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Robots on Self-Organizing Knowledge Networks

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Abstract

In this work, we propose a new framework for better deployment and utilization of robots in our uncertain, unstructured everyday environments. Programming robots can be a very time-consuming process and seems almost impossible for ordinary end users. To cope with many challenges in the user programming, this work is to provide an open environment for building robot programming automatically, where we have robots learn how to accomplish commanded tasks interacting with the object. An integrated sensing and computing tag is embedded into every single object in the environment. In the robot controller, only the basic software libraries for low-level robot motion control are provided by the robot manufacturer. The main contributions of this work is to develop the knowledge integrator platform that we call Omniscient Organizer that generates the application programs and send them to the robot controller through networks. In the Omniscient Organizer, the object-related information downloaded from the object web server merges into robot control software based on the task commands from the human. We have built a test bed and demonstrated that a robot can perform common household tasks such as clearing the table within the proposed framework.

1 Introduction

Controlling a robot is not as easy as we think, particularly if the robot is deployed in complex, unstructured environments. Currently, a massive amount of knowledge about the environment and high-level intelligence has to be centralized in the robot controller and also programmed in detail to have robots perform commanded tasks even in well-known environments. Programming robots has proven to be quite an experience and seems almost impossible for ordinary end users. We approach the problem of programming robots from the point of view of task-oriented integration of distributed knowledge. For this, we build perception-rich environments from which the robot extracts and collects useful information easily. An integrated sensing and computing tag is embedded into every single object in the environment. This is quite similar to bar codes printed on products. However, besides the serial number of the object, the tag includes task-related information such as the geometric and physical data, built-in features, and operation constraints and user manual of the object in order to handle the object properly. Such information will be provided by the object to robots whenever requested. Specifically, we expect each of the manufacturers to input all the information about their product when it is manufactured. By doing so, the end user will not need to provide environmental data beforehand into the robot controller.

An architecture for knowledge-based object registration was similarly proposed in computer vision [2], [3]. The features of the environments embed themselves in every entity, allowing robots to easily identify and manipulate unknown objects. We proposed a new paradigm of the interaction through radio frequency identification (RFID) to control and activate tag-embedded home appliances [7]. This paper proposes a framework for knowledge networking and integration that enables easy deployment of robot systems into our everyday environments without detailed knowledge of robot programming. We have built a test bed and demonstrated that a robot can perform common household tasks such as clearing the table within

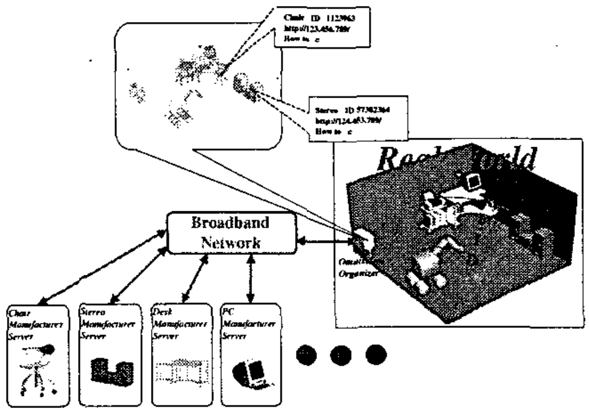

Figure 1: A proposed framework for knowledge acquisition and integration networking.

the proposed framework. This work mainly describes the logical architecture of the proposed distributed knowledge system and the physical components that comprise our test bed followed by an ongoing implementation.

2 Knowledge Networks

Normally a robot's behavior is generated by end user programming integrating diverse information about any particular environment that the robot might face. We have been trying to centralize and manage all the knowledge about robots' environments in their controller. Thus, programming robots can be a very time-consuming process and seems almost impossible for ordinary end users. Better management of environment knowledge will lead to an easy-to-program robot system. This work addresses how to allocate individual information resources and integrate them through knowledge networking as shown in Fig. 1. Knowledge networking focuses on the integration of knowledge from different sources. Achieving such networking requires re-structuring functionalities in creating and using knowledge.

2.1 Knowledge creation

So far, end users have been trying to create and/or collect all the knowledge about objects in robots' environments to build task programs. No one doubts that each of the object manufacturers can create knowledge and that is the best available. Once knowledge is created, it can be kept up-to-date and optimized based on experience feedback sent by the end users.

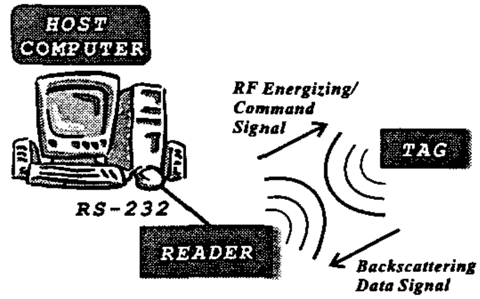

Figure 2: Radio frequency identification.

2.2 Knowledge storage

An end user centered knowledge base has been used to store all knowledge acquired from the environments. However, thanks to recent advances in information and communication technology, efficient storage and retrieval of data and information became possible. Therefore, each of the product manufacturers can maintain their own database server on the network that provides up-to-date knowledge of product features and the latest user manual.

2.3 Knowledge integration

Knowledge integration mainly concerns interaction between new and prior knowledge in a knowledge base [15]. By uniquely identifying objects in the environments and locating the object's data and information over the network, diversely distributed knowledge is easily incorporated into the knowledge integrator platform and robot task programs can be generated automatically.

3 Omniscient Spaces Through RFID

In highly informative, perception-rich environments that we call Omniscient Spaces, robots interact with physical objects which in turn afford robots useful information. "Omniscient" literally means "knowing everything." Thus, in Omniscient Spaces, every objects are known to robots. However, we do not provide robots with any information about their environments directly. In robot programming, environment modeling always becomes a troublesome issue requiring very time-consuming efforts. In Omniscient Spaces, a source of information is the object or environment itself. Any information can be collected through mutual interaction between the robot and the object and seamlessly converted into a robot data. This work is to provide an open environment for building robot application programs automatically, where we have robot learn how to accomplish a commanded task interacting with the object. To achieve this, we need to make sure the object in our environments is ready to provide useful information. An integrated sensing and computing tag is embedded into every single object in Omniscient Spaces.

Specifically, we employ passive RFID systems to collect information from the environments [6], [10], [16]. Passive RFID systems generally consist of three components, namely a reader, passive tag, and host computer as shown in Fig. 2. Using radio frequency waves, the reader transmits a signal to activate a passive tag. The tag, in turn, transmits encoded data back to the reader, which acknowledges and logs the signal via the host computer. The tag has read-write capabilities, enabling its data to be modified remotely, as necessary. The encoded information is decoded by the reader's on-board micro-controller [14].

Despite the many advantages of the RFID systems, one of the shortcomings is that they are not able to exactly localize tagged objects. A variety of techniques have been used to locate objects and people indoors [5], [17], [19]. Especially, in inductively coupled RFID systems, if the measuring point of radio signal is moved away from the signal source, the strength will decrease. We proposed that a robot equipped with RFID reader can identify a tag within its read range and measure multiple signal strength samples of the tag with changing the robot positions. Then, from the known path of electromagnetic field strength, the distance of each sample data can be estimated. Given a set of distance samples, the robot can triangulate the positions and orientations of tagged objects [8], [11]. Such an RFID system is currently under development by the authors. To be sure, RFID systems that provide exact localization capability are not yet available, thus a simple vision system is incorporated in this work.

4 Test bed

We have built a test bed as shown in Fig. 3 to verify our proposed concept. As a common household task, clearing the dinning table is considered. A set of dishes and bowls is brought in and set on the table. A robot is commanded to clear the table. Currently object web servers and control systems for RFID data acquisition, vision recognition and positioning, and the robot agent are connected to a Fast Ethernet network, which is to be replaced by a radio transmission where appropriate.

Table 1: Reader specifications in the experiments.

Function	Reader/writer
Communication protocol	ISO 15693-2 26 kbps
Operating frequency	13.56 MHz
Host interface	RS232C or RS422A 9.6 kbps
Read range	up to 40 cm
Power requirements	AC 100V, 0.1A
Power consumption	10W
Dimensions [mm]	200 × 172 × 40
Operating temp [$^\circ C$]	-10 to 50
Operating humidity [$\%RH$]	5 to 95

4.1 RFID system

Each of the objects is tagged as shown in Fig. 5. A film-type tag of 35mm × 35mm in size and 2Kbit memory is attached [4]. The dinning table is equipped with a set of RFID reader/writer as shown in Fig. 4. Detailed specifications of RFID system are given in Table 1 [4]. This reader/writer is connected to the host PC running Linux via RS-232C serial communication.

4.2 Object web server

Detailed information about the object is stored in each of the object knowledge servers on the network that consists of PCs running Linux and the open, real-time embedded systems platform μT-Engine [18]. They have template images of each object.

4.3 Vision system

A ceiling mounted CCD camera is used to get the correct positions of the objects on the table. The Hitachi IP5000, a fast image processing system on a half-size PCI board, is inserted into the controller PC running Linux to connect an NTSC camera and video output monitor. The board is equipped with 40 video memories of 512 × 512 pixels and provides plenty of fast image processing functions in hardware

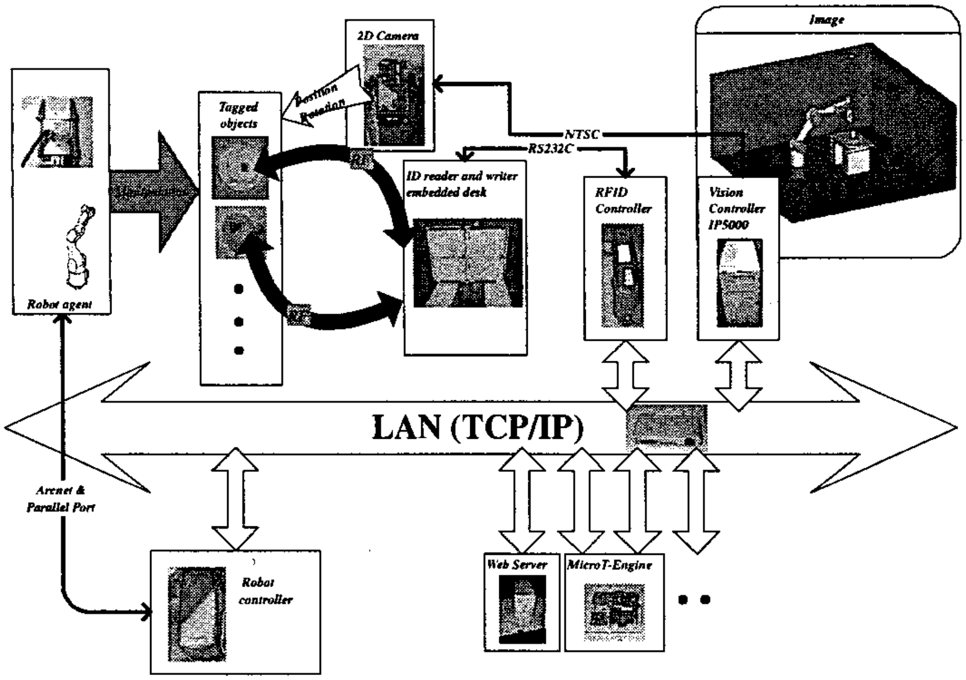

Figure 3: An experimental testbed.

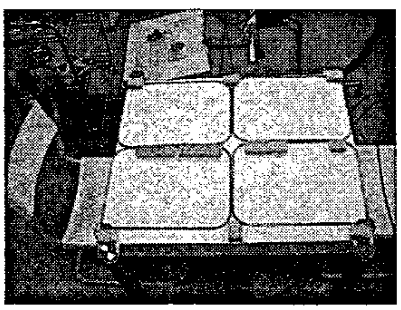

Figure 4: An RF reader/writer embedded table.

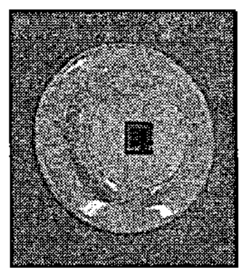

Figure 5: A tagged dish.

[12]. Specifically, the least square algorithm is incorporated in the Direct Linear Transformation method [1] in camera calibration (Fig. 6).

4.4 Robot agent

A Mitsubishi PA-10 robot is controlled by the motion control CPU board in the robot controller PC running Windows XP. The motion control CPU board and the servo driver are communicated at a control frequency of 2msec through the high-speed serial communication ARCNET. The Takano Bearing Model RH707 is attached as an end-effector and connected to the same controller PC through parallel digital I/O.

5 Experiments

Fig. 7 illustrates the knowledge acquisition from the environments and integration process at the knowledge integrator platform Omniscient Organizer implemented in EusLisp [9]. EusLisp is an object-oriented Lisp-based programming system designed

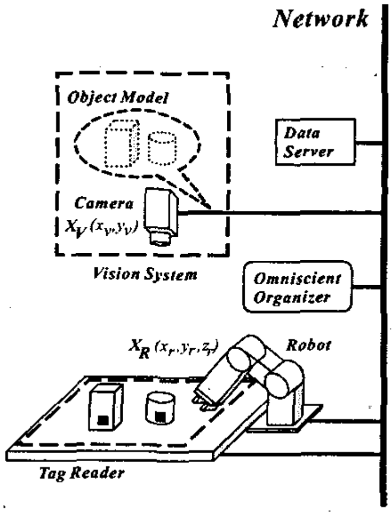

Figure 6: A vision-based positioning system.

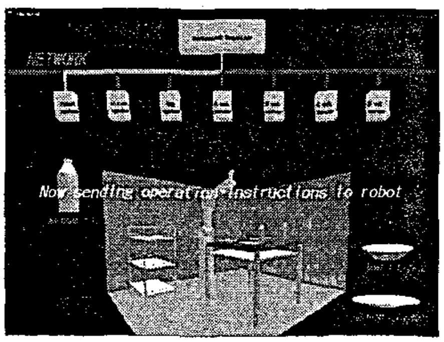

Figure 7: Omniscient organizer.

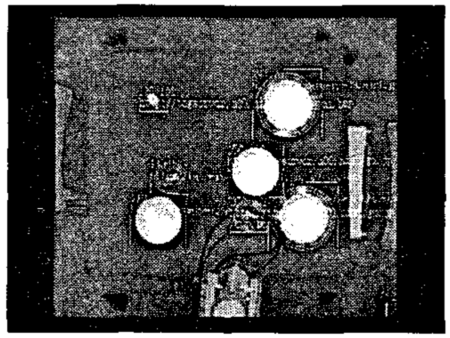

Figure 8: A Tag-based vision system.

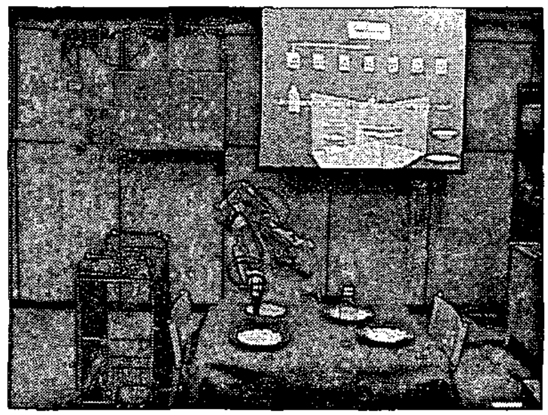

Figure 9: A look at experimental scenes.

specifically for the development of robotics software. Our current task is to have a serving robot take objects on the table to the wagon. The robot needs to know proper grasping positions of the objects and approaching configurations to pick them up. Once the command is given, the Omniscient Organizer generates the list of objects first communicating with a set of built-in RFID readers under the table. If an object is identified, the Omniscient Organizer will receive the address of URL of the object server from the RFID system. An object's tag acts as a pointer to storage locations for data and information about that object. For instance, dish makers tag product features and manipulation manual to their dishes. Then, the Omniscient Organizer downloads necessary information off corresponding object server and request information about the position of the object to the vision system. The vision system detects the position of objects [13] using the prestored template images and sends the Omniscient Organizer the transformed position data with respect to the robot coordinate system. Fig. 8 illustrates the object positions with URL addresses affixed. Omniscient Organizer finally builds detailed motion planning data based on the position information and manipulation knowledge, and sends grasping position and orientation data to the robot. This process will generate robot programming automatically and make the robot perform a commanded task (Fig. 9).

Detailed information provided includes the height of the grasping point, the deviation from the center of dishes, the orientation of the robot end-effector. Such an instructive knowledge merged into the robot control software to run built-in programs in the robot controller. Once the target position and orientation was given from the Omniscient organizer, the robot system approached the dishes and bowls with optimal grasping configurations. The robot then moved them to the wagon and separated and positioned them properly. It is noted that the RFID system increased the accuracy and speed of recognition of the vision system. For instance, many of the objects on the table were perceived as having the same shape. However, the data of tag allowed the Omniscient Organizer to generate different robot behaviors and the robot could separate sets of dishes properly.

6 Conclusions

Programming robots has proven to be difficult, particularly if the robots are deployed in complex, unstructured environments such as our everyday environments. We approached the problem of programming robots from the point of view of task-oriented integration of distributed knowledge. To achieve this goal, we have proposed Omniscient Spaces based on environmental intelligence and knowledge networking. End users will be relieved of the burdens of complex robot programming challenges through the proposed approach, which emphasizes the necessity of keeping the knowledge about the object and environment distributed and communicated whenever requested. This work explored innovative ways to allow for the realistic deployment of current robot systems, especially into man-made unstructured environments with minimal robot programming efforts. The test bed will support future implementations of household robotization.

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