Technical Review of Force-Reflecting Telemanipulator System

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1. Introduction

In a broad sense, teleoperation encompasses all techniques that allow a human operator to replicate or manipulate from a remote position based on his ability to act on objects in real time through sensory feedback (vision, touch, motion and so on). In the nuclear industry, teleoperation is used to handle objects located either in inaccessible zones or dangerous areas (nuclear cells, sub-sea, and human body). Over the last several decades, the nuclear industry has remarkably contributed to the development of the useful tools for teleoperation. In the most general case of teleoperation system, a master system is handled by the operator and a slave one located in the remote area replicates the movements of the master. The first mechanical Master Slave Manipulator (MSM) was developed in 1948 by R. Goertz at Argonne National Laboratories. In MSM system, a mechanical connection using rod and cable is applied for force and movement transmission between the master and the slave workstations. However, this mechanism intrinsically has limitation of distance between the master and slave arm. To overcome this issue, servo-type manipulators were designed [1, 2], and the master-and-slave units which have the same kinematics are driven by electrical motors. Practically, a bilateral joint control is established to the servo manipulator: i.e. each movement of master arm is perceived and instantly mimic by the slave one. The level of control algorithm and operational reliability of such systems are now highly improved. This has been proven during the long-term evaluation of maintenance programs of experimental target facilities such as the Joint European Torus in the UK [3, 4] or the Spallation Neutron Source in the US [5]. Meanwhile, a computer-assisted teleoperation systems proposed in the late 90's and it was new evolutions focused on increasing the control sensitivity and interoperability between the equipment. Consequently, requirements for such type of systems were to develop an improved controller [6] that could address both master and slave systems even designed with different kinematics and actuation technologies [7,8,9]. Due to the different type of kinematics between master and slave arm, the control strategy for these systems in computer assisted teleoperation systems is generally performed in the Cartesian space (i.e. bilateral control between a reference tool-frame attached to the slave arm and a control grip-frame attached to the master arm). This scheme is generally applied in industrial nuclear hot cells [9] and finally recent developments introduced Virtual Reality (VR) techniques and supervisory control systems in an attempt to improve the efficiency of entire processes through the introduction to the programmed motions and assistances for the operator. In this regard, this paper presents the technical review of the force-reflecting manipulators widely used in the teleoperation systems of nuclear facilities.

2. Design Requirements for Force-Reflecting Telemanipulator

Table 1 shows the comparison of characteristics between a force-reflecting telemanipulator and industrial robot based on the generally accepted performances in each individual domains. Table 2 shows the design requirements for force-reflecting performance of a telemanipulator system and technical selections of transmission type for each parameter of force-reflecting performance.

Table 1. Comparison of performances between force-reflecting manipulator and industrial robot

Parameters	Force-Reflecting Manipulator	Industrial Robot
Friction	1~5 % of capacity	30% or larger
Backlash	Low to medium	No backlash
Input device	Master (Replica)	Teach pendant, keyboard
Deflection	2.5~5 cm at full load	No deflection
DOF	6 DOF arm with end effector	4~6 DOF arm with end effector

Controller	Bilateral force reflection with operator in the loop	Force reflection with direct sensing
Inertia	Relatively low (for minimum fatigue)	High (for high stiffness designs)
Kinematics	Approximately similar to human arm	Mission dependent
Accuracy and repeatability	Not important	Important
Total weight/ payload ratio	< 3	10 ~ 40
End effector	Universal	Interchangeable

Table 2. Design requirements of the force-reflecting manipulator

Requirements	Force-reflecting manipulator	Transmission	
		Wire	Gear
		Manipulator	Robot
Maximum speed (No load)	> 1 m/sec, > 6.28 rad/s (360 deg/s)		O
Joint index speed			
Maximum acceleration	1 g (unloaded) 0.5 g (loaded)		O
Damping (Load)			O
Backdrivability*	1~5 % of capacity	O	
Backlash	Low to Medium	O	
Deflection (Load)	2.5~5 cm at full load		O
Motion coupling	< 1 mm		O
Arm gravitational balance	< 0.4 kgf		
Payload/Weight ratio	0.1~0.25 (1/10~1/4)	O	

* Backdrivability means that a force applied at the end-effector will be reflected on the actuators.

3. Conclusions

This paper covers the technical review of performance of force-reflecting telemanipulator to understand the design concept and purpose of the considered system. As a future work, it is required to standardize the effective handling capacity with the corresponding static and dynamic safety factors. It is important in the nuclear facilities because the various kinds of customized telemanipulators could be considered for the target facility and those systems have to be compared with each other more quantitatively. Furthermore, up-to-date telemanipulator systems and their innovative applications need to be surveyed even the teleoperation systems in nuclear areas generally have a tendency to stick to the traditional approaches for safety and reliability.

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