Comparative Study of Servo-type Telemanipulator Systems for Nuclear Facilities

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1. Introduction

Practically, various control schemes have been established to the servo manipulator for teleoperation. The level of control algorithm and operational reliability of such systems are now highly improved, and these have been proven during the long-term evaluation of operation and maintenance programs. This study tries to classify the existing development cases of servo-type telemanipulator systems in a nuclear area, and introduce the specification of the BDSM developed by KAERI for the performance comparison [1-3].

2. Comparison of existing telemanipulator systems

Table 1 shows the typical classification of telemanipulator system according to the components, operation type and payload. Table 2 shows the characteristics of servo-type telemanipulators for their specifications, and several development cases are introduced as follows. First, the remote handling system for ORNL SNS hot-cell had developed for the facility maintenance. This system is a servo-type EMSM-2B (Telerob^{TM}) with 24 *kgf* payload and integrated with bridge transporter developed by PaR Systems. The target operation had started in April 28, 2006 and the 1st module replacement had performed in Aug. 2009. Second, the remote handling system for fusion had developed for remote maintenance in the nuclear fusion research facility by Joint European Torus (JET). The system has long reach with the articulated boom, and the servo-manipulator is based on the MASCOT-IV system with 20 *kgf* payload. This system extensively performed various remote tasks such as a welding, cutting, bolting, and inspection. Third, the equipment handling system operated in INL has around 5 *Ton* (4,540 *kg*) of maximum capacity with 3.91 *m* of maximum lifting height. A repair hoist (for maintenance only) and crane operated in INL has 6 *ton* and 5 *ton* capacity respectively. Table 3 shows the specification of BDSM system which has dual arm servo manipulator and telescopic tube mechanism for teleoperations in the confined argon cell of KAERI [4].

Table 1. Types of telemanipulator systems

Types	Components	Operation	Payload	
MSM (~45 kg) Mechanical force reflection	1. Dual arm master manipulator 2. Dual arm slave manipulator 3. Hot cell trough-tube	Through the working window, operate the slave system with master (Force reflection)	Middle and low payload (Material handling)	
EMSM (~25 kg) Electrical force reflection	1. Dual arm master manipulator 2. Dual arm slave manipulator 3. Bridge-transported system 4. Control panel (Camera, Monitor, Electric/Computing system)	Through the monitor, operate the slave with master (Force reflection)	Similar to MSM (Spatial transportation of low weight materials)	
PM (100 kg~)	1. Joystick (Master) 2. Slave manipulator (Single arm) 3. Bridge-transported (Slave attached) 4. Control panel (Camera, Monitor, Electric/Computing system)	Through the monitor, operate the slave with joystick (Force reflection is not applied)	Handling of high and middle weight materials	
Robot (~100 kg)	1. Joystick 2. Various kinds of robot system 3. Control panel (Camera, Monitor, Electric/Computing system)	Running the program and use the joystick for system operation	Repetitive works and Decommissioning	

Table 2. Comparison of the teleoperated servo manipulator systems

Model	Manufacturer	DOF (Master, Slave)	Type of DOF**	Lift Capacity (kg)***	Reach (m)	Tip Speed (m/s)	Force-Reflecting Ratios	System Launching (Year)
SM-229	Teleoperation Systems, USA	6, 6	PRPRPR	10	1.23	~ 1	1:1	1981
M2	CRL/ORNL, USA	6, 6	PRPRPR	23	1.26	0.15 (1.5)	1,2,4,8:1	1978-1983
ASM	ORNL, USA	6, 6	PRPPYR	23	1.40	~ 1	1:1 o 16:1	1983-1989
BSM	JAEA, JPN	6, 6	PRPPYR	23	1.40	~ 1	1:1 o 16:1	1982-1989
LTM	ORNL, USA	7, 7	PYPYPYR	20	1.40	>1	1,2,8,16:1	1987-1989
CESARm	ORNL, USA	7, 6	YPRPPYR	13	1.52	3.0	1:1 to 8:1	1990
Telemate	TeleRobotics, USA	6, 6	PRPYPR	12	1.1	>1	0.5 kgf ****	1992
EMSM-2C	Telerob, GER	6, 6	PRPYPR	10;	0.85	>1	1:1 to 4:1	1997
EMSM-2B	Telerob, GER	6, 6	PRPYPR	24;	1.6	>1	2,6,20:1	-
MA-23	CEA, FRA	6,6	PRPYPR	25		0.5~1.5	1:4	1979
MASCOT IV	Oxford Tech., GBR	6, 6	PRPYPR	12	1.43	0.79	1:1.5,3,6	-
BTSM	KAERI, KOR	5, 5	PPYPR	15	0.82	>1	1,2,4,6:1	2006
FSM	BARC*, IND	6, 6	PRPYPR	25	1.2	-	< 8 kgf	2009
BDSM	KAERI, KOR	6, 6	PRPYPR	25	1.52	>1	1,2,4,6:1	2012

*BARC: Bhabha Atomic Research Centre, ** P: Pitch, R: Roll, Y: Yaw, *** Continuous Peak, **** Force-Reflection Sensitivity,

Table 3. Specification of BDSM

Mechanical specifications (Replica type)		
Degree of freedom		6 + gripper/handle
Load capacity (Slave)		250 N (Continuous)
Force feedback capacity (Master)		50 N (Continuous)
Upper arm	Incline (axis 1)	± 45°
	Rotation (axis 2)	± 45°
	Length (mm)	600 (Slave), 375 (Master)
Forearm	Incline (axis 3)	± 45°
	Rotation (axis 4)	± 110°
	Length (mm)	800 (Slave), 500 (Master)
Wrist	Incline (axis 5)	+37 ~ -143°
	Rotation (axis 6)	± 170°
Grip opening width (mm)		0 ~ 100
Reach (Master/Slave)		0.95 m / 1.56 m
Total weight (Master/Slave)		45 / 165 kg
Power transmission		Gear/belt (#1), Motion-decoupled wire cable (#2~#7)
Contamination protection		Boots, cover
Electrical/Control specifications		
Motor type		BLDC with resolver
Motion control hardware		DSP controller
Motion control software		GUI (PC) Firmware (DSP)
Control algorithm		PD, PID, TDC, etc.
Camera		2 EA, attached to gripper

3. Conclusions

This paper covers a comparison of telemanipulators which have different specifications of in their geometry, actuation type and control strategy as well as the comparison of their performances and specifications with the ones of BDSM system originally developed in KAERI. As a future work, it is required to standardize the effective handling capacity with the corresponding static and dynamic safety factors. It is important, especially in nuclear facility when various kinds of customized telemanipulator systems have to be compared each other technically. Also, up-to-date telemanipulator systems and their innovative applications will be surveyed even the teleoperation systems in a nuclear area have a tendency to stick to the traditional approaches for safety and reliability.

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