robot, and then discusses a number of potential applications of ambient intelligence. Section 5 proposes the associated scenarios of the intelligent library space and shows the experimental results. Finally, Section 6 makes concluding remarks.

2. LIBRARIAN ROBOT SYSTEM

Fig. 2. The librarian robot system, the intelligent floor, and the intelligent bookshelf.

The librarian robot has a few essential devices for sensing and manipulation to pick up the book on a table, to recognize its information, and to arrange it into a bookshelf properly. Basically, the hand-eye vision system to recognize the books of the bookshelf and on the rack attached to the robot, the gripper and 7-DOF manipulator to reduce the interference of other books as much as possible by choosing the target book exactly, the force/torque sensor to measure the weight of a book and the force from the contact occurred when the robot picks up a book from the rack or place a book into the bookshelf, the the mobile platform to move from the current position toward to the bookshelf, the RFID tag based localization sensor to recognize the current position of the robot, and the RFID tag

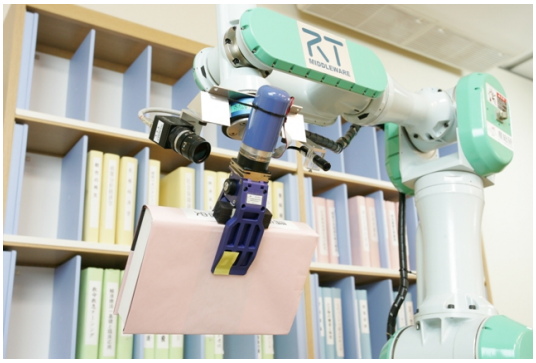


Fig. 3. The book handling.

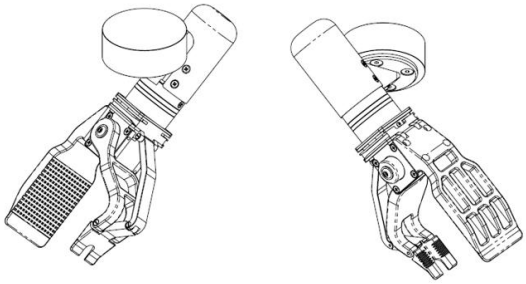


Fig. 4. Robot hand designed to handle a book.

Fig. 5. Image processing procesure using vision and laser.

reader to recognize the category and related information about the target book belong to these devices. Figure 2 shows the whole librarian robot system. As shown in this figure, the intelligent floor for the robot localization and the intelligent bookshelf for checking the book status are being connected to network based on the middleware and also supporting the librarian robot system.

Figure 3 shows the snapshot when the robot gripper handles a book. To place the book picked up from the rack into the bookshelf, the relative position between the book and the gripper should be maintained. For this, the robot gripper developed in AIST was used, which is shown in Fig. 4. Because the thickness and weight of the book are changed according to the book, the librarian robot system retrieves the physical information from the knowledge database using the RFID tag which the book has, and then it can decides the grip position and power using this information. And it is very important to recognize the exact target position to pick up the book from the rack. Hence, using the hand-eye vision and the laser installed on the gripper, the robot gets the image of the arranged books of the rack and then find out the target book position through the simple image processing as shown in Fig. 5. And also, because the exact manipulation without the fine force control is impossible, the robot system observes the force change using the force sensor attached on the gripper. Figure 6 shows the relationship among these sensors.

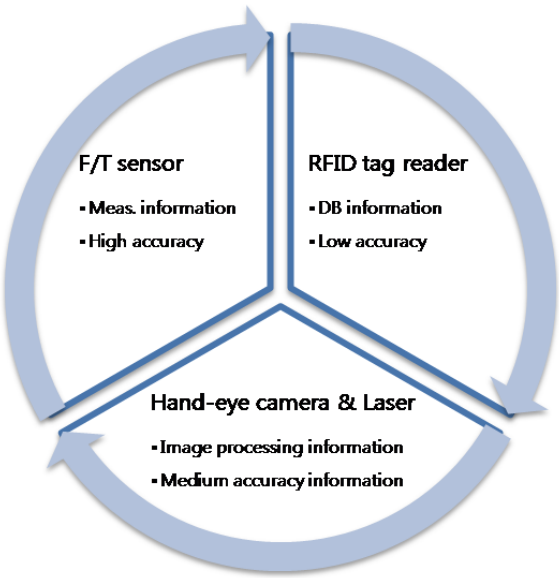


Fig. 6. The relationship among the sensors.

3. INTELLIGENT BOOKSHELF

To recognize all kinds of books and the position change of books in the bookshelf, the bookshelf has to be able to read the tag information which the books has, and using this it has to be able to retrieve the related information from the knowledge database or modify the status information of books. For this end, we have developed the intelligent bookshelf as shown in Fig. 7. As shown in this figure, the bookshelf has six RFID tag readers, where the RFID tag reader is shown in Fig. 7 (a). Hence it provides the slot based classified book information. Using this information, we can know the rough position of all books. Figure 8 shows a book with an RFID tag, where this tag information is used as physical hyperlink to access all the information on centralized or distributed data servers. We have realized the Web service function for this bookshelf and it can be used by other software component designed based on RT-Middleware.

As one of the examples, Fig. 9 shows the Web application for the intelligent bookshelf, which provides the current status of the intelligent bookshelf and sends email to the end user when some book is picked up or placed on.

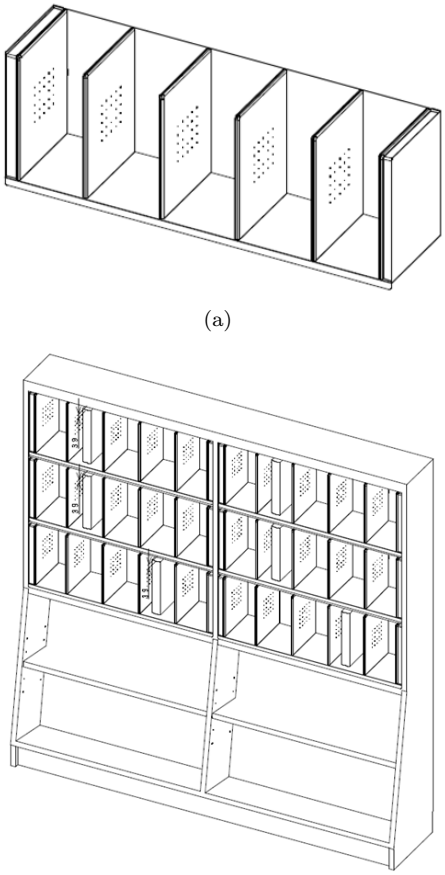
4. U-RT SPACE AND ROBOT LOCALIZATION

4.1 u-RT Space

Figure 10 shows the u-RT space for ubiquitous robots and ambient intelligence. We have developed a few kinds of intelligent systems for this space. The proposed intelligent bookshelf is one of these systems.

4.2 Physical Hyperlink : RFID Tags

In order for a robot to be able to perceive space and to recognize everyday objects, the information mediator which transmits the information about space and objects to the robot is required because the real living space and



(a)

(b)

Fig. 7. Intelligent bookshelf with RFID tag readers to sense the status of books. (a) Bookshelf RFID tag reader. (b) Overall structure.

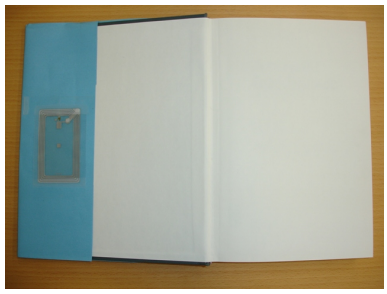


Fig. 8. A book with an RFID tag which gives the link information for a robot to access the Web DB.

objects have no computation and network access ability. This kind of information mediator should be implanted into spaces and objects in an invisible manner, and also should store and transmit the specific information. RFID tags have lately attracted considerable attention as the most proper mediator with this end in view. Using radio frequency, RFID tags can transmit ID and information, which are used for robots to perceive space and location, and also to access the information about objects. Hence, a series of information and knowledge are separately stored to objects and database in advance and the distributed information and knowledge are integrated through RFID tags when a new event is invoked. Each RFID tag has a native network address, which enables robots to access

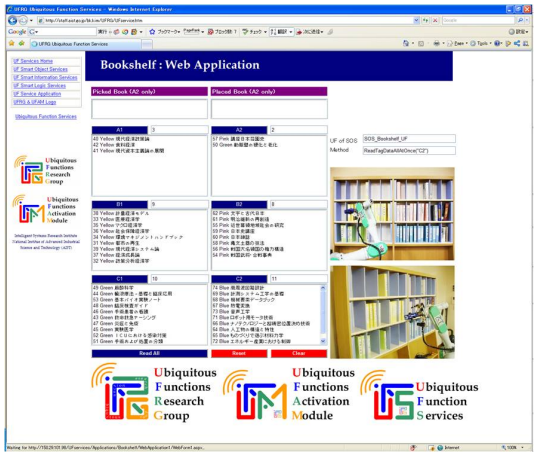


Fig. 9. Web application for the intelligent bookshelf.

Fig. 10. u-RT space with ambient intelligence.

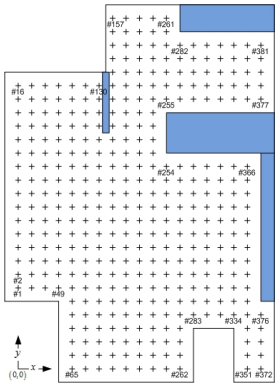
the object information through the network. As a result, this scheme allows robots to perceive space/location more easily and to handle objects more naturally, and also realizes ambient intelligence.

4.3 Ubiquitous Function Services

Networked robots will have greater sensory capabilities,more intelligence, higher levels of manual dexterity, and adequate mobility compared with humans. Hence, in order to control the networked robots with ambient intelligence and to realize various applications, it is essential to develop ubiquitous function services which enable robots to perceive spaces, to interact with everyday objects, and to learn about them in the everyday environment through the computer network. To meet the requisite of ubiquitous functions for networked robot systems with ambient intelligence, we are now developing the ubiquitous function services composed of smart object, smart logic, smart information, and smart discovery service to distribute knowledge flexibly and reliably to the dynamically changing environment, and also to actualize the ambient intelligence which allows robots to invoke and merge the distributed knowledge more freely.

4.4 Ambient Localization Systems

In order for a robot to navigate, a robot must build a map of its environment and then localize using this map. If the relative locations and the map information about the environment are given to the robot in real time, then



(a)

#	Tag ID	x	y
1	3843380000000C00	0	1.5
2	8A36380000000C00	0	1.75
3	4A23380000000C00	0	2
4	6D1C380000000C00	0	2.25
5	552A380000000C00	0	2.5
6	3327380000000C00	0	2.75
7	E532380000000C00	0	3
8	511B380000000C00	0	3.25
9	843B380000000C00	0	3.5
10	881C380000000C00	0	3.75
11	8031380000000C00	0	4
12	303A380000000C00	0	4.25
13	5823380000000C00	0	4.5
14	CC1E380000000C00	0	4.75
15	3E26380000000C00	0	5
16	6044380000000C00	0	5.25
17	8624380000000C00	0.25	1.5
18	7733380000000C00	0.25	1.75
19	4646380000000C00	0.25	2
20	0331380000000C00	0.25	2.25
...	.....	...	...
...	.....	...	...
...	.....	...	...
...	.....	...	...
375	CD3A380000000C00	4.5	0.75
376	8D1C380000000C00	4.5	1
377	0922380000000C00	4.5	5
378	3F2338000000C00	4.5	5.25
379	1242380000000C00	4.5	5.5
380	A538380000000C00	4.5	5.75
381	9623380000000C00	4.5	6

(b)

Fig. 11. Intelligent floor which has embedded RFID tags. (a) Map of the u-RT space. (b) Floor tag information DB.

this problem is fairly straightforward to solve. This means that if the information of real space is stored in the virtual space and networked robots can find the relative locations and the map information about the environment accessing directly the virtual space, then the localization problem can be easily solved. This approach, called informative space, relieves robots of many burdensome tasks involved in localization, path planning, and navigation by providing a simple, physical hyperlink to the information. Thus the system for the informative space stores information and knowledge in the network and associates IP address to the information and knowledge with the physical space. By linking the physical and virtual spaces, robots can easily perceive the environment and localize their position (Kim et al. [2006b,a]). We are now developing u-RT space using this concept based on the following systems.

1) Intelligent floor: About 400 pieces of RFID tags were implanted at 25cm intervals of each x and y axis in the floor for the reasonable localization and their ID and relative position data were stored into the virtual space as shown in Fig. 11. As a result, the networked robot can localize using the map of this space and the position information based on this map.

2) StarLITE: Figure 12 shows the StarLITE system used in the u-RT space (Chae et al. [2005]), which is used for the robot localization. This system consists of CCD board camera device which has a fisheye lens, a DSP image processing unit, an IR communication unit, and infrared beacons which is attached under the ceiling.

5. IMPLEMENTATION

We have built u-RT space with ambient intelligence. We have realized the intelligent bookshelf and the intelligent floor as potential applications of ambient intelligence using various kinds of sensor technologies. For the middleware of the proposed systems, we have used RT Middleware and Ubiquitous Function Services. Figure 13 shows the whole process of book arrangement by the librarian robot system.

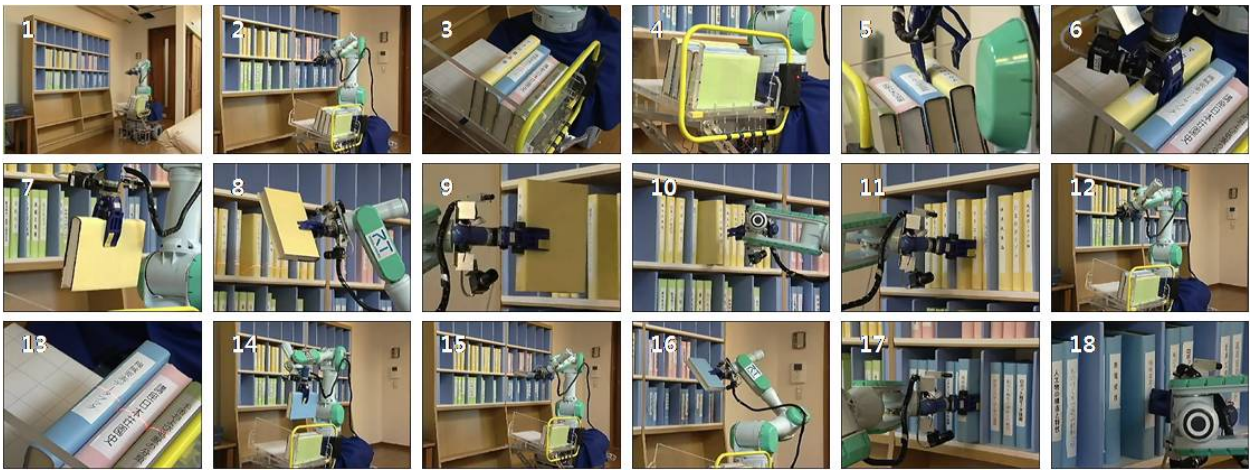


Fig. 13. The whole process of book arrangement.

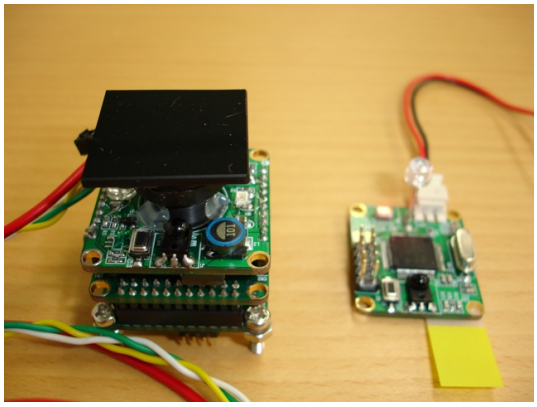


Fig. 12. StarLITE for the localization of the mobile robot, which consists of a vision device and infrared beacons.

6. CONCLUSION

In this paper, we have presented the robotic library system which consists of the ubiquitous mobile manipulator, the intelligent bookshelf, the intelligent floor system, ambient localization sensor, and the middleware which connects the whole system seamlessly. The control architecture for the whole system was illustrated and the experimental results have shown the feasibility of the proposed system.

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