Networked Robots in the Informative Spaces

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Abstract: In this paper, the informative space is proposed to implant ubiquitous functions into physical spaces. We merge physical and virtual spaces through the space structurization using an RFID system, and solve the space localization and mapping problem for a robot to navigate through the distribution and synthesis of information and knowledge. To distribute knowledge flexibly and reliably to changing environment and also to develop a system which allows a robot to invoke and merge the distributed knowledge more freely, we employ a novel approach of knowledge management based on Web services. The proposed method is verified by building a physical space with two kinds of RFID tags and a virtual space with knowledge database based on Web services.

Keywords: Informative space, Networked robot, Ubiquitous functions, RFID tag, Web services

1. Introduction

Ubiquitous computing brought about the paradigm change that the robot technology transforms itself to the technology for everything which includes a robot and object. The application of a robot is moving up rapidly to the unstructured environment such as an office from the typical structured environment such as a factory. As a result, the house management and the aged support service using an intelligent robot have become the most ideal robot technology which can be realized in the ubiquitous environment. But the real human living environment is too complicated to apply this ideal technology at once, and also there are still many difficult problems for a robot to understand the identity of every object which exists in the real world. Hence, the research which allows robots to localize themselves, to recognize the environment, and to get information about the target object simultaneously by structurizing human daily living environment and giving every object ubiquitous functions was emerged as a new issue of the recent robotics field. This technology aims to improve the intelligence of a robot and to realize the robot-human interface easily through the component based distributed computing service which supports the distribution and collection of knowledge and information based on wire/wireless network. Hence, it is essential in many applications to combine the information technology, which is for the creation of the ubiquitous environment by connecting every thing in physical spaces and merging virtual spaces, and the robot technology required in this environment. Ubiquitous computing will enable a robot to access various applications and provide a robot with many intelligent functions.

In this paper, we discuss the space structurization, called informative spaces, which implants ubiquitous functions into the space and propose the knowledge distributed system for the intelligent interaction among a robot, environment, and object. In order for a robot to be able to perceive space and to recognize the identity of an object, an information mediator which transmits the information about an object and space to a robot is required because the real living space and objects have no computation, network ability and also they can be changed as time passed. This kind of information mediator should be implanted into space and an object, and also should save and transmit the specific information. An RFID tag has lately attracted considerable attention as the most proper mediator with this end in view [1–7]. Using radio frequency, an RFID tag can transmit its ID and information, which are used for a robot to perceive space and location, and also to access the information about an object. As a result, the structurization of space is actualized through bridging physical and virtual worlds by implanting an information mediator, RFID tag, into physical spaces. Hence, RFID can structurize space, implant ubiquitous functions into objects, and enable a robot to perceive space/location and to handle objects more naturally. In this paper, we build informative spaces using two kinds of RFID tags and Web services, and then show the effectiveness of the proposed method using a networked robot with ubiquitous functions.

In what follows, we first introduce the networked robot with ubiquitous functions. We then present details of our informative spaces implementation based on Web services. Finally, we present experimental results illustrating the effectiveness of the proposed method based on RFID tags.

2. Networked Robots

The current robotics based on artificial intelligence and image processing technologies has reached the limit for ensuring robot working in the everyday environment because diverse objects make it extremely difficult to recognize the real world. But on the other hand, the ubiquitous computing which allows a thing of daily life intelligence and network ability is being realized. As a result, robot technologies are on the important turning point. It is because that the concept of ubiquitous robots which can work for a human being at any time, any place, connecting on the network and sensor net in the daily living space is being actualized. Thus, this section presents physical hyperlinks as a way to link the physical environment and objects with virtual Web resources, and then describes the ubiquitous functions control platform for the design and implementation of a networked robot system with ubiquitous functions.

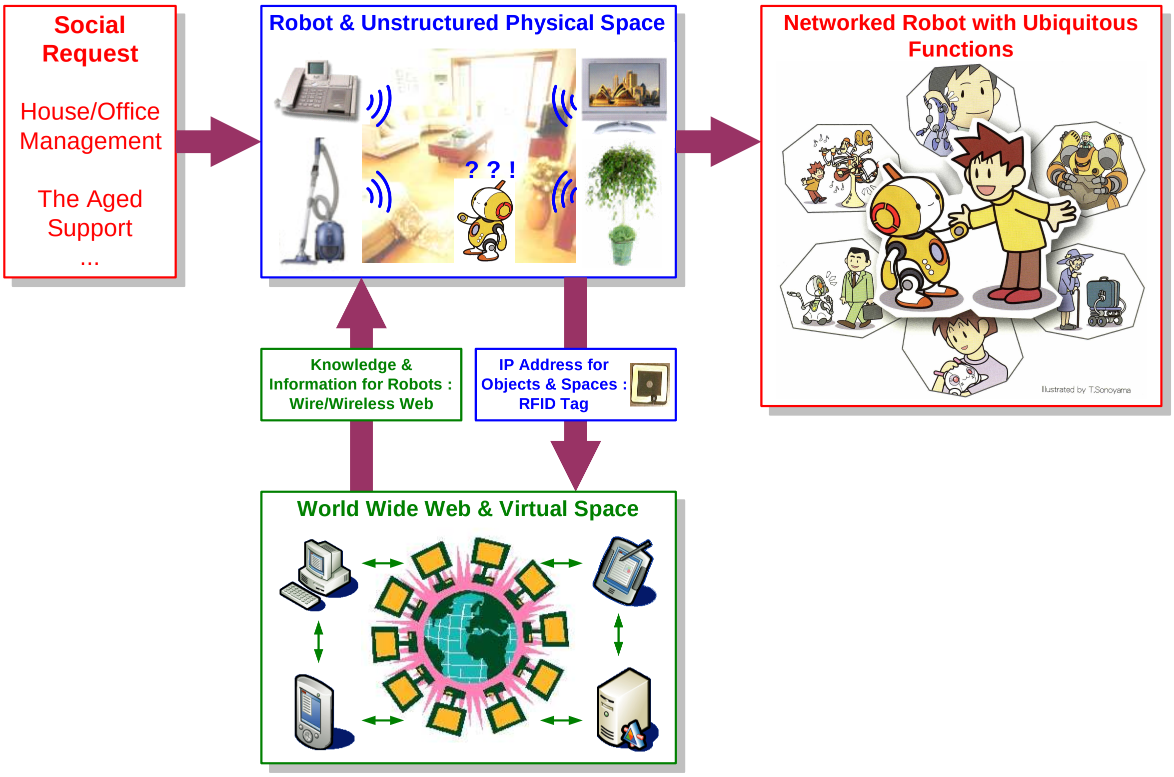


Fig. 1. Physical hyperlinks for networked robots with ubiquitous functions.

2.1. Knowledge Distributed Robot System

Social requests such as house/office management and the aged support using a robot are being highly increased. In order to meet these requests, we need to develop a robot which can interact with common objects and physical spaces. But our daily spaces and objects have no computation and network access ability. As a solution to this problem, robot technologies based on an RFID tag have been published in succession. The newest research about the knowledge distributed robot system is a good example [7–9]. This technology proposed the concept of ubiquitous functions of a robot in the knowledge distributed environment and the technology about the knowledge distribution itself. A series of information and knowledge are separately saved to an object and database in advance and the distributed information and knowledge are integrated through an RFID tag when a new event is invoked. Each RFID tag has a native network address, which enables a robot to access the object information through network. As a result, this scheme allows a robot to recognize objects and to perceive spaces more easily, and also allows the manufacturers to save the burden of programming.

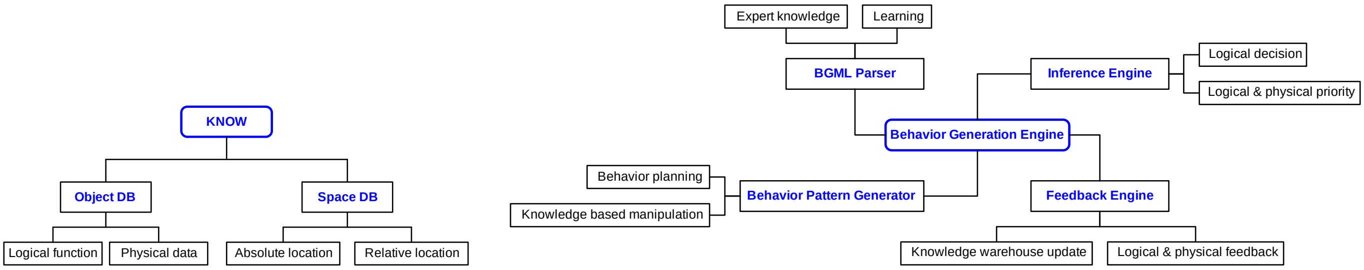
Figure 1 shows the whole architecture of knowledge distributed robot system. As shown in this figure, the environment can be structurized by physical hyperlinks from the physical spaces to virtual resources on the Web [10]. Human beings imagined that an intelligent robot which can keep house will be a high-tech product with mobility, the ability to grasp the situation, and very complex machinery. But, it is unnecessary to make an expensive and big robot housekeeper if the artificial intelligence and sensing ability can be distributed to surrounding environments.

2.2. Ubiquitous Functions Control Platform

Controlling an autonomous robot entails specifying how a robot is to react to perceptual input in order to accomplish a given goal. One of these specializations' key challenges is the creation of an autonomous robot that performs everyday activity in real world environments over extended periods of time. Everyday activity requires such a robot to accomplish complex routine jobs in changing environments where they face familiar but often not completely known situations. To ensure continuing utility, robots must manage their mission and execute them flexibly and reliably. Hence, there are two major issues that must be adequately addressed to develop a versatile and successful autonomous robot system. One, a robot should be able to perceive spaces. And two, a robot should be able to identify objects scattered in the human everyday environments more naturally and to understand their built-in features based on the interaction with them.

The information infrastructure that settled down in human daily life through the advancement of computer and network technologies is providing the social environment that allows a robot to interact with objects and to access new information at any time, any place. In this ubiquitous environment, a robot will grow as the advanced shape of a personal computer system, learn knowledge and information, and provide many applications which have various cultural, social, and educational contents.

A networked robot will have greater sensory capabilities, more intelligence, higher levels of manual dexterity, and adequate mobility compared with human beings. Hence, in order to control networked robots and to realize various applications, it is essential to develop a ubiquitous functions



(a)Knowledge oriented Web. (b)Behavior generation engine.

Fig. 2. Ubiquitous functions control platform.

control platform (UFCP) which enables a robot to perceive spaces, to interact with objects, and to learn about them in the everyday environment through networks.

To meet the requisite of ubiquitous functions for a networked robot system, the proposed UFCP consists of Knowledge Oriented Web (KNOW) and Behavior Generation Engine (BGE). KNOW is a kind of database system, which has the environment information as well as object knowledge. And BGE is the main control unit of UFCP, which uses the environment information to perceive spaces and the object knowledge to identify them and learns about their tangible and intangible features, and also generates intelligent behavior pattern through inference and feedback. Figure 2 shows the structure of KNOW and BGE, respectively.

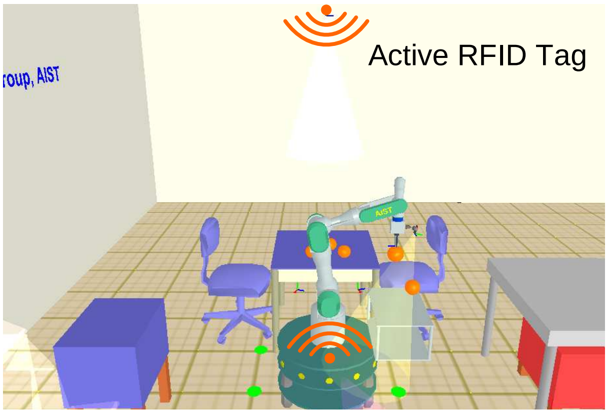
3. Informative Spaces

Now we continue with a discussion of the knowledge distribution method for physical spaces in detail. In this section, thus we first present our method for attaching information to spaces, and we then discuss the methods used for accessing information attached to spaces.

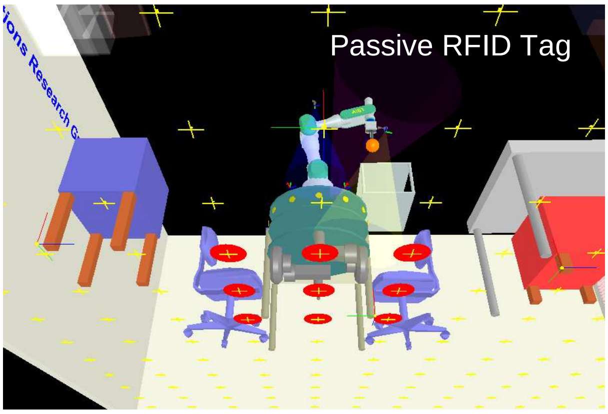
3.1. Physical Hyperlinks

The typical utilization of robots in the structured environment such as a factory has moved up to the unstructured environment such as home and office. Hence, the space structurization for bridging physical space and virtual space using virtual annotations or physical hyperlinks is prerequisite to the networked robot with ubiquitous functions. If every object in the daily environment could inform a robot of their position, it would be not so hard for a robot to move to the target position with the optimum path and to complete the given mission. The work ability of a robot makes a rapid progress in the ubiquitous residential environment which communicates with surrounding objects. This means that robots can understand the surrounding condition actively and manage their duty by themselves. As a result, in order for a robot to evolve into not a passive machine slave but an agent which can complete the given mission autonomously, it is essential to build the ubiquitous environment above all else.

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 a robot in real time, then this problem is fairly straightforward to solve. This means that if the



(a)Active RFID tag.



(b)Passive RFID tags.

Fig. 3. Informative space based on RFID tags.

information of real space is stored in the virtual space and a networked robot 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 spaces*, relieves a robot of many burdensome tasks involved in localization, path planning, and navigation by providing a simple, physical hyperlink to the information.

The system for informative spaces stores information and knowledge in the network and associates IP address to information and knowledge with the physical spaces. By linking the physical and virtual spaces, robots can easily perceive the environment and localize their position.

One location of physical spaces is fixed by the relative distance from the absolute location, and robots also can localize their exact position using these absolute location information and relative information. Thus a virtual space system needs two kinds of databases which store the absolute location information and the relative location information, respectively. Robots access each database using RFID tags which are different in style. Figure 3 shows a example of the proposed informative space that employs RFID tags. A robot can access the absolute location information about the room using an active RFID tag and the relative location information about one location in this room using passive RFID tags.

Actually, the present style building is very functionally designed. Especially, a library and art museum are easy to structurize because of the clearness of the use. The inside structure of these buildings is well known and there are clear differences of the use in each floor and each room. And also because database systems of books and works of art are already builded up, these buildings are the most suitable place for the informative space of networked robots. Hence these kinds of buildings which can be easily structurized are the target applications of this paper.

3.2. Web Services for virtual spaces

Everyday activity requires a robot to accomplish complex routine jobs in changing environments where they face familiar but often not completely known situations. To ensure continuing utility, a robot must manage the missions and execute them flexibly and reliably. Hence, we need a system which links physical and virtual spaces organically, and manages this efficiently. For this, we propose Web services based on the recent Internet technologies like XML, SOAP, WSDL, UDDI. A Web service is a software interface that describes a collection of operations that can be accessed over the network through standardized XML messaging. It uses protocols based on the XML language to describe an operation to execute or data to exchange with another Web service. A group of Web services interacting together in this manner defines a particular Web service application in a service oriented architecture (SOA).

Web services use XML that can describe any and all data in a truly platform-independent manner for exchange across systems, thus moving towards loosely-coupled applications. Furthermore, Web services can function on a more abstract level that can reevaluate, modify or handle data types dynamically on demand. So, on a technical level, Web services can handle data much easier and allow software to communicate more freely. At the most recent step, Web services have moved towards the concept of XML-defined interfaces and communications, finally uniting any kind of application with another, as well as providing the freedom to change and evolve over time, as long as they are designed to the appropriate interface. The versatility of XML is what makes Web services different from previous generation component technologies. It allows the separation of grammatical structure (syntax) and the grammatical meaning (semantics), and how that is processed and understood by each service and the environment it exists in. So now, objects can be defined as services, communicating with other services in XML-defined grammar, whereby each service then translates and analyzes the message according to its local implementation and environment. Thus a networked application can truly be composed of multiple entities of various makes and designs as long as they conform to the rules defined by their service oriented architecture.

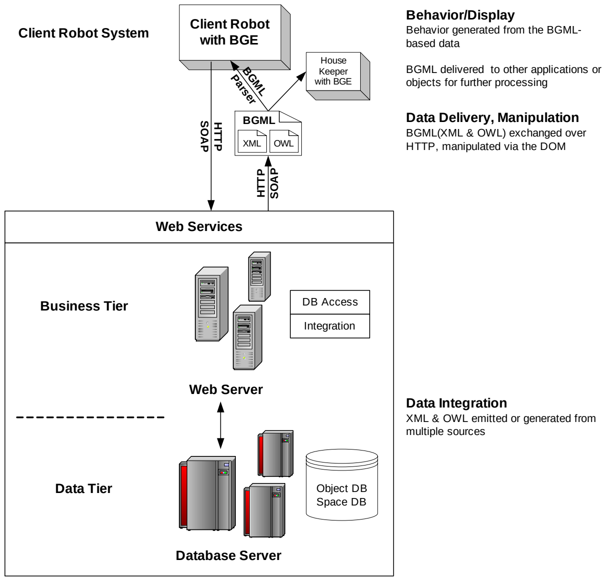


Fig. 4. KNOW framework with Web services.

3.3. KNOW for Informative Spaces

Figure 4 shows a generic architecture for Web services in the KNOW framework. The architecture of Web services is divided into two logical tiers. Furthest from the client robot system is the *data tier*, which stores information required by the Web service. Above the data tier is the business tier, which implements the business logic of the Web service. It is often subdivided into three parts: the *data access*, the *business facade*, and the *business logic*. The data access presents a logical view of the physical data to the business facade and the business logic. The data access isolates business logic from changes to the underlying data stores and ensures the integrity of the data. The business facade provides a simple interface that maps directly to operations exposed by the Web services. The business facade uses services provided by the business logic.

In the proposed UFCP framework, an application is constructed from multiple peer Web services that work together to provide data and services for the application. Figure 5 shows the whole system interface of the UFCP for the knowledge distributed robot system. As in this figure, KNOW includes application specific Web services, object data specific Web services, and space specific Web services, which work together through HTTP/SOAP. Application specific Web services provide application logic which a robot needs to manipulate the target object properly. Object data specific Web services provide physical data for the manipulation of the target object. Space specific Web services provide the absolute and relative location information about the space.

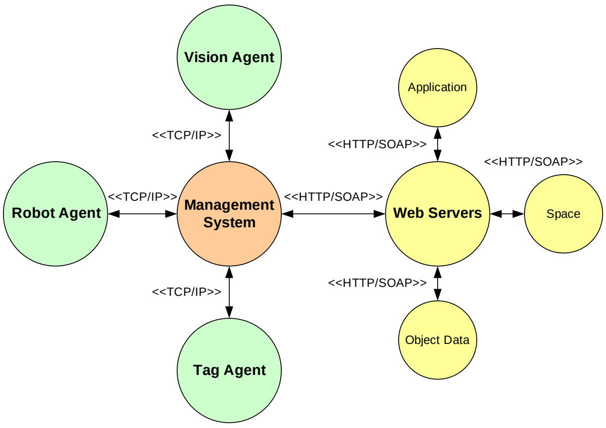


Fig. 5. UFCP architecture.

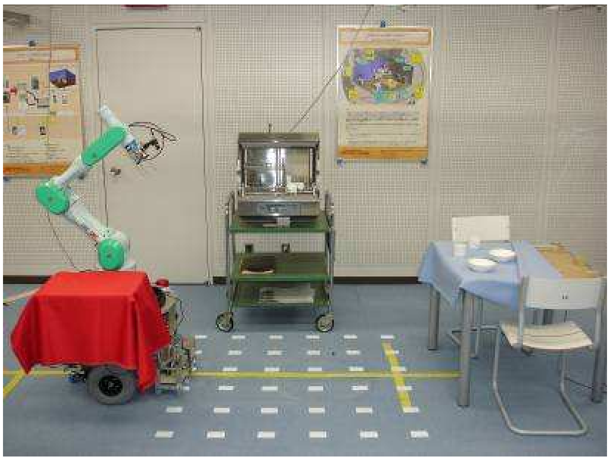


Fig. 6. Networked robot in the informative space.

(a)Ubiquitous functions activate module (active).

(b)RFID tag and reader (passive).

Fig. 7. Two kinds of RFID tags for the informative space.

Table 1. Specification of the UFAM.

CPU	PIC16F627A
Clock	4MHz
Trans./Recept. IC	TA32305FN
Baud rate(TX/RX)	9600bps
I/O Device	Switch, LED
Free I/O port	I/O(5bit)
Battery	3V(Button Type)

4. Experiments

We have implemented an RFID tag based system embodying the concept of the informative spaces. Figure 6 shows the experimental test bed for the networked robot with ubiquitous functions in the informative space. This robot system is composed of a tag agent for localization and object recognition, a vision agent for object localization, a robot agent for object handling, Web servers for applications, object data, space information, and a management system for the control of the whole system.

To link the physical space and virtual space, we implemented physical hyperlinks using two kinds of RFID tags. Figure 7 (a) shows the active type of RFID tag, called *ubiquitous functions activate module* (UFAM), which is used to access the Web services for the absolute location information of the test place [6]. Hence the networked robot can download the map of the test room using this RFID tag. Table 1 shows the specifications of this module. Figure 7 (b) shows the passive type of RFID tags implanted under the floor and tag reader equipped under the bottom of the networked robot. This RFID system is used for the relative location information of the test place. Every tag was implanted at 25cm intervals in the floor for the reasonable localization and their ID and relative location data were stored into the space specific Web services. As a result, the networked robot can localize using the map of the test room and the location information relative to this map.

If the mission is to clean off the dining table shown in Fig. 6, the sequence of information management controlled by the networked robot is described as follows:

1. The user orders the task of cleaning the table to the networked robot.
2. The active tag system of the networked robot communicates with the active tag system of the informative space and the passive tag system reads the current information of the floor tags.
3. The active tag offers ID, URL, and user information of the test room and the passive tags offer ID, URL, and user information of the relative location.
4. The networked robot retrieves necessary knowledge from the data source provided by Web services.

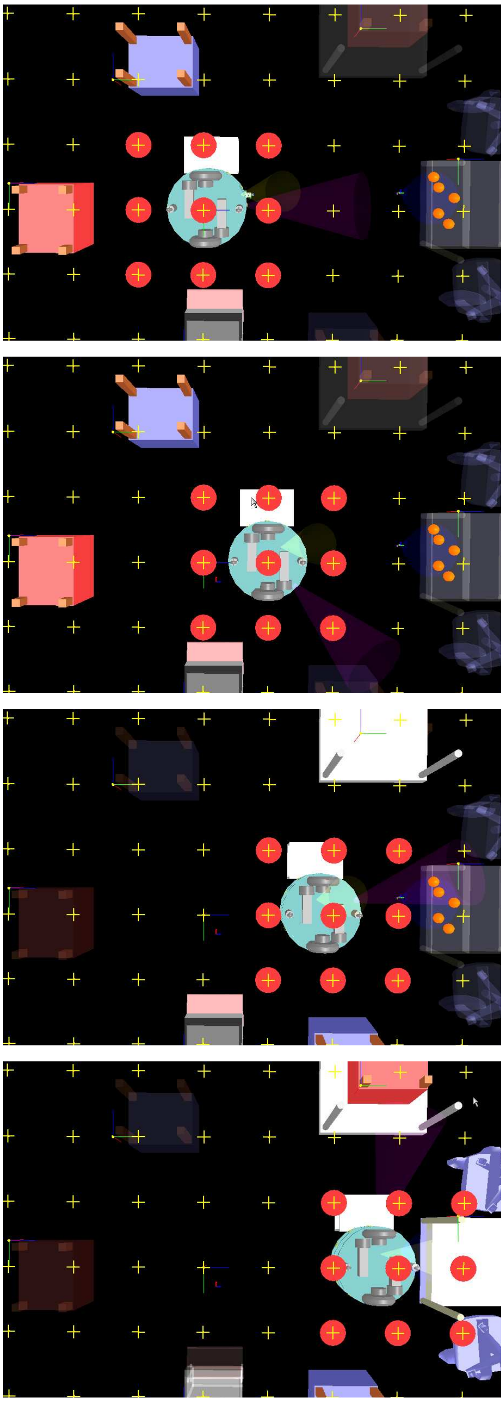


Fig. 8. Localization of the networked robot.

5. The networked robot localizes the current position and composes the path to navigate to the target position.
6. The networked robot navigates to the target position and compensates the path following error continuously using the information from the informative space.
7. If the networked robot arrives at the target position, the robot carries out the given task.

Figure 8 shows the trace of the networked robot when this mission was given. In this figure, the nine red circles means that the RFID tags around the robot are activated by the tag reader. In this manner, the networked robot can localize and navigate to the target position.

5. Conclusion

We have proposed the physical hyperlinks based on RFID tags as a way to link the physical environment and objects with virtual Web resources. In order to relieve a robot of many burdensome tasks involved in localization, path planning, and navigation, we have proposed the informative space and actually built the informative space which consists of the physical space based on the active type of RFID tag called ubiquitous functions activate module (UFAM) and passive type of RFID tags, and the virtual space based on Web services which provide application, object data, and space specific services. Through the experiment in this space, we have shown the feasibility that a networked robot with ubiquitous functions can evolve into an autonomous agent in the proposed informative space.

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