# Cooperative Formation among Multiple Mobile Robot Teleoperation in Inspection Task

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**Abstract**

The paper discusses multi-robot teleoperation system considering cooperation between human operator and multiple robots in inspection task. A prototype of the teleoperation system is developed and implemented on an actual testing platform that consists of multiple omni-directional mobile robots. Cooperative formations among multiple mobile robots are proposed. Performance of the developed system is examined through the experimental example of an inspection task.

## 1 INTRODUCTION

A concept of distributed autonomous robotic systems (DARS)[1] which are composed of multiple robotic agents has been attracting many researchers' and system designers' interests as one of the possible solutions which could realize flexible, robust and intelligent robotic systems. It is expected that high-level tasks can be executed by the DARS. Such tasks as emergency treatment or inspection of delicate damages, etc. have been usually carried out by human workers. In most of the research projects on DARS, it seems that the primary goal is to improve conventional systems' performance and to achieve autonomous task execution by the systems [e.g.2]. However, it seems that it is not realistic for those robots to carry out all the high-level tasks autonomously by themselves. It is more feasible to build a system in which the human operator and the robots interact with each other and carry out the required tasks cooperatively. Recently, cooperation between a human operator and robots has been discussed from several standpoints in the field of human-machine systems [e.g.3]. However, only few studies have focused on cooperation between a single operator and multiple robots or development of the human interface to realize those cooperative works [e.g.4,5].

In this study, we develop a multi-robot teleoperation system for inspection tasks from a remote site considering the cooperation between human operator and robots. We assume that a single operator maintains the plant by operating the multiple mobile robots using the teleoperation system as shown in Fig. 1[6]. Each robot carries a camera, and inspects objects according to the operator's requirement.

The paper describes about a multi-robot teleoperation system. Especially, we focus cooperative inspection between an operator and multiple mobile robots. A prototype of the teleoperation system is developed and implemented on an actual testing platform that consists of multiple omni-directional mobile robots equipped with cameras. Cooperative

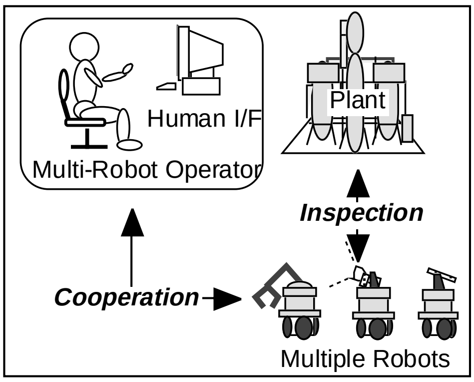


Fig. 1 A concept of plant maintenance system considering the cooperation between human operator and multiple robots

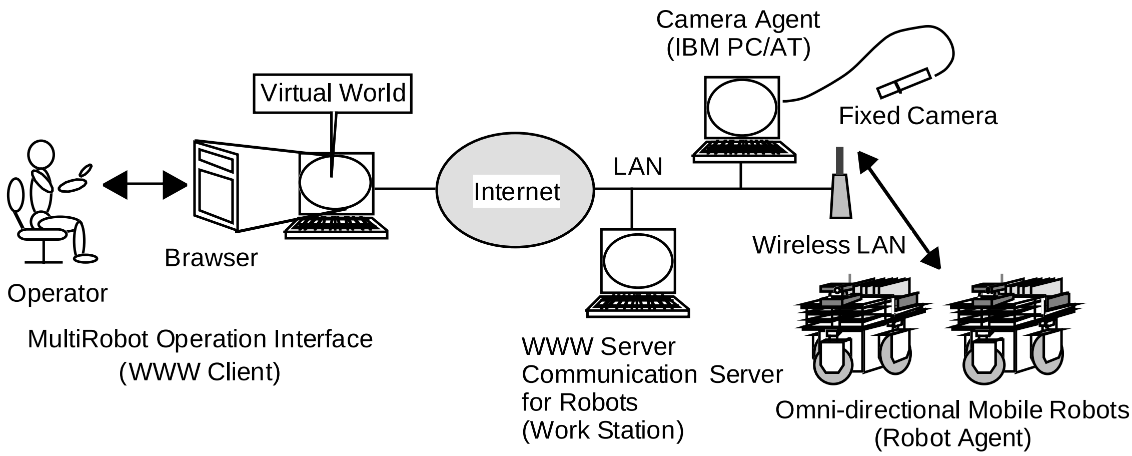


Fig. 2 A teleoperation system for a multirobot by utilizing WWW

formations among multiple mobile robots are proposed for inspection task. Performance of the developed system is examined through the experimental example of inspection task.

## 2 TELEOPERATION SYSTEM FOR MULTIPLE MOBILE ROBOT

We have developed a prototype system based on the concept presented above. Figure 2 shows a schematic view of the system. The system enables the operator to send operation commands to the robots and monitor them through a WWW (World Wide Web) browser and a virtual world.

### 2.1 Human interface for multi-robot teleoperation by utilizing WWW

The Internet and the WWW system provide flexible networking environment to build a human interface system for exchanging information through the Net. The robots in the system are regarded as terminal devices or autonomous agents, which can interact physically with the real world, providing the advantages as follows;

- the operator can control the robots by the same interface from any places connected to the network without constructing additional infrastructures for communication,
- the system can utilize skills of the operator who is in a distant place,
- the operator is able to communicate with other operators through robots' physical interaction.

Figure 3 shows the operation environment of prototype system. WWW technique is used for easy operation of


Fig. 3 A operation environment

the multiple robots on the browser. Joystick and HMD (Head Mounted Display) are used for direct operation of the robot.

### 2.2 Virtual World for Supporting Human's Operation

In the multi-robot system, increasing of the number of robots bring a network traffic. Moreover, it is difficult to grasp a situation of the remote site because many robots exist in the environment. Hence, we utilize a virtual world for better image display of multi-robot status to human operator [7]. The virtual world gives the operator a realistic and smooth visual display for a comfortable operation of the multi-robot. The operator does not have to feel the delay of communicating the information and operates the robot smoothly. The virtual world is made by computer graphics based on the real environment and real robots. Figure 4 shows an indication of the interface that is constructed using HTML and VR (Virtual Reality) technique.

### 2.3 Omni-directional Mobile Robot

In order to realize flexible cooperative action, the omni-

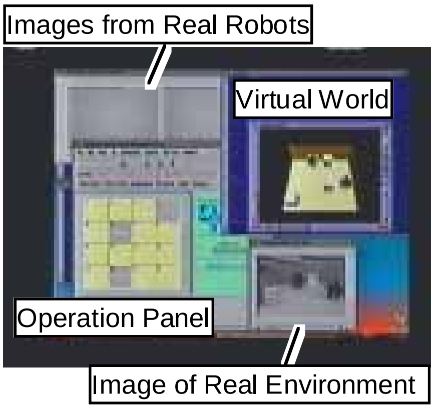


Fig. 4 Interface for multi-eobot operation

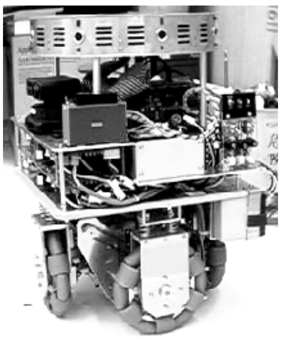

Fig. 5 Omni-directional mobile robot

directional mobile robot has been already developed [8]. The control system is mounted on the robot. Batteries are also mounted on the robot for electrical devices and actuators. The robot can behave autonomously and independently. Each robot can communicate with each other through a radio Ethernet equipped on the robot.

They have cameras for inspection tasks, and can get the observed images by using the image capturing board mounted on the robot. These images can be communicated through the Ethernet.

## 3 COOPERATIVE INSPECTION BETWEEN A HUMAN OPERATOR AND A MULTI-ROBOT

### 3.1 Cooperative Formation among a Multi-Robot for Inspection Task

It is important for the multiple robots to execute tasks autonomously according to the requirements of the operator. For example, in the case that malfunction occurs in the plant, the human operator has to correctly recognize the situation of the plant as if he is present at the actual malfunctioning point and is able to inspect it at sight. Concerning the formation of robots for such inspection tasks, coordination of a robot with a light source and another robot with a camera is one of relevant examples, which has been reported so far [11]. In order to achieve more flexible and effective operation of multiple robots, various formations should be prepared as one of the autonomous function of the multi-robot system. Here, we propose the following formations for inspection tasks in the plant as a subset of such formations:

**a) Multi-angle formation**

A dead angle always exists in a scene observed by a single robot. However, it is possible to compensate the dead angle by scenes observed from other robots. Dead-angle-free images can be displayed to the operator by this formation of the robots (Fig. 6). It means that two or more robots cooperate with each other, and they send the images observed

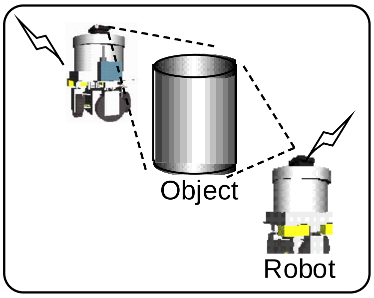


Fig. 6 Multi-angle formation

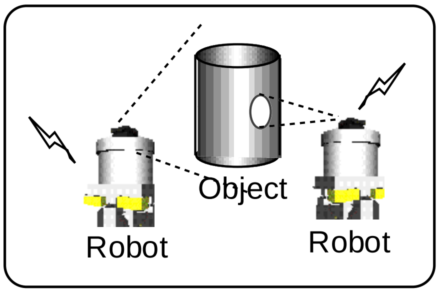


Fig.7 Multi-zoom formation

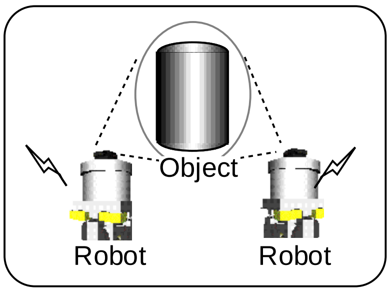


Fig.8 Binocular stereopsis formation

from multi-angles simultaneously to the operator.

**b) Multi-zoom formation**

Multi-Zoom formation is a formation for simultaneous inspection in multiple views with different magnification and resolution. With this formation, the operator is able to have a detailed image of the working point while observing the over-all situation around the object as shown in Fig. 7. It is combined combination of macroscopic and microscopic views.

**c) Binocular stereopsis formation**

When the operator makes a decision by visual information sent by the robots, the depth information is essential to reconstruct the situation in the remote place. By this formation, the robots provide a stereoscope vision for the operator as shown in Fig. 8. When the formation can be used with a HMD, the system will provide VR sensation to the operator.

## 3.2 Process for teleoperation

Figure 9 shows a software process for teleoperation system. System's execution scenario is as follows:

1) At first, the robots wait the commands from the operator at the initial position. The operator grasps the system's status as an environment and robots by looking WWW browser and the virtual world.

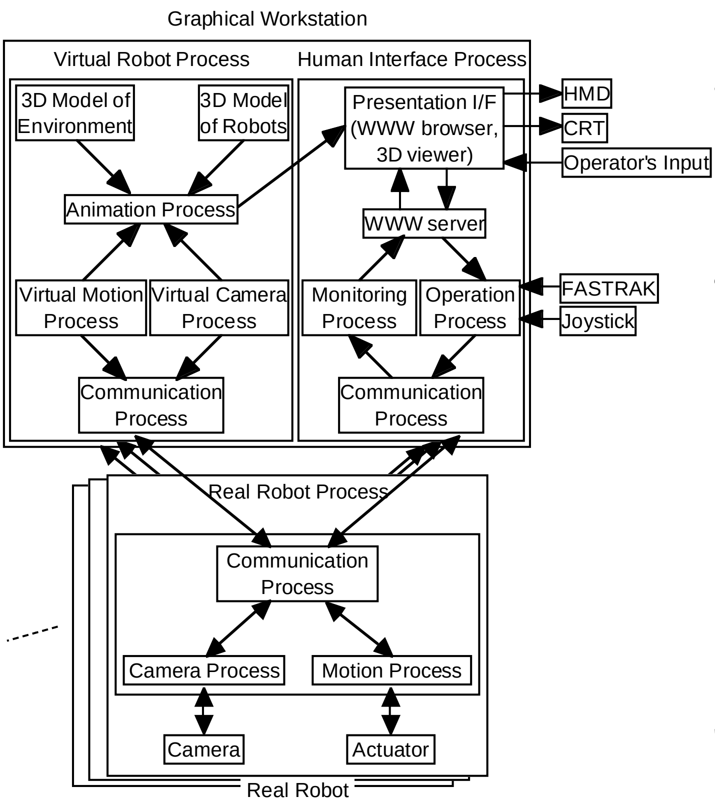


Fig.9 Process for teleoperation

2) In the case that the operator needs to inspect the objects by judging from the system's status, s/he inputs task commands by selecting items in the operation environment; menu, pushing button or clicking the object on the clickable map of HTML, or joystick.
3) The operation porocess accepts operator's command from the WWW server or the joystick, and gets task contents and object's information.
4) Consulting the database in which a table indicating the relationship between known tasks and robot functions is started, the operation process determines necessary facilities and operations for the given task, and allocates robots available in the working place. With this complete set of information, the process contacts the communication process.
5) The communication process transmits commands to both real and virtual robots via wireless LAN.
6) The robots reply to the task request, then, the operation process negotiates with robots through the communication process in order to specify the robots that execute the task.
7) In the virtual world, virtual robots simulate the required task in order to help grasping the real robots' situation for human operator.
8) While the real robots execute the tasks, they send the data (own positions, images and/or messages) to the monitoring process through the communication process. After the robots complete the all tasks, they wait the next commands.
9) The monitoring process saves these execution data to the database, and writes the data to HTML format file so that the WWW server can read it. The monitoring data also use in the virtual world for correcting errors between real and virtual robots.
10) Finally, the data of HTML format are called up by the WWW server and presented in the WWW browser. If the robots are busy or send back no replies, the Monitoring Module sends the messages such as "Cannot execute task, because...".

## 3.3 Communication methods among the robots

Considering various situations, a communication system that enables the flexible communication among the robots is essential. Hence, the communication system and protocols have been developed to realize the communication between multi-robots [9]. The robots have a common communication format, and can exchange information with each other by radio communication among them. The organization strategies using the communication system have also developed to realize the cooperation among the robots [10]. The communication between the human interface and multi-robots conforms to these communication strategies.

In this system, all agents have unique IDs such like “G1VsVcO1”. This ID consists of 4 separate fields; Group field (“G1”), Function field (“Vs”), Equipment field (“Vc”) and Type and Number field (“O1”). The Group field is used to identify the temporarily grouped agents for making some formations. The Function field represents the function of the agent to execute tasks by using own equipment. The Equipment field shows kind of the device or device name which the agent carries. The Type and Number field represents an agent type and it’s own unique ID number to identify the agent. For example, “G1VsVcO1” represents “omni-directional robot No. 1 which is equipped camera (VC-C1), has visual sensing function, and is belong the temporary group 1”. By using this IDs, the other agents can know the characteristics of robot easily as same as communication among them. Thus, the agents that have necessary functions for the specific tasks can be organized grouped and coordinated.

## 4 EXPERIMENTAL EXAMPLE

We observed objects by teleoperating multi-robots with considering actual inspection task. We executed an observation task with giving commands to the robots by clicking an object on the environment map (clickable map of HTML) shown in Fig. 10. The operator required the robots to observe the object “OBJ 14”. The observation can be achieved using the multi-angle formation. System’s execution scenario was as follows:

1) At first, the robots waited the commands from the operator at the initial position shown by Fig. 11. The operator grasped the system’s status as an environment and robots by looking WWW browser and the virtual world.
2) The operator needed to inspect the object “OBJ 14” by judging from the system’s status, then he inputs commands by selecting the object “OBJ 14” on the map.
3) The WWW server accepted operator’s command and sent task contents and object’s information to the robots via

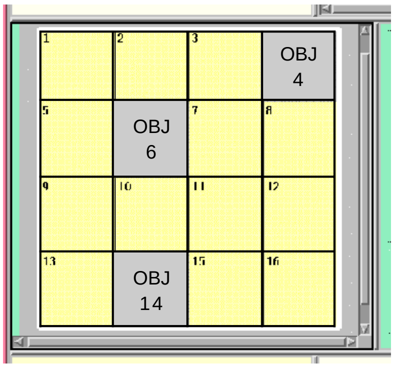


Fig.10 Operation map on the browser

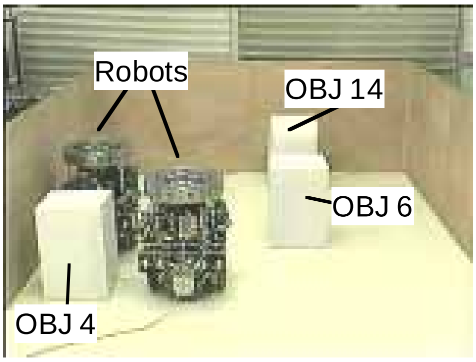


Fig.11 Experimental environment

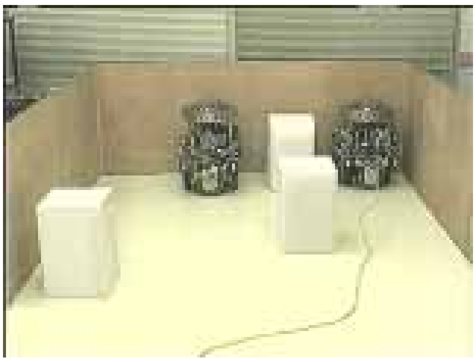

Fig.12 Inspection by using multi-angle formation

Fig.13 Indication of human interface

network. Then, the robots executed the task by using required formation (Fig. 12). The virtual robot also simulate the task simultaneously.

4) The robots sent the data (own positions, images and/or messages, etc.) to the operator. Then, the operator could observe the object on the interface (Fig. 13). After the robots complete the task, they wait the next commands.

## 5 CONCLUSION

In this paper, a multi-robot teleoperation system for inspection task was discussed. The prototype of the teleoperation system was constructed utilizing the WWW system and virtual world as a developing and operating environment. A prototype of the teleoperation system is developed. In order to carry out an inspection task effectively, cooperative formations among multiple mobile robots ware proposed. Performance of the developed system is examined through the experimental example of inspection task. The system can be used for teleoperation experiments via network to investigate various issues related to multiple robots operation by a single remote operator.

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