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DISTRIBUTED TASK PROCESSING BY A MULTIPLE AUTONOMOUS ROBOT SYSTEM USING AN INTELLIGENT DATA CARRIER SYSTEM

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ABSTRACT—This paper presents a new device called intelligent data carrier (IDC) for local information management. This device is useful for multiple autonomous robot systems which operate in a dynamically changing environment. In this paper, an IDC system which consists of IDCs attached to objects or environment and reader/writers mounted on autonomous mobile robots is introduced, and various IDC applications are proposed. As an example of the applications, a method for distributed task processing using the IDC system is mentioned, and the applicability of the system is verified through numerical simulations and experiments using actual robots.

Key Words: Multiple autonomous robots, Distributed task processing, Intelligent data carrier, Local information management, Indirect communication, Environmental agent

1. INTRODUCTION

Distributed autonomous strategies aiming at flexible, adaptive, robust and fault tolerant robot systems have recently attracted the attention of many researchers[1][2]. However, in order to realize a distributed autonomous robotic system operating in a real environment, it is important to make realistic and technical discussions. Based on discussions on cooperation of actual multiple robots[3], the authors have developed a new device called intelligent data carrier (IDC) as an efficient hardware for cooperative multiple mobile robots, which enables local and decentralized information management[4]. This paper presents the ideas to utilize the IDCs for distributed task processing among multiple autonomous robots.

2. IDC SYSTEM FOR DISTRIBUTED AUTONOMOUS ROBOTIC SYSTEMS

IDC System Concept

Recently, many researches on Distributed Autonomous Robotic Systems or Multi-Agent Robotic Systems have been reported. However, a large part of them are simulation-based researches, and there are few researches where multiple autonomous mobile robots are used in a real world. In order to realize such a cooperative multi-robot system, it is required to discuss how each robot should operate from a realistic and technical point of view.

There exists a technical limit in a strategy to make each robot intelligent enough to acquire necessary information in real time by available sensors, because huge computing power and speed are required to recognize dynamically changing environment where multiple mobile robots operate. Moreover, active sensing is restricted in a multi-robot environment because of mutual interference between multiple active signals. In addition, since the communication bandwidth is limited, it is hard to manage all the information by using communication in a centralized manner, which is necessary for each robot to operate.

Some types of information are desired to be managed globally such as global map information, emergency alarm information, etc. On the other hand, there is another type of information which has only to be managed locally for a robot operating in a multi-robot environment, such as local map information, information depending on places or objects, etc.

Based on the discussion above, we have proposed a concept of IDC (Intelligent Data Carrier) system which is very useful for local information management (Figure 1). The IDC system consists of many IDCs scattered in an environment and reader/writers mounted on multiple robots. The data in the IDC can be written and read locally by mobile robots through the reader/writers. Each IDC has a computing functionality and can be regarded as an agent. Namely, with the IDC system, the environment can be made intelligent by attaching IDCs to the environment, and the robots can execute their tasks efficiently by communicating with the environment (floor, wall, etc.). Moreover, the objects to be handled can also be made intelligent by attaching IDCs to the objects, and the robots can work for handling the objects communicating with the objects.

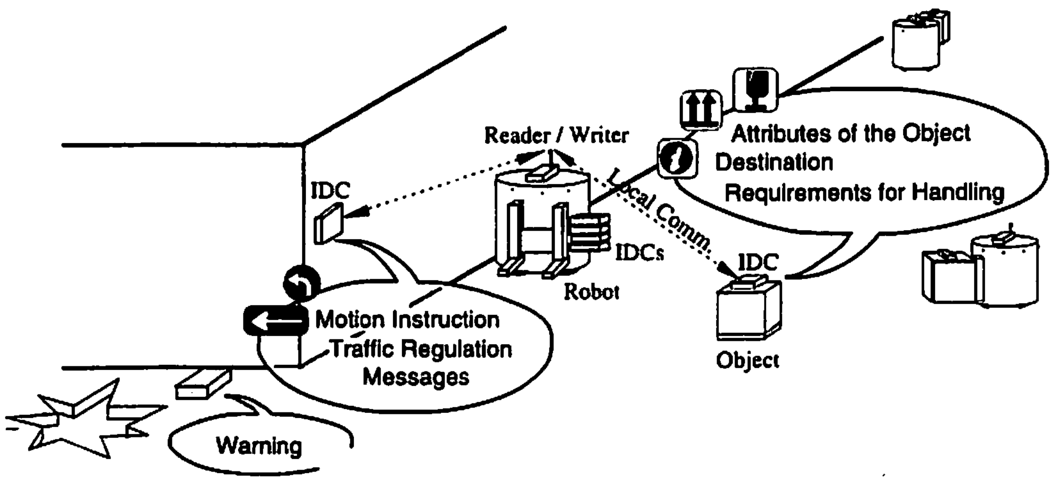

Figure 1. Concept of the IDC system.

Since the IDCs can be carried by the robots in this concept, each robot can set or remove the IDCs in the environment. All robots can, therefore, share information (knowledge) dependent to the places by leaving (writing in the IDCs) information (knowledge) and by extracting (reading from the IDCs) it in the environment.

IDC System

We have developed an actual intelligent data carrier (IDC) system as electronic devices[3]. The IDC is composed of a processing unit including CPU and memory, a communication unit including an antenna and a modulator, and a power unit including batteries as shown in Fig. 2. Table I shows the specifications of the IDC system.

In the IDC, computing functionality is realized by the CPU, and the data can be stored by accessing to the memory. FM radio communication is employed for local non-contact communication between an IDC and a reader/writer. The communicable range is regulated by transmitting power of the hardware. If the range is long, the conflict of communication between the reader/writer and multiple IDCs may occur frequently. If the range is short, it becomes difficult for a robot to detect the IDCs. As for the prototype system, it is set about 70[cm]. As a result of experiments for analyzing the characteristics of the prototype system, it is proved that highly reliable communication was achieved within 70[cm] and low interference effect was observed if the distance between an IDC and a reader/writer is more than 90[cm].

The weight of the IDC is light enough to realize the portability. The shape of the IDC is a small box, and it is easy to set IDCs anywhere in the environment. We have also designed a mushroom-like shaped case for the IDC to enable the robot to carry many IDCs and set in or remove from the environment easily with the forklift mechanism of the robot[4]. The IDC equipped in this special case is called an IDC unit.

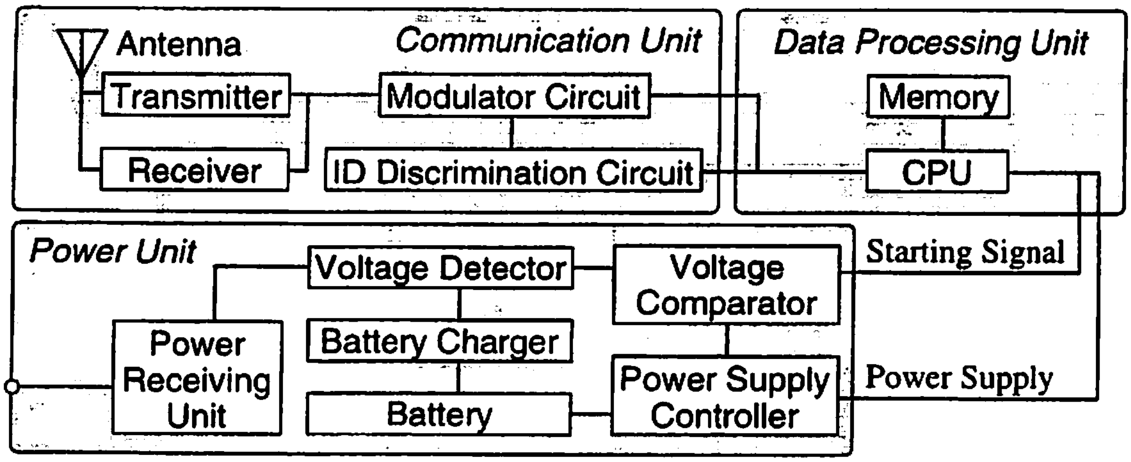

Figure 2. Schematic circuitry of the IDC.

Table I. Specifications of the IDC system.

Size:	135x85x40[mm]
Weight:	200[g] (without battery)
Media:	Electromagnetic Wave
Frequency:	44.7[MHz]
Modulation:	FM
Communication Rate:	9600[bps]
Communication Range:	< 70[cm]
Intensity:	< 10[mW]
Memory Capacity:	32Kbyte
CPU:	Z80 class
Power Supply:	DC 5[V]

Applications of the IDC System

(1) Local and decentralized information management

The IDC is suitable for managing information which is better to be managed only in a local manner or which is difficult to be managed in a global manner in a technical or practical sense such as maintenance information of equipments in plants.

Global or centralized information management in a multiple robot environment has disadvantages in terms of computation load and communication load. In case of global communication, as the number of robots increases, the communication traffic might exceed the communication capacity and a limited bandwidth, and consistent information processing in real time in a dynamically changing environment would become very difficult. Even though the global communication is enabled, and centralized information management might require huge computational power and memory capacity. Therefore, if we assume a large number of robots operating in a dynamically changing real environment, local communication is considered indispensable.

In addition, the information which depends on a specific object or a specific place doesn't have to be managed in a global manner. It is enough for robots to acquire the information when the robots arrive at the location. This kind of local and decentralized information management can be easily realized by attaching IDCs to the object or the place.

(2) Flexible and easy setup of infrastructure for multi-robot operation

It has been proposed to prepare infrastructure for robots to enlarge the area of their applications. Generally speaking, it is not easy in technical and economical sense to construct such infrastructure, for example, as roads for automobiles. However, flexible and easy setup of information infrastructure is enabled by using IDCs. The local information which is required for robots to operate in the surrounding environment can be provided by the IDCs fixed in the environment. The IDC can be also used as infrastructure to guide or navigate mobile robots. Furthermore, if it is technically difficult for a robot to recognize the local information by available sensors, the IDCs would be helpful for providing a robot for such information by local communication. This means IDCs would be a useful alternative for sensing utilities to recognize surrounding environment.

(3) Distributed task processing

Generally speaking, it is difficult to realize flexible processing of the tasks which arise randomly or whose requirements are changing dynamically, such as container handling in a container yards or parcel handling in distribution centers. There is a technical limit in a centralized strategy to manage the information for such kinds of tasks. If we attach an IDC to each object to be handled and write the information required to process it in the IDC, distributed task processing can be achieved only by a simple strategy that each robot which finds the object with IDC reads the information inside and processes it according to the information. In the next section, an object transportation task is discussed as an example application of this strategy.

(4) Active interaction with an environment

Adaptability against the changing or unknown environment is one of the targeting keywords for researchers interested in intelligent robots. However, the adaptability in terms of information, which has been discussed so far, is meaningful only in the passive sense. Namely, the robot has always been considered as a passive one to the environment from a viewpoint of information processing. A new idea of the IDC application is to make the robots interact actively with the environment. This idea is motivated by marking behaviors of animals. By using the IDC system, robots can change the environment with leaving some information there and utilize the changed environment to make adaptive behaviors.

(5) Indirect communication among multiple robots

The marking behaviors of animals mentioned above originate in the purpose of territory declaration to other individuals. To leave information in the environment by an individual and to extract it by other individuals corresponds to indirect communication among plural individuals via the environment. The IDC system is effective to realize such indirect communication. By utilizing the indirect communication, the local information or knowledge which was acquired by a robot can be shared by all the robots without increasing the global communication load. For example, if a robot acquires information (knowledge) during operation in an environment, the robot can leave it in the environment as a message to other robots by putting an IDC on the floor and writing the information (knowledge) in it. By reading the message in the IDCs, multiple robots can share the information (knowledge) which is acquired by other robots via environment. This application is very similar to a pheromone system in an ant society, which corresponds to local communication by chemical trail.

Furthermore, this consideration is also extended to another application where the multiple robots share the behaviors each robot acquires, with which emergent behaviors of multiple autonomous robots coevolving with its working environment is expected[5].

(6) Dynamic organization of a distributed computing environment

New concepts of distributed computing environments have recently been proposed, such as Things That Think (TTT)[6] or Ubiquitous Computing[7]. Since the IDCs are programmable and the program running in the CPU in the IDCs can also be downloaded by the robots through reader/writers, the IDC would contribute to realization of such a distributed computing environment. It is also effective to develop a robot system operating in a distributed computing environment, because such a distributed environment can be implemented only by attaching an IDC on the object and make it an agent without developing new objects which can think and communicate. In other words, organization of such a distributed computing environment according to the situation is expected, which leads to dynamic design of so-called Affordance[8] for a robot to execute required tasks effectively.

In this paper, we focus on (3) and discuss a method for distributed task processing by utilizing the IDC system taking an example of an object transportation task.

3. METHOD FOR DISTRIBUTED TASK PROCESSING

Object Transportation Task

We take object transportation as a typical task where flexible task processing in a dynamic and changing environment is required. Object transportation is a task to transport multiple objects scattered in a working environment, which appear in arbitrary location at random time to each destinations predetermined randomly. We assume multiple autonomous mobile robots to deal with the task. It is hard to manage the global situation of task processing and its environment in a centralized manner because they are changing dynamically. In order to manage such a situation, we propose a distributed task processing method by utilizing the IDC system developed so far[4]. The illustration of the object transportation task is included in Fig. 1.

Object Transportation Method

As the method for the object transportation task, a decentralized autonomous strategy is adopted as well as the literature of [9] where not the robots but the objects have initiatives for the object transportation tasks. The concept of the distributed object transportation is that the objects request robots to transport themselves as a subject the task processing, and the robots behave as servants (tools) for the objects according to their requests.

An IDC is fixed on each object to be handled, and the local information which is necessary to transport the object is stored in the IDC. While each robot wanders along a predetermined traveling path (random walk to look for objects is also applicable), it always tries to connect communication with an IDC looking for objects. And the robot can find an object in a heuristic manner, when it comes within a range where the robot is communicable with the IDC on the object, and succeeds in connecting the communication link with it.

When a robot finds an object, it reads the following information stored in the IDC on the object; (1) ID of the object, (2) Position of the object, (3) Destination of the object, and (4) Flag on "requesting"/"done". The robot can identify the object by its ID number. If the flag on "requesting"/"done" is "done", which means the object has been already transported to the destination, the robot does nothing with the object. If the flag is "requesting", the robot recognizes the request from the object, and executes transportation motion. Reading the object's position from the IDC will help the robot to access to the object without recognizing the object and measuring its position by sensors. After the robot transports the object to its destination which can be known by reading information in the IDC, the robot rewrite the IDC information to change the flag from "requesting" to "done", and then returns to the traveling path. The algorithm of each robot to process the object transportation task in a distributed manner is shown in Fig. 3.

Even if the robot cannot move to the final destination due to environmental constraints which cannot be overcome with its own limited performance, it is expected to achieve the task only with small extension of this algorithm. Namely, by combination of multiple robots working within various environmental constraints, the objects can be handed over repeatedly to the final destination via subgoals set by the robots.

4. EXPERIMENTS

Verification by Simulation

To verify the proposed method, simulation was carried out. In this simulation, autonomous omni-directional mobile robots we have developed so far[10] are assumed as mobile robots to transport objects. Figure 4 illustrates the simulation environment. In this figure, round dots scattered in a square shaped room denote the objects to be transported. The squares denote the mobile robots and the circle surrounding each robot denotes the communicable range of IDCs. If we start the simulation, each robot starts moving along the predetermined path (raster scan) as to sweep all the working environment. The operator can put any objects anywhere in the environment at anytime during the simulation with specifying the ID, current position, destination, and flag "requesting" which are assumed to be written in the IDC on each object.

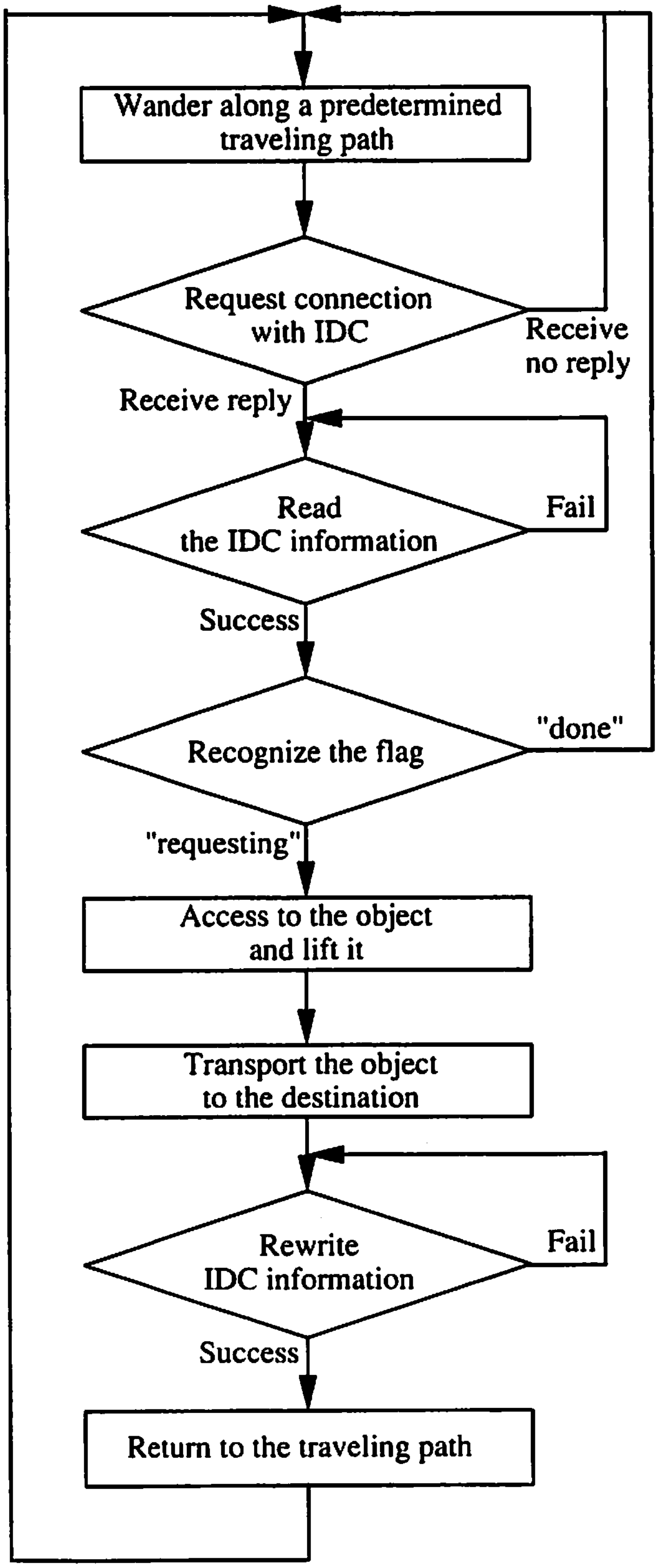

Figure 3. Algorithm for the object transportation task.

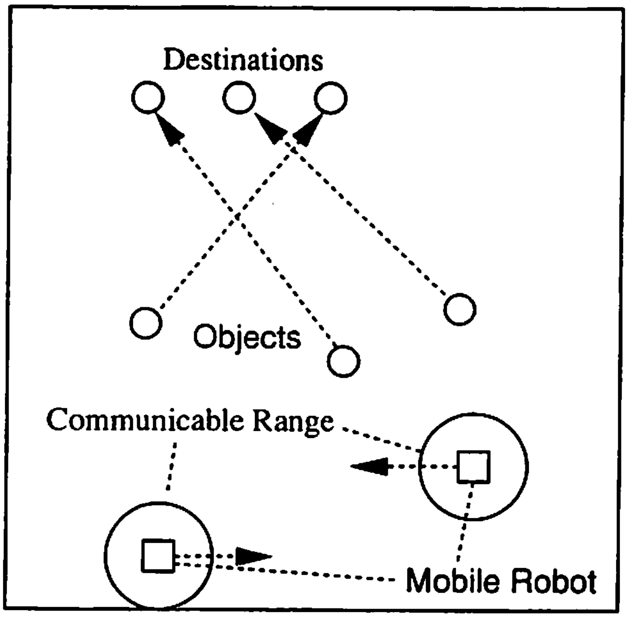

Figure 4. Illustration of the object transportation task simulation.

Figure 5 shows an example of the simulation result of object transportation task executed by three omni-directional mobile robots, which is carried out on a workstation. The trajectories along which all the mobile robots swept are shown in this figure. Each robot moves based on the algorithm mentioned above. As the result of the simulation, it is verified that without any centralized systems, the multiple robots could flexibly deal with the tasks to transport objects which appear in arbitrary location at random time.

Object Transportation by Actual Mobile Robots

In order to verify the feasibility to realize proposed object transportation task, a series of object transportation experiment was carried out using an omni-directional autonomous mobile robot equipped with a forklift mechanism[10]. The size of the self-contained omni-directional mobile platform is W:400[mm] x D:400[mm] x H:500[mm] and its weight is 45[kg]. The weight of the forklift is 8[kg].

The developed robot is self-contained, and the control system is mounted on the robot. The control system architecture of the omni-directional mobile platform is shown in Fig. 6. A CPU (i486 DX4), a D/A converter to drive DC servo motors for a forklift and a mobile platform, a counter to read the encoders, a parallel I/O for sensory systems, and a ethernet card are connected to the PC ISA bus. A radio Ethernet is equipped for each robot, which enables mutual global communication. The reader/writer of the IDC system is connected to CPU board via a serial interface.

A real time multi-task operating system, VxWorks, is run on the CPU to control the robot. The motion programs for the object transportation method proposed in this paper was implemented and down loaded to the robot. The motion control of the mobile robot was done by deadreckoning based on the output of encoders attached to the actuators. Figure 7 shows a photo of the mobile robot accessing to the object with an IDC.

The executed motion is recorded and the resultant trajectory can be displayed on a workstation. Figure 8 shows the display of the trajectory of the robot which executed the object transportation motion. The overall motion is described as follows:

(a) Motion for searching an IDC attached to an object
(b) Motion for approaching to the object
(c) Motion for inserting its fork to the object
(d) Motion for transporting the object along x-axis direction
(e) Motion for transporting the object along y-axis direction
(f) Motion for pulling out the fork from the object
(g) Motion for returning to the initial position

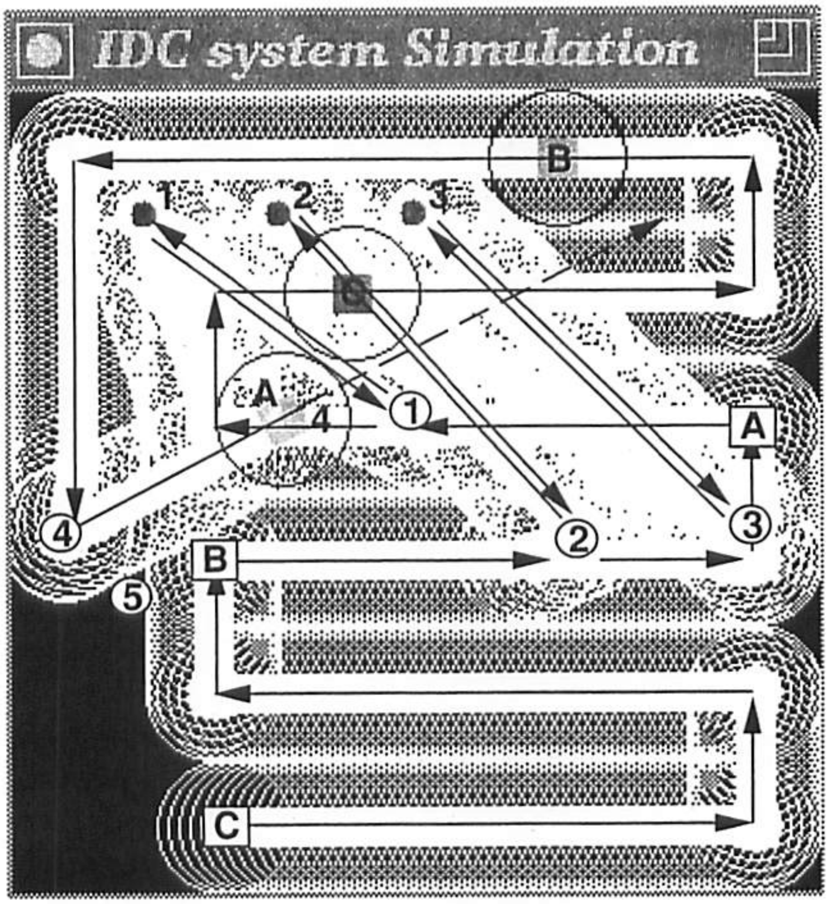

Figure 5. Simulation result. Circles and Squares indicate the initial positions of the objects (1, 2, 3, 4, 5) and the robots (A, B, C), respectively. The object 4 and 5 are put at indicated positions at 341 time steps. The robot A transported the object 1 at first and the robot B transported the object 2 and 3 to their destinations and now the object 4 is carried by the robot A in this snapshot.

As a result of the experiment, it was verified that the communication between the reader/writer mounted on the mobile robot and the IDC attached to the object was established and achieved successfully when the robot moved into the communicable range, and the object transportation motion could be realized according to the IDC information.

5. CONCLUSION

In this paper, a new device called intelligent data carrier (IDC) was introduced for local information management, and various applications of an IDC system which consists of IDCs and autonomous mobile robots with reader/writers were proposed. As an example of the applications, a method for distributed task processing in the object transportation task using the IDC system was proposed. The proposed method was verified through a simulation and an experiment by operating actual mobile robots. It is planned to realize various IDC applications introduced in this paper in near future.

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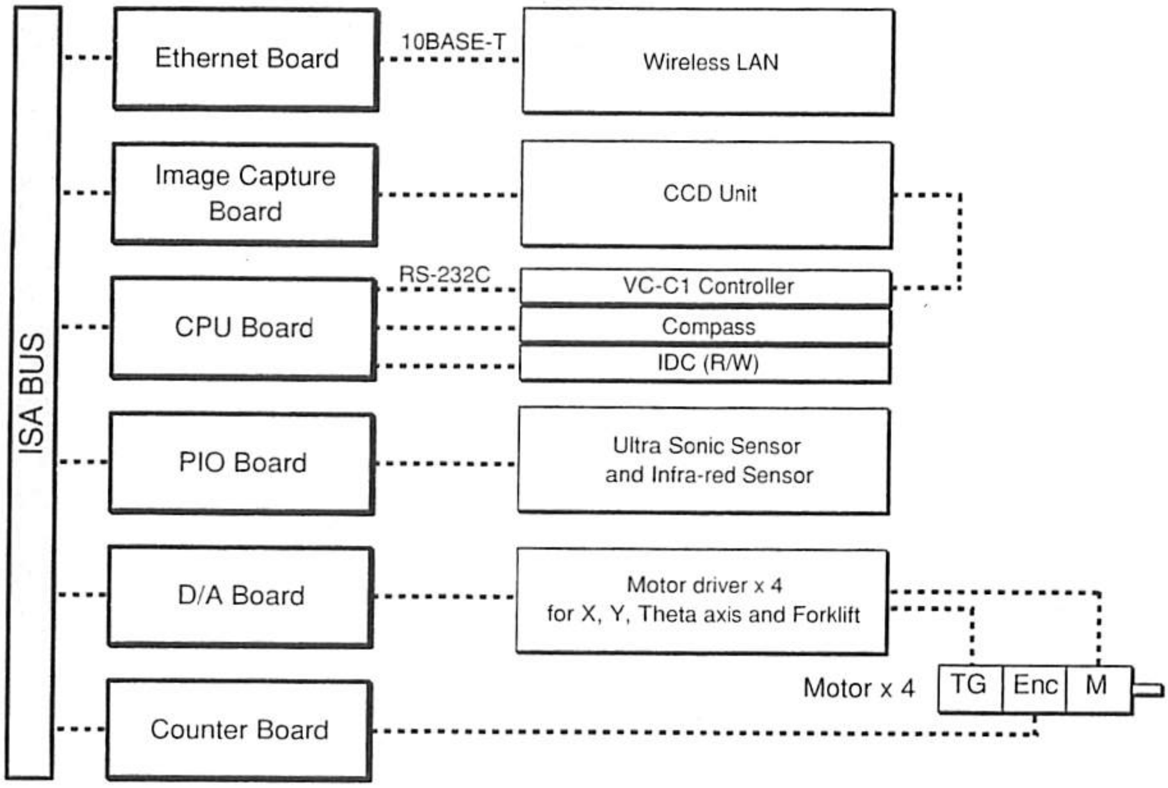

Figure 6. System configuration in actual robot experiment.

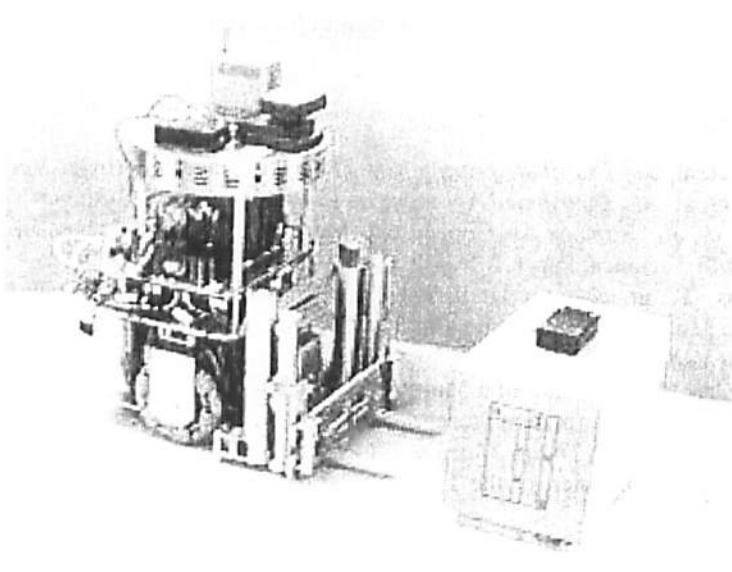

Figure 7. An omni-directional mobile robot and an object (a box on the right side) with an IDC. A black box set on the object is the IDC. The robot is equipped with a forklift to handle the object and a reader/writer device to communicate with the IDC.

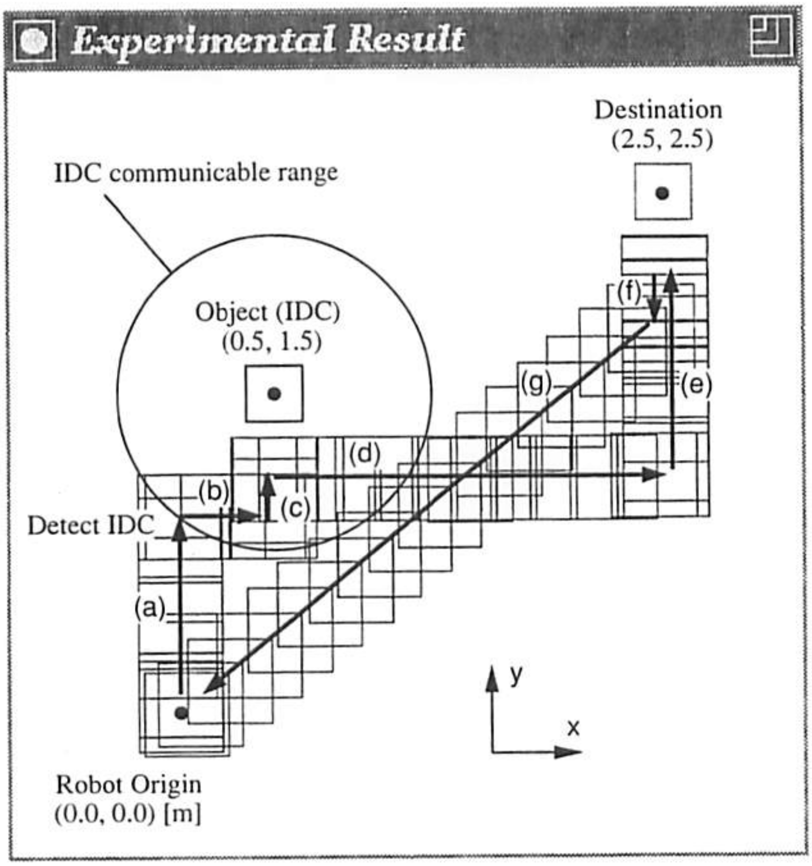

Figure 8. Trajectory of actual mobile robot in object transportation task.

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