Management of a Single-user Multi-robot Teleoperated System for Handling Large Valves in Offshore Plants

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ABSTRACT

This paper proposes a new approach to task management method of a single-user multi-robot teleoperated system for handling large valves in offshore plants. The task management method is designed to perform a 1:N mode (here, "1" refers to the number of operators, and "N" denotes the number of robots), in which a single operator teleoperates a number of slave robots directly to conduct a large valve handling task, or in an autonomous cooperation mode between slave robots in order to overcome the limitations of the aforementioned 1:1 (here, "1" refers to the number of operators and slave robots) teleoperation mode. The aforementioned management method is responsible for the role sharing and integration of slave robots to divide the operation mode of the slave robots into various types according to the operator's intervention level and the characteristics of the target operation (valve handling) beforehand and to perform the target operation using the robot operation mode selected by the operator.

Keywords -
Management; Single-user Multi-robot; Teleoperated System; Large Valves; Offshore Plants

1 Introduction

Teleoperated robot systems have been developed for operator to allow for various tasks via the remote control system. The 1:1 teleoperation method is most frequently used in typical teleoperated robotic systems, and involves a master device that collects target task commands from an operator to a slave robot that carries out the commands [1], [2]. For example, Heikkila et al. proposed functional design of a manufacturing robot cell [3]. Yamada et al. introduced construction tele-robot system with virtual reality [4]. Zhao et al. developed a construction tele-robotic system that has wide applications in restoration work in stricken areas [5]. Kwon et al. developed a microsurgical telerobot system [6]. Geerinck et al. introduced the operability of an advanced demonstration platform incorporating reflexive teleoperated control concepts developed on a mobile robot system [7]. But 1:1 system is unsuitable due to limits of the robotic workspace or power of only one slave robot. When this method is applied to the handling large valves in offshore plants, one slave robot is insufficient for performing the installation processes because of the length and weight of the valves. When two of these systems are used to install the valves, communication between the operators and cooperation between the robots through the two master devices are not smooth, and this reduces the work efficiency. Even though they have been used in industrial applications such as construction, assembly, maintenance and etc., we cannot find a multi-agent remote controlled robot system as 1:N cooperated multi-robot system. The use of a multi-robot system makes it possible to perform various kinds of sophisticated tasks, such as handling large or heavy objects.

This paper proposes task management method of a single-user multi-robot teleoperated system for handling large valves in offshore plants that is designed to perform a 1:N mode, in which a single operator teleoperates a number of slave robots directly to conduct a large valve handling task, or in an autonomous cooperation mode between slave robots in order to overcome the limitations of the aforementioned 1:1 teleoperation mode. In particular, this paper introduces a multi-robot task management software (MTMS) for allocating roles to slave robots and creating autonomous motion commands for robots when valve handling is done by the 1:N teleoperation method.

2 Task Management of Single-operator Multi-robot Teleoperated Systems

The task management method is responsible for the role sharing and integration of slave robots to divide the operation mode of the slave robots into various types according to the operator's intervention level and the characteristics of the target operation (valve handling) beforehand and to perform the target operation using the robot operation mode selected by the operator. The tsak management method also includes technologies for the following: (1) a role change between slave robots that are controlled remotely and slave robots that perform the autonomous operation, (2) path generation for slave robots that perform the autonomous operation, and (3) path compensation when slave robots contact the surrounding obstacles while performing the operation under various situations where one of the slave robots simply follows the operation command given by a remote operator via the task management software and the rest of the slave robots follow the operation of a slave robot that is remotely controlled, or where all slave robots perform an autonomous operation, to achieve the operation goal set by the operator. Further, when the target operation (valve handling) is a simple repetitive job that is performed continuously, the management includes a storing and playback technology using which the slave robots edit and store the operation command created from a remote operator, thereby following the stored operation commands repeatedly without any operation intervention for the subsequent repetitive operations performed to achieve the operation goal.

As shown in Fig. 1, the issue of whether the robots perform a teleoperated or autonomous motion is determined by selection of the cooperation mode (Monopoly, Following, and Imitation mode) selected by the operator. The cooperation mode can also be divided into Linear, Rotational, or Combination motion based on the physical motion characteristics of the robot that performs the particular task.

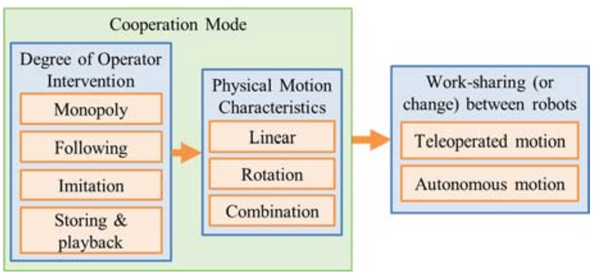

Figure 1. Cooperation mode of single-operator multi-robot teleoperated system

In particular, in the monopoly mode, the master device completely controls a particular slave robot. Hence, the commands related to the robotic path created by the operator via the master device are transferred to a specific robot that performs the teleoperated motion. Secondly, in the Following mode, the operator controls one slave robot, while the other slave robots support the motion of this robot through autonomous motions, thereby facilitating cooperation among the slave robots. Thirdly, in the Imitation mode, the slave robots imitate the motions of each other or autonomously perform independent motions to carry out the commands of the operator regarding the target objects. Finally, in storing and playback mode, the robotic path of each slave robot that corresponds to a single iteration can be stored and repeated as necessary.

Furthermore, with the task management method, the multi-robot task management software (MTMS) is produced for cooperation in 1:N teleoperated robot systems. Fig. 2 shows the structure of MTMS based on the task management method. A user creates a robotic path for the target slave robot teleoperated motion through the mater device, the MTMS transmits the path to that robot while it also creates (including calibration) robotic paths for other slave robots autonomous motion based on the motion information of the teleoperated robot.

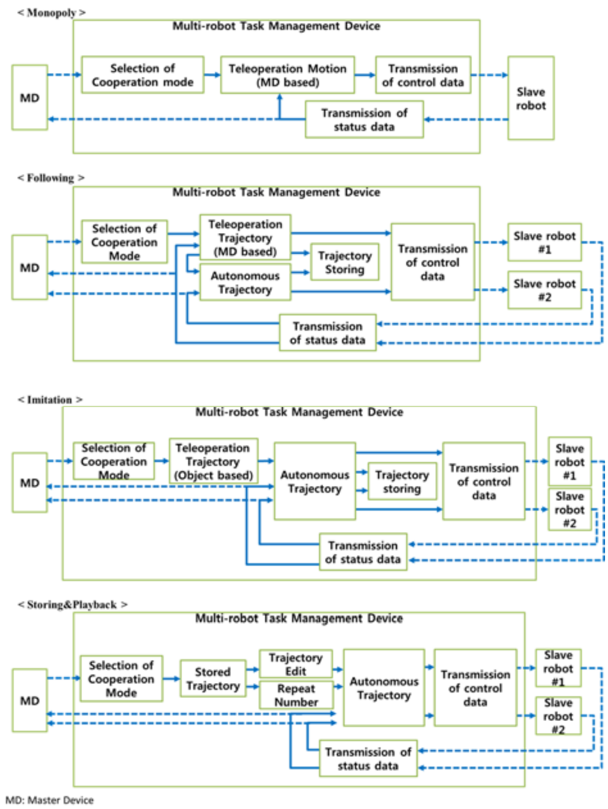

Figure 2. Cooperation mode (Monopoly, Following, Imitation, Storing & Playback) structure of multi-robot task management software (MTMS) based on the proposed task management method

The physical characteristics of the motions in the Following or Imitation mode of the MTMS during valve handling are shown in Fig. 3. As shown in the figure, Linear motion (generally a teleoperated motion) allows the generation of each robotic path based on position information or by applying a Cartesian coordinate system to the slave robots. Rotational motion allows the generation of position and orientation commands regarding the robotic path based on the center of a valve and commands for the rotation of the slave robots generated by the master device. In addition, Combination motion allows the simultaneous performance of Linear and Rotational motions.

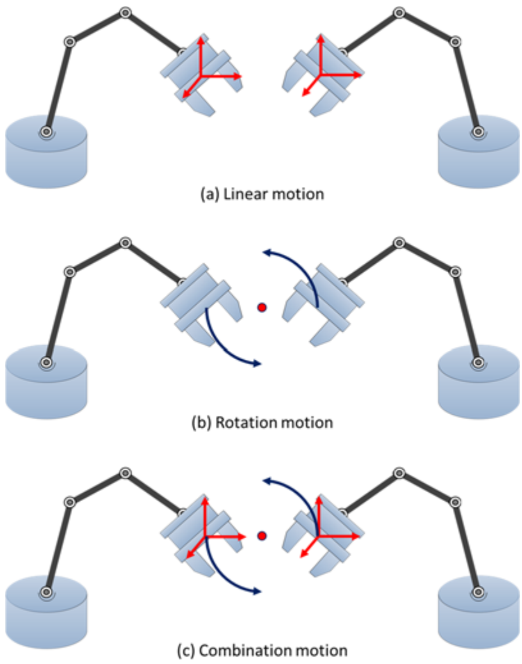

Figure 3. Physical motion characteristics for valve handling. (a) Linear, (b) Rotation, and (c) Combination motion

As shown in Fig. 4, an operator can select a teleoperated slave robot to be interchanged with another slave robot via the GUI of the MRTM software.

Figure 4. Graphical User Interface (GUI) of multi-robot task management software (MTMS)

A teleoperated or autonomous motion of a slave robot can also be performed by selecting the cooperation mode (Monopoly, Following, or Imitation) through the GUI. In addition, the GUI enables real-time observation of the status of bilateral communication between the operator and the robots, jobrelated information, and the status of currently operational robots.

3 Verification of Multi-robot Task Management Software (MTMS)

Fig. 5 shows the simple experimental setup of multi-robot teleoperated system for valve handling, including the MTMS proposed in this paper. The multi-robot teleoperation system is intended to work in places where people cannot easily access due to safety concerns and/or geographical restrictions, such as remote offshore plants, disaster relief sites, or nuclear power plants. Such simulated environments simulate the various types of maintenance work common across a variety of fields in offshore plants. In particular, the experiment aims to validate feasibility of operation of the teleoperated robotic system for the rotation of large valves, which cannot be accomplished with a single robot.

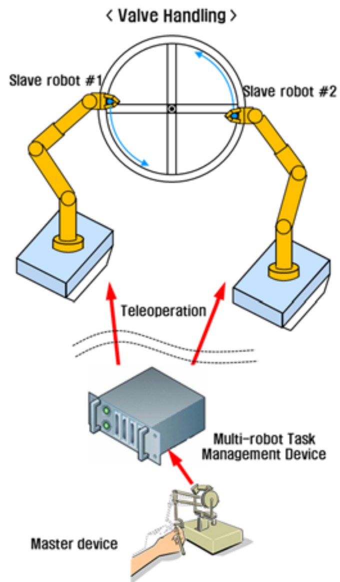

Figure 5. Configuration of multi-robot teleoperated system

Fig. 6 shows a valve handling work scenario in an offshore plant that utilizes a 1:N teleoperated robotic system, including the MTMS proposed in this paper. The task scenario is defined for the 1:N teleoperated robotic system based on the valve handling processes performed by human workers on a real site. The aim of the experiment was to assess the feasibility of using the teleoperated robotic system instead of human workers to perform valve handling processes that cannot be accomplished by a single robot.

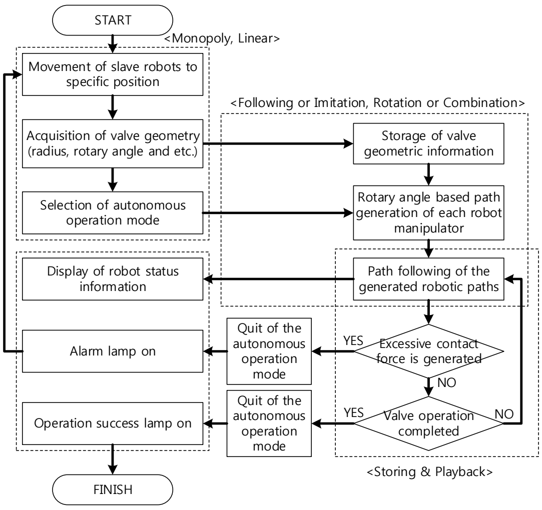

Figure 6. Flow chart of a valve handling with multi-robot task management software (MTMS)

The valve handling experiment was accomplished by cooperation motions between two robots through the multi-robot teleoperated system using the Monopoly and Imitation modes (including Linear, Rotational, and Combination modes) of the MTMS. To evaluate the efficiency of the 1:2 teleoperated system and MTMS, the total time required to accomplish the work was compared with that required by two sets of the existing 1:1 teleoperated robotic system under the same conditions, as presented in Table 1.

Table 1. Comparison of working time between 1:1 teleoperated robot system and 1:2 teleoperated robot system

	1:1 (sec)	1:2 (sec)	Decrement ratio (%)
1st	72.9	56.6	16.3
2nd	83.4	68.5	14.9
3rd	80.9	69.0	11.9
4th	99.5	70.9	28.6
5th	101.3	79.1	22.2

As indicated in Table 1, the total valve hadling time was reduced by about 80% by the proposed 1:N teleoperated robotic system compared to the existing 1:1 system.

4 Conclusion

In this paper, a 1:N teleoperated robotic system and its associated MRTM software were proposed. The system enables cooperation between an operator and multiple robots for improved work efficiency. The proposed MRTM software was developed for valve handling in an offshore plant, but further study will be conducted to expand the application of the system to fields involving high dimensional tasks. Studies will be conducted to verify the practical application of the MRTM software to a variety of industries.

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