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Remote Handling Teleoperators in Hostile Environment

°J.S. LEE, J.S. YOON
Korea Advanced Energy Research Institute

Abstract : Teleoperator as a special robotic system for remote handling in hostile environment is reviewed in this article. Inherent features and prospective applications pertinent to teleoperator are indentified with particular concern for nuclear applications as major area of teleoperator technology exercise. Korean status as well as major world programs of teleoperator R&D are also reviewed with perspectives.

1. Introduction

Robotics became a popular topic now with sincerely inside and with curiosity outside technical communities. While robot builders are concentrating efforts toward better motor control and sensor signals, the public is fascinated by the idea of dancing or flying robots of humanoid sorts. Down the application area, engineers are bustling over bulky technical documents to look "here and now" service for a particular robotic task in mind. They may be nuclear engineers trying to take radioactive materials out from contaminated enclosure or marine engineers trying to recover precious rocks from deep sea.

Teleoperation or telemanipulation is a technological exercise from human intention to extend his physical effort into work spaces which are difficult or impossible to access. Teleoperator or telemanipulator would thus be appropriate machine system that would enable such mechanical operation at distance.[1]

Useful applications of teleoperator are, among others, remote handling in hostile environments such as radioactive, toxic, excessive pressure or temperature environments. Nuclear has been the first and still the major application area of teleoperator technology which is now expanding into deep sea or space.

Tepeoperator design is much dependant on the hostile environment which is usually ill-defined than manufacturing line using inaustrial robot. Intervention for odd tasks in odd locations is the major use of teleoperators. Prerequisite of this kind of interactive operation is the following functions ;

- o Identification of problem
- o Decision of strategy
- o Execution of task

In conventional teleoperation, all these

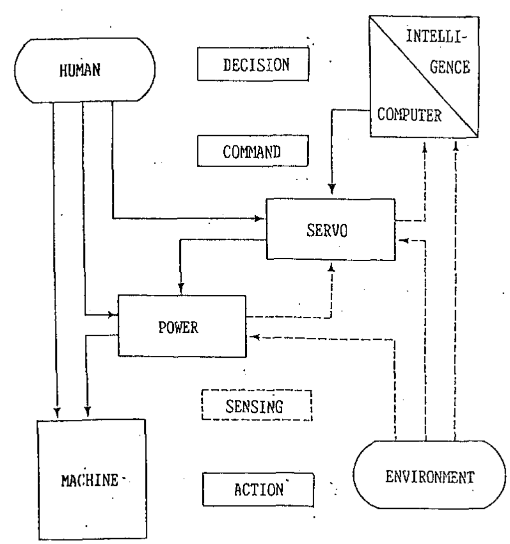

Figure 1. Teleoperation system elements and information flow relations.

procedures are supervised by a human "mastor" who is himself integrated in the interactive loop to control the mechanical "slave". He or she takes care of the first two fuctions which are partly replaced by machine system. Modern anticipation of robotics is totally autonomous robotic system which would make the meaning of teleoperation robotic system obsolete if no connection between the human master and machine slave is supposed. Highly effective sensory systems and machine intelligence well integrated with high performance manipulator would be the direction to the cybernetic goal. (Figure 1)

Current practice of teleoperator application is parallel use of those various manipulator types ; master-slave, power, bilateral servo etc. depending on required access range, handling capacity, dexterity, etc. (Table 1) Commercial appearance of different teleoperator types in the past market has been at a pace of decade. M/S type in the fifties, power type in the sixties and servo type in the seventies. The past eighties have shown a tendency to apply various technology elements from industrial robot development. Machine intelligence coupled with highly sophiscted sensory system is the encouraging aspect worard autonomous teleoperator in similar trend to flexible manufacturing system in factory floor by industrial robot. Of particular interest in recent teleoperator development seems focussed on mobile robots with as much as sensory and intelligent provisions. The trend should continue in the coming decade.

Most early efforts of teleoperator development have been made through large national programs such as nuclear, space, undersea, etc. Recent trend shows merging of government effort with those of commercial or academic sector toward an integrated multidisciplinary program. In Korea, teleoperator has attracted concern only recently

Generalized Manipulator features	Mech. M/S Manipulator	Power Manipulator	Force Reflecting Servo Manipulator
Capacity	Light duty 4 – 9 kg Heavy duty 23 – 48 kg	60 – 180 kg [a]	10 – 48 kg
Weight/Capacity	Poor	Very good(1:0.8~1.5) [a]	Poor(3~12:1)
Volumetric coverage	2.5 by 2.5 m	full volume [b]	full volume
Ease of multi-joint operation in real time	Excellent	Poor(switch control) Better(joystick control) [c]	Excellent
Force reflection	Good	None [d]	Very Good

Table 1. Summary of characteristics of different teleoperator types.

with the nuclear power program. Backed up by robotic technology already launched in industrial sector, Korean contribution to teleoperator technology has good perspective.

2. Types of Teleoperator

Teleoperator, originally intended to replace human arm and hand by mechanical extension was pioneered by R. Goertz of ANL during the wartime effort to handle radioactive material in protective enclosure. Following several decades have withnessed evolution of teleoperator technology up to modern mobile robots. (Figure 2)

Master-Slave (M/S) Type

Human master (operator) exerts physical manipulative force to slave machine which mimicks exactly master's control action through direct mechanical linkage between the two counterparts. This type has since then sufficiently been optimized to commercial perfection with sales record of some 15000 units mostly for nuclear installations throughout the world.

In this type, the slave manipulator is entirely passive in its action which is observed by the human operator through the protective window[2]. There is, however, counteractive transmission of manipulative force from slave to master by the mechanical linkage. This apperently helps the operator with "muscle feeling" of the operation although it can cause him physical fatigue. Auxiliary systems to aid manipulative force has been developed in many models.

Even though this ingenious mechanical invention has offered invaluable services of teleoperation, its access range is limited to only several meters due to restrictive mechanical extension. Handling capacity is another limitative factor of M/S type manipulator which is not beyond that of human equivalence. These limitations inevitably call for motorized power in the slave operation.

Power (Electro/Mechanical) Type

Larger access range and heavier duty manipulators call for motive power and human involvement in the operation is diminished. Electrical power drive is the most convenient system to this purpose. Mechanical link of M/S type is thus replaced by electrical cable which is far more extensible and flexible to link the operator with manipulator[3] .

Crane operation transporting the slave arm driven by appropriate motors is just the principle. This independence from human operator finds its similarity with industrial robot in that the operation is programmed type in open loop. Improved access and load handling ability of E/M manipulator by motorization pay its cost by reduced intimacy with human operator. For interactive teleoperation, this is an important handicap which would be less severe were it repetitive operation on manufacturing floors. This unilateral action of E/M manipulator has to be complemented by some means of feedback system to make it bilateral for more useful teleoperation system.

Servo Type

Further improvement of E/M type manipulator by applied force feedback was achieved also by Goertz ten years after his first M/S manipulator. Continuous measurement and control of acting mechanisms by power supply to the motors of slave manipulator enable interactive teleoperation from master counterpart with some ratio, the whole system is then a similtude to M/S type of mechanical vantage with E/M type mobility. In each couterpart (master/slave) local force feedback loop is established and communication between the two equivalent systems is done in continuous and interactive manner. The bilateral feature of servo manipulator enables, above all, improved safety and performance of teleoperation[4] .

Servo manipulator is considered to be actually the most advanced type of teleoperator and occupies the core position of various modern robotic teleoperation. Current efforts are directed toward more advanced versions such as intelligent, sensory, mobile ones. Dual arm versions which has more resemblance to human morphology with sensory functions are in demonstration stage. For maintenance task in nuclear installations, comparative study at ORNL on several alternatives of different teleoperators by combination shows clear advantage of servo manipulator. (Figure 3)

Mobile Type

Apart from the M/S type which is usually fixed to a location on shielding wall, E/M or servo type manipulators are in fact mobile within their operation boundary which is usually limited by manipulator transperator access range. Most common installation of these motorized types in nuclear enclosures is the pended mode even though floor or wall mounting is also possible. The transporter is usually moved on rails installed for X-Y direction and vertical (Z direction) movement is assured by telescopic coulumn. In maintenance operation by these types of manipulators, careful design of the installation to be serviced is also important. Equipment design with modular concept and replaceable parts with easy connection/disconnection are encouraged to facilitate the operation wherever possible in nuclear installations.

What is meant here by mobile type is autonomous navigation. There are many cases of teleoperator intervention with no provision for easy access to locations of problem. Nuclear power plants, for example, are very complex design with many inaccessible areas. Mobile teleoperators with wheels or legs are developed to get them into problem locations for maintenance. Well

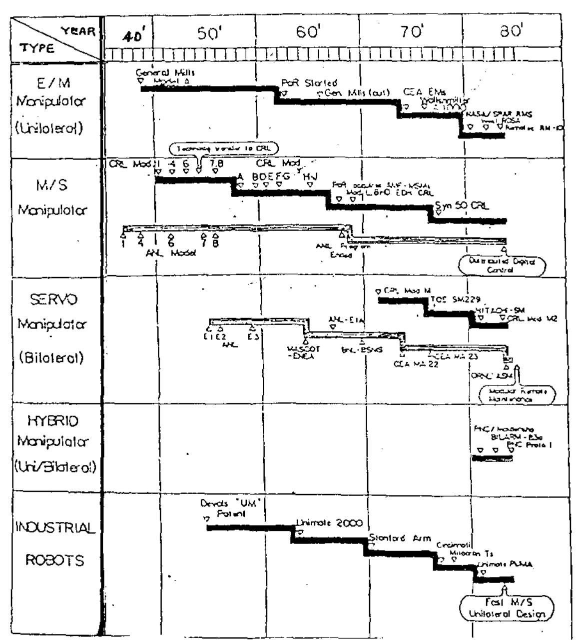

Figure 2. Geneology of manipulator developments in public (solid) and private (fade) sectors.

known case is the Three Mile Island plant where several robots of mobile type are reportedly introduced for various tasks. As standard of safety regulation to plant worker getting severer, much effrots are requested for mobile teleoperator that would render services of dose rate reduction to human body. Recent report from U.S on Robots Users Group activities shows such concern[5]

Space and deep sea applications are potential areas of mobile type teleoperation. Sample collection on the moon or in deep ocean has to be done by mobile type teleoperators. There are other areas of application such as mining, military, etc.

Articulative motion control principle of other types of teleoperator should equaly be applicable to mobile teleoperators except navigation mechanism. Machine intelligence also plays important role in mobile teleoperator given its autonomous nature of action in close integration with sensory and communication function. Due to the diversity f application, considerable number of different models have already been produced (Table 2) and this seems to multiply in the future.

3. Status and Perspectives

U.S.

Fist and the largest programmes of teleoperator development are U.S. initiatives. Government programs for nuclear (AEC) and later space (NASA) applications are followed by commercial manufacturing of various and models. By the largest sale in the world M/S manipulator is recorded by CRL and power type by PaR.

Several national laboratories continue their efforts to improve existing designs or develop new designs. ORNL demonstration of its prototype ASM which is bilateral servo type of two arms is representative.(Figure 4) More recent CESAR program is another example indicating new direction of U.S. national initiative aside from many other commercial or academic activities[6] . With hi-tec mood, U.S. teleoperator would probably be on the frontier to sometine to come at least.

Europe

Several european countries have followed U.S. efforts with some time delay. Some unique European designs are competitive with U.S. designs. Servomanipulator developed by CEA (France) for nuclear maintenance (Figure 5) is reported to be applied for underwater operation with some modification. A comprehensive program of U.S. equivalence (CESAR) has recently been launched also in France[7] . Harwell (U.K) reported its M/S model with hydraulic steering[8] and GEC announced new model of high performance Germany has done notable efforts also.[9] HWM (W.G) models of power type teleoperators are well known in world market. Other countries in Europe are known to have their respective programes of R&D or application.[10]

Japan

Japanese efforts are better known in industrial robots than in teleoperator development. Systematic programs seem to have started recently.[11] PNC prototype BILARM in demonstration is hybrid equivalence of ASM, in U.S. with simular morphology (Figure 6). Utilities effort for mobile robots, assisted by local robot makers are, remarkable. Teleoperator technology is very promising in Japan.

4. Korean Program

Several programmes of robotic activities are already in progress in academic and industrial sectors in Korea.[12] Expanding industries, expecially electronic and automotivce manufacturing, are showing strong interest in plant automation

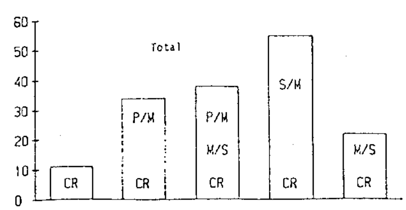

Figure 3. Comparative performances between different types of teleoperators(ORNL)
CR = Crane
M/S = Master-Slave Mechanical Manipulator
P/M = Power (E/M type) Manipulator
S/M = Servo Manipulator

facing up potential lobor problems. Advanced R&D programs are also hosted by government plans which include computer and robotics.

Current programs of teleoperator development are negligible, however, in Korea. Several units of M/S and power manipulator have been installed at nuclear research installations at KAERI up to now only for operative purpose. Few more units are installed in other places for similar use. In Remote Technology Department of KAERI, more systematic study of teleoperation with major focus on nuclear applicationha has just been initiated. The primary goal is to computerize existing teleoperator model (HWM A1065) (Figure 7) and to provide with sensory performance. Further steps of our efforts are ;

- o Vision and force sensing
- o Application of AC power drive system
- o Remote communication with the slave
- o Machine intelligence application
- o Bilateral servo prototype of dual arm.

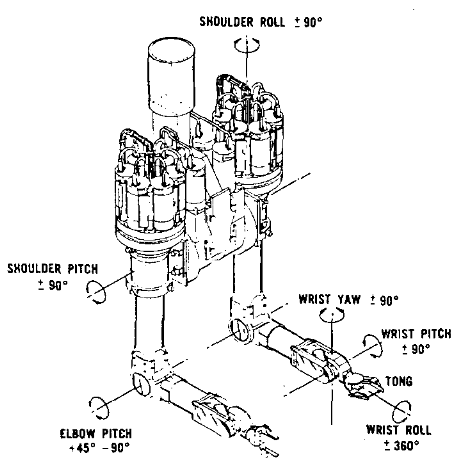

Figure 4. Advanced Servo Manipulator (ASM) of Oak Ridge National Laboratory.

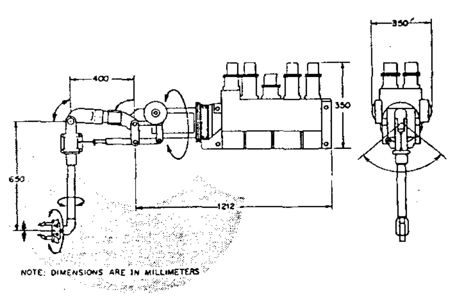

Figure 5. MA-23 Servo Manipulator of Commissariat d'Energie Atomique.

5. Conclusion

Teleoperator has special features of application in hostile environments. Remote handling of untouchable materials in inaccessible area with varying access range and performance is typical of teleperator task. Servo type manipulator is the most useful in shielded hot cells and mobile type robots are promising for remote maintenance in larger and complex environment. Several countries having substantial experiences in teleoperator technology are now looking for expanded application through more comprehensive development programs.

Korean programs of teleoperator R&D have just been initiated with little experience. With fast growing concern for advanced technologies in Korea, contribution to teleoperator technology is expected not too far.

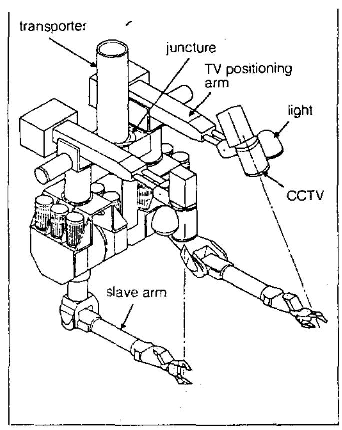

Figure 6. BILARM-83A Servo Manipulator of PNC (Japan)

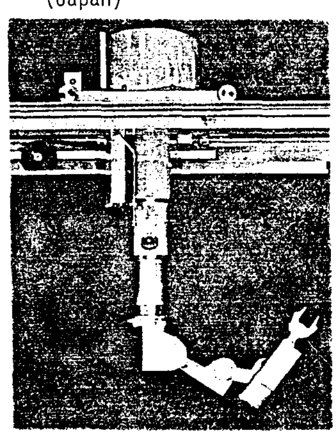

Figure 7. Power Manipulator of Hans Wallishmeir installed at Korea Advanced Energy Research Institute.

Manufacturer (country) Name of device	Locomotion/ primary mission/ status
ACEC (BL)	
Telemac Vampire	T N A
Andrus	T E A
Allied Chemical – Bendix (US)	
Rover (Bendix)	W E R
Analytical Inst. Ltd (UK)	
Ro-Veh	WT E A
Assistance Industrielle Dauphinoise (FR)	
AID – RM 200	W E A
Automation Technology Corp (US)	
Surveyor	T N A
Battelle Columbus Laboratory (US)	
Rocomp	T N 1
Bechtel National/GPU Nuclear Corp (US)	
Louie-2	W N 1
Blocher-Motor GmbH (FRG)	
MF3 (Blocher)	T N A
MF4	T E A
Carnegie-Mellon University (US)	
RRV (CMU)	W N 1
Remoteborer	W N 1
RWV	W N 1
Cimcorp (US)	
PAR-1	T N N
PAR-2	T N N
Herman	T N 1
Louie-1	T N 1
GCA Par-1	T N A
Commissariat à l'Energie Atomique (FR)	
Virgule	W N A
Commissariat à l'Energie Atomique/ Matra (FR)	
AMPR2	T EHN D
Cybermation Inc (US)	
K2A	W MI A
Denning Mobile Robots (US)	
Sentry (Denning)	W S A
ENEA (formerly CNEN) (IT)	
Mascot	W N R
ENEA/Ansaldo (IT)	
AMRI	W EHN D
Foster-Miller Inc (US)	
Ramrod	T E N
Ferret (F-M)	T E A
Recorm	T MI D
Framatome (FR)	
Frastar	T N A
Gesellschaft-Karlsruhe (FRG)	
MF2	T N A
Global Fire Equipment Corp (US)	
Fire-Cat	T F A
GMH Security (US)	
Snoopy	T E N
Gould Inc (US)	
Samson	T M D
Hitachi (JA)	
P 5	W N D
FMR	L N D
AMR	T N D
Hodges Robotics (US)	
Fred	W FN 1
Hovey & Associates (CN)	
Ferret (Hovey)	T E A
Hughes (US)	
Mobot-1	W N R
Mobot-2	T N R
India Atomic Energy (IN)	
	N
Inspectronic (FR)	
Ariane	T N A
Oscar	T N A
Oreste	T N A
Japan Atomic Energy Research Institute (JA)	
MWS	T N 1
Kentree Ltd (IR)	
Hobo	W E A
Kenure (Casa) (UK)	
Wheelbarrow MK 8	T ME A
Lawrence Livermore Laboratory (US)	
Atom	T N 1
MB Associates International (US)	
Roboteer	T ME R
Meidensha Electric Manufacturing Co (JA)	
Meirobo	T NH A
DCR	W N A
DIR	W N A
Ministry of International Trade and Industry (JA)	
CDRV	T N D
Mitsubishi-Kobe Shipyard (JA)	
CRDM Mobile Car	W N D
C V Robot	WL N D
Underwater Robot	W N A
Mitsubishi Electric Corporation (JA)	
MRV-1	T N D
Monitor Engineers Ltd (UK)	
Hadrian	W EM A
Morfax Ltd (Narco Associates) (UK)	
Wheelbarrow MK 7	T EM A
Wheelbarrow MK 7M	T EM A
Marauder	T E A
NTG Neue Teknologie GmbH (FRG)	
MF 3 (NTG)	T N A
NTG2 Arms	T N D
Odetics Inc (US)	
Odex-3	L N D
Robin	L N 1
Ove Pilskar AB (SW)	
Walking Viking	T EM A
Pedsco-Canada (CN)	
RMI-1	W E A
Pentek Corporation (US)	
Moose	W N A
PLS International (US)	
Eric	T H A
Remote Technolog Corp (US)	
Surbot	W N 1
Surbot-A	W N D
Surbot-T	T N D
Robot Defense Systems (US)	
Prowler	W S N
Robotic Systems International Ltd (CN)	
Hazcat-M500	W NH 1
Hazcat-M100	W NH D
Rockwell International Corp (US)	
Worm	T N 1
SAS R & D Services Ltd (UK)	
Hunter I	WT E A
Hunter II	WT E A
SNE La Calhene (FR)	
Romain	T N A
Standard Manufacturing Co (US)	
Mars-V	W MI A
Sumitomo Electric Manufacturing Co (JA)	
IRS	W N A
Toshiba Corp (JA)	
TBIS	W N D
LCR-1	D N D
21st Century Robotics-Sivan (IS/US)	
Wasp (TSR-700)	W EM A
TSR-150	W EM D
Hornet (TSR-70)	T EM A
UK Atomic Energy Authority (UK)	
Roman	T N A
Spider	T N A
University of Tokyo/Miti/Toshiba (JA)	
Amooty	W N D
US Navy (US)	
Rover (US Navy)	T EM N
Firefox	W F R
P16	W F D
Robart-2	W S D
Vale Security (UK)	
Scout (Vale)	T E A
Viking Energy Corp (US)	
Rod	W N A
Westinghouse-Hanford (US)	
Sisi	T N N

Table 2. Summary of mobile teleoperators (Nuclear Engineering International '87)

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