Multi-Agent Interface Architecture for Human-Robot Cooperation

Yasushi Nakauchi  Toyoshi Okada  Nobuyuki Yamasaki  Yuichiro Anzai

Department of Computer Science
Keio University
Yokohama 223 Japan

Abstract

One of the important factors to substantialize robots is mutual cooperation among human and robots. In order to support human cooperative work based on asynchronous communication, we had developed a groupware toolkit Michele[9]. In this paper we propose a multi-agent interface architecture RT-Michele to support cooperative work among multiple-human and multiple-robots. We implemented a prototype of RT-Michele and also developed autonomous mobile robots. RT-Michele was applied to office automation where a groupware for cooperative work among human and the mobile robots was implemented.

1 Introduction

The development of robots has been showing remarkable progress and robots had taken a part in factory automation. However, today most robots are used in restricted industrial environments. We believe that, some time in a future, virtually each person may possess and use personal robots, analogously to the cars in present society.

In order to realize such a future, it is important to improve the ability of each robot. But even if the ability of each robot is limited, there is a possibility by cooperating with other robots, the performance of the robots can be multiplied. Therefore, the cooperation of multiple robots has been studied by using the technology developed in DAI (distributed artificial intelligence) [2]. But we believe that, in order to have such personal robots in use, it is much more promising to develop the system that supports cooperation of not only multiple robots, but also among multiple human and multiple robots. As for as we know, virtually nobody seems to have proposed such a system up to now.

Figure 1: The mobile robot Einstein I.

By considering these facts, we have begun the project called PRIME (Physically-grounded Human-Robot-Computer Interaction in Multi-agent Environment) in our laboratory. One of the goals of PRIME project is to realize an environment where personal robots could be used for cooperative work. The environment could be an office, a factory, a field of education, etc. We have developed autonomous mobile robots (named Einstein I) as shown in Figure 1 for the project.

On the other hand, human cooperative work is studied as the field of CSCW (Computer-Supported Cooperative Work) and many groupware systems have been developed. We have developed a groupware toolkit called Michele (Multi-agent Interface with

1Systems which support cooperative work of human.
Communication by Hectic ELEments) [3], that supports human cooperative work based on asynchronous communication. Human cooperative work can be represented rigorously with the multi-agent model of Michele.

In this paper we propose RT-Michele, an expansion of Michele. RT-Michele is to support cooperative work among human and robots. RT-Michele provides not only asynchronous communication, but also real-time interactive communication. We have implemented a prototype of RT-Michele, and applied it to office automation application that is cooperation of human and Einstein I.

2 Human-Robot Interaction

The characteristics of human-robot communication can be classified according to whether communication is based on synchronous interactive communication or based on asynchronous communication. Also it can be classified by whether communication is via electronic information or physical information.

We discuss each of four communication types briefly below. Synchronous/electronic communication is real-time communication via computer network or via radio. Example systems include teleoperation with virtual reality technology. Asynchronous/electronic communication is asynchronous communication such as teleoperation of a planetary rover where a human operator expects that a message issued will be received by the robot some time. Synchronous/physical communication is real-time interactive communication. That is passing from human's hand to robot's hand — cash dispensers, vending machines, time recorders, etc. Asynchronous/physical communication is asynchronous interaction. That is to say, raw material is supplied to a robot where it will process and produce merchandise with time.

In particular, in an office environment, when worker A wants to ask a mobile robot to take some physical stuff to worker B, the procedures are as shown in Figure 2. In order to support cooperation among human and robots, we need to have an interface architecture that can support heterogeneous communication.

3 Interface Architecture for Human-Robot Cooperation

3.1 Multi-Agent Model

We will propose an interface architecture based on the multi-agent model of Michele[3]. To present various functions in cooperative work, the concept of an agent has evolved from the actor in Actor Model [1]. Within the group work, the number of users and robots is unlimited and they execute concurrently in a distributed environment. For every user and robot to work simultaneously, each agent has its own processing power and local persistent memory called fields. The contents of an agent's fields define its internal state. Each agent also has procedures called methods that specify its behavior. Any communication from one

1. Worker A calls one of mobile robots in the office. (Async/Elec)
2. Worker A hands some stuff to the robot. (Sync/Phys)
3. Worker A tells comments for worker B to the robot. (Sync/Elec)
4. The robot moves to the office of worker B.
5. The robot hands the stuff to worker B. (Sync/Phys)
6. The robot tells comments of worker A to worker B. (Sync/Elec)

Figure 2: Procedures of an office work.
agent to another is realized as a methodcall defined by a method.

As shown in Figure 3, an agent can be a system-agent, a user-agent, or a robot-agent. A system-agent is an entity realized as a process of a computer system. A system-agent can represent electronic information such as specification of a task, plan structure of a robot, and an office document. A user-agent is the combination of a user and a MI (Message Interpreter). A robot-agent is the combination of any kind of autonomous robot and TI (Task Interpreter). Corresponding to functions of the robot, a robot-agent has a set of methods. Only through methodcalls, other agents can invoke and ask services for the robot.

3.2 Environments

To deal with both asynchronous and synchronous real-time communication, each user has his or her own user-environment and each robot has its own robot-environment. Any of a user or a robot can create a meeting-environment dynamically (See Figure 3). An environment is a notion to distinguish asynchronous communication and synchronous communication. Communication between two environments is asynchronous, while communication within one environment is synchronous.

A user-environment is a metaphor of the private office of a user. If a user is in his or her own user-environment, he or she can execute a task represented as an agent within the user-environment through synchronous interactive communication. A robot-environment is a metaphor of working environment for an autonomous mobile robot. The information of the task that the robot is currently executing, and the information of allotted and queued tasks to the robot are represented as system-agents in the robot environment.

A meeting-environment is a metaphor of a council room for humans or a shared space for human and robots. This notion is incorporated to realize synchronous interactive communication among human and robots. Every time a human or a robot decides to communicate with companions (human or robots) through interactive communication, he or she creates a meeting-environment, then migrates into the meeting-environment, and ask the companions to join the meeting. When the companions migrate to the meeting-environment, they can communicate through interactive communication. In the case of interactive communication between a human and a robot, they may talk to each other by using voice recognition and voice synthesis systems, and they may hand or take physical entities between them.

3.3 Management of Physical Information

There are some characteristics for physical information that discriminate it from electronic information. For example, it is unique in the world and can not be duplicated. It represents the information that describes the object itself, such as size, weight, color, etc., and the information that describes the task attached to the object such as whom it is carried to and how it is processed.

Therefore, to handle these characteristics of object, we define physical-agent as a special system-agent. The physical-agent manages characteristics of the object. A robot receives an object from a human, then a physical-agent is instantiated by the robot corresponding to each object. When the object is passed to a human, the physical-agent corresponding to the object can be deleted. The specification of physical-agents can be described by the programmer using the multi-agent description language MDL/C++[9] we have developed.

4 Conclusion

A prototype of a multi-agent interface architecture for human-robot cooperation using our autonomous mobile robots was developed, and the application described in Figure 2 was also implemented. We believe that this work opened up an interesting field of modeling and implementing human-robot-computer interaction.

References