TELEOPERATION AND TELEROBOTICS

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DEFINITIONS

According to Raimondi **[Raimondi,88]**, "The telemanipulator is a device which allows an operator to perform a task at a distance, in a hostile environment where human access is impossible or inadvisable." Telemanipulators are operated by a human operator. Teleoperator systems consist of one or more telemanipulators, task and environmental sensing systems, and a human machine interface. Hot cells for the nuclear power field have been one of the primary application areas for teleoperator systems because of the hazardous radioactive environment involved and because cost is not the primary concern. Underwater, space, and military applications are also important.

A telemanipulator is often composed of two manipulators¾a master manipulator that is held by a human operator and a slave manipulator that will perform (or try to perform) the desired task. The master manipulator is located in a safe, clean environment where information (typically visual, sound, and force information) is fed back from the slave manipulator to the human operator. Human-machine interface concepts are critical to the successful utilization of such systems. The slave manipulator is located at the intended task typically at some distance from the human operator.

A telerobotic system is a system that is capable of performing as either a telemanipulator (master/slave mode) or with the slave manipulator performing alone as a robotic manipulator. In the latter case, the slave's trajectory and forces/impedance are determined by computer commands rather than master-arm inputs. The advantage of having a merger of these two capabilities is that repetitive tasks have the potential of being automated, thereby diminishing the physical demands placed on the human operator.

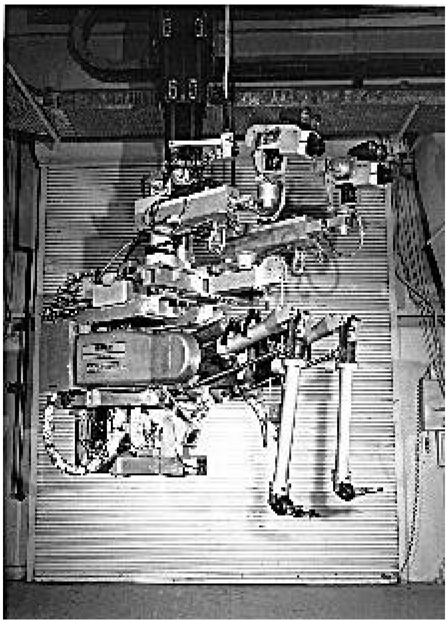
HISTORICAL PERSPECTIVE

In the late 1940s, Goertz and his colleagues at Argonne National Laboratory (ANL) developed one of the earliest recognizable mechanical master/slave manipulators without force reflection and later with force-reflecting capabilities **[Goertz,52]**. Force reflection refers to the capability of reflecting the external forces experienced by the slave manipulator to the master manipulator and is typically described as bilateral control: force on the slave (master) will cause the master (slave) to move. In the early 1950s, Goertz and his colleagues developed an electric master/slave manipulator in which each slave joint servo was tied directly to the master joint servo since both the master and slave were kinematically similar **[Goertz,54]**. Carl Flateau **[Flateau,65]** made major contributions to teleoperator development in the 1960s. Hydraulics, too, have been used from almost the beginning of this field, starting with the Handyman system developed by Mosher and his team at General Electric in the late 1950s **[Johnsen,67]**. Today, hydraulic actuators are not usually selected for high radiation environments because the hydraulic fluid and its associated seals suffer from radiation-induced degradation, but some examples of high radiation applications have been found **[Kaye,92]**. These two problems are ignored when significant payload to overall weight ratios are required, in which case, hydraulics are almost always selected. Interested readers can consult with Vertut **[Vertut,85]** for a detailed discussion of the history of teleoperator systems. Table 1 compares teleoperators with industrial manipulators.

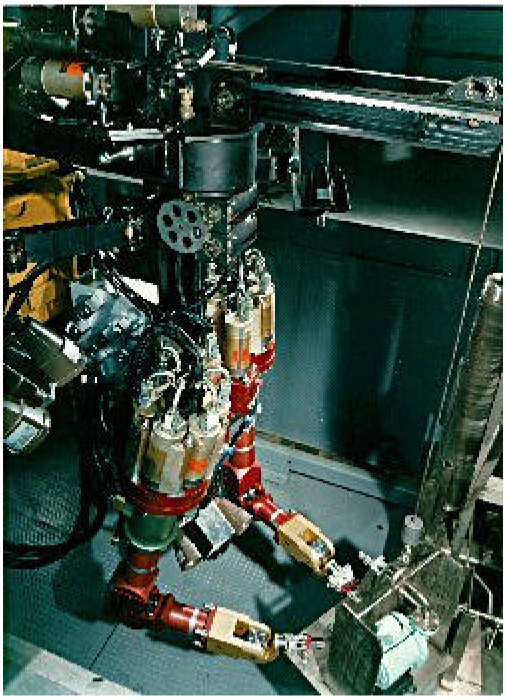
Table 1. Distinction between a telemanipulator and an industrial robotic manipulator.

Good force-reflecting teleoperator	**Good industrial robot**
1. End effector speed 0.91 m/s (36 in./s)	1. End effector speed 30 to 50 in.
2. Friction 1-5% of capacity (at expense of increased backlash)	2. Friction 30 to very large
3. Medium to low backlash	3. No backlash (at expense of increased friction)
4. Replica master control	4. Teach pendant, keyboard
5. 2.5- to 5-cm (1- to 2-in.) deflection at full load	5. Minimal deflection at full load (0.010 to 0.05 in.)
6. 6 DOF and end effector	6. 4 to 6 DOF and end effector
7. Bilateral position-position control for force reflection with man in the loop	7. Force feedback with 6-axis end effector sensing
8. Relative low inertia for minimum fatigue	8. High stiffness designs yield high inertia
9. Kinematics approximately manlike	9. Kinematics mission dependent
10. Accuracy and repeatability not important	10. Accuracy and repeatability very important
11. 1:40 to 1:10 capacity/weight ratio	11. 1:40 to 1:10 capacity/weight ratio
12. Universal end effector	12. Interchangeable end effector

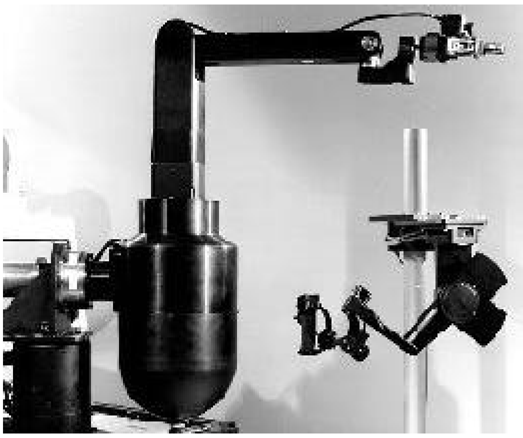
PHOTOS OF SOME TYPICAL TELEOPERATOR SYSTEMS



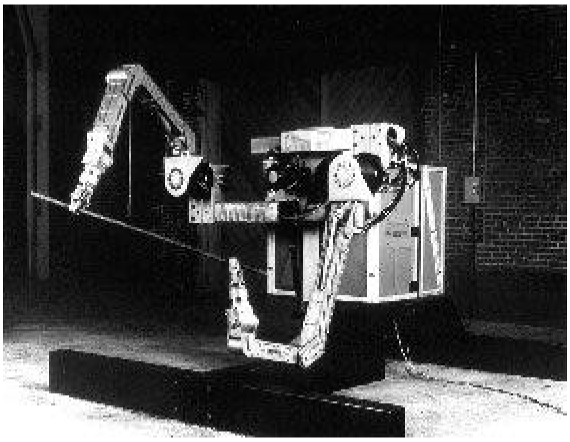
M2 Servomanipulator Slave Side



Advanced Servomanipulator Slave Side



The CESARm/Kraft dissimilar teleoperated system



The Dual Arm Work Module Slave Manipulators (Two Schilling Titan II Arms)

EXAMPLE TELEOPERATOR SYSTEM DATA

The following tables summarize the major features of the teleoperator and telerobotic manipulator systems developed at Oak Ridge National Laboratory (ORNL) **[Kress,97]**. Table 2 provides the mechanical and control system specifications, and Table 3 provides the computer specifications.

Table 2. Example of telemanipulator specifications from systems developed at Oak Ridge National Lab.

System Name	Elbow Config.	DOF*	Type of DOF	Lift Capac.	Reach	Tip Speed	Act. Type	Force-Reflecting Ratios	Date
				(kg)**	(m)	(m/s)			
SM-229	up	6,6	PRPRPR	10	1.23	~1	ELE	1:1	1981
M2	up	6,6	PRPRPR	23;46	1.26	1.5	ELE	1,2,4,8, 8:1	78-83
ASM	down	6,6	PRPPYR	23;46	1.40	~1	ELE	1:1 to 1:16	83-89
LTM	down	7,7	PYPYPYR	20;30	1.40	>1	ELE	1,2,8,16:1	87-89
CESARm	up	7,6	YPRPPYR	13	1.52	3.0	ELE	1:1 to 8:1	1990
DAWM	either	6,6	YPPPYR	109;544	1.99	>1	HYD	1,2,8,64 8:1	1993

* Master, Slave
**Continuous; Peak.

Table 3. ORNL teleoperated manipulator computer specifications.

System	CPU	Bus	Language	Operating System	Loop Rate (Hz)
M2 Master/Slave	(37) Intel 8031	Custom	Assembly	N/A	53
M2 Operator Interface	Z80	S100	Basic	CPM	N/A*
ASM Master/Slave	(15) Motorola 68000	(7) Multibus-I	FORTH	Poly FORTH	100
ASM Operator Interface	(1) Motorola 68000	Multibus-I	FORTH	Poly FORTH	N/A*
LTM Master/Slave	(9) Motorola 68020	VME	C	0S-9	250/500
LTM Operator/Interface	Macintosh 68020	NuBus	C	Mac OS	N/A*
CESARm	(3) Motorola 68020	VME	C	OS-9	100
DAWM Master/Slave	(5) Motorola 68030	VME	C/C++	VxWorks/ Control Shell	120
DAWM Operator Interface	Sun Sparc R4000	Sparc 5 SGI	C/C++	UNIX	N/A*

* Event-driven processes so loop rate is not applicable.

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