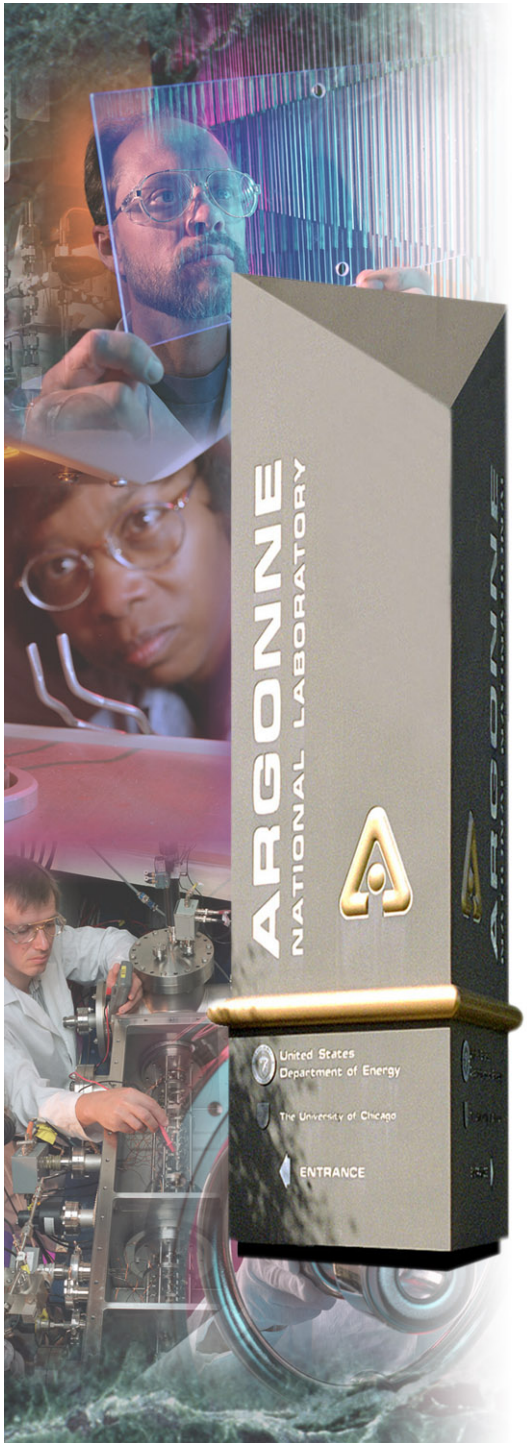


Use of Robotics in Radiological Areas

2nd High Power Targetry Workshop

October 13, 2005

Young S. Park
Robotics Laboratory
Nuclear Engineering Div.

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Contents

- **Introduction of remote handling / robotic equipment**
- **Review of requirements and options for remote handling systems in high power target stations**
- **Identify challenges in RIA target handling**
- **Suggestions on telerobotic technologies**
- **Conclusion**

Remote handling equipment:

Mobile Manipulator

EMM, 1:60-80, 250kg

M-S Manipulator 1:8

Servo Manipulator, 1:8

- **Transporters**
  - Cranes
  - Mobile Robots/Trolley
  - Telescopic Transporters
- **Teleoperators**
  - Master-slave manipulators
  - Servo manipulators
  - Electro-mechanical manipulators
- **Robotic Manipulators**
  - Industrial Robots
  - Force / Haptic Controlled Manipulators

Environments and Robotic Technologies

	Structured	Partially Structured	Unstructured
Characteristics	Complete and precise environment model available	Environment model available, and updated with sensing	-Environment model built from sensing, difficult
Representative Facilities / Environment	Manufacture / Production Lines	Nuclear/ Waste Facilities Accelerators Hot Cells Surgery (hard tissue)	Accident Remediation Nuc. Decommissioning Space/Underseas/Mining Surgery (soft tissue)
Representative tasks	Material processing Material handling	- Material handling - Inspection/Maintenance - Plant operation	Exploration Sampling Transport
Manipulation Equip.	Industrial Robots	- Cranes + impact wrench - Teleoperators: M-S / EM / Servo manipulators - Industrial robots	-Telerobotic Manipulator: servo or ind. manip. with advanced control -Haptic manipulators
Material Transporter	Cranes Conveyors AGVs	- Cranes - Overhead transporter - AGV / Mobile robots	Cranes Mobile robots
Emphasis	Efficiency, Accuracy	Efficiency, Accuracy, Flexibility, Reliability	Flexibility, Reliability, reactive control prefered
Operation Modes	Programmed Automation	Manual / Semi-automatic / Guided teleoperation	Manual teleoperation, Autonomy

Few Facts about Remote Handling

- Remote handling systems are
  - slow,
  - imprecise, and
  - may introduce additional maintenance needs
  - Require experienced operator, which is scarce and difficult to train

- Thus, its use must be justified, based on
  - Level of radioactivity
  - Replacement cycle

What about
High power driver accelerator targets

Source	Facilities	Status	Target Material	P-Beam Energy	P-Beam Intensity	P-Beam Power
Neutron	**ISIS** (RAL, UK) LANSCE (LANL, USA) SINQ (PSI, Swiss) SNS (ORNL, USA) ESS MLF (JPARC, Japan)	Existing Existing Existing/plan Under constr Under study Under constr	Ta W Pb/Pb-Bi Hg Hg Hg	800MeV 800MeV 590MeV 1GeV 1.3 GeV 3GeV	200 ❍A 1.8 mA	160 kW 160 kW (1 MW) <4 MW 5 MW 1 MW
Special use of Neutron	IFMIF* APT** (SRL, USA)	Under study Under study	Li W	40 MeV 1.7 GeV	250 mA 100 mA	(10 MW) 120MW
Radioactive Ion	ISOLDE (CERN, Swiss) HRIBF (ORNL, USA) **ISAC** (TRIUMF, Canada) SPIRAL (GANIL,France) SIRIUS (RAL,UK) SIS (GSI, Germany) RIBF (RIKEN, Japan) RIA (ANL-MSU, USA) EURISOL(GSI, Germany)	Existing Exisitng Existing Existing ? Existing Under study Under study Under study	Various Ge, Al U C W ? (Solid) Li Hg	1 GeV 60 MeV 500MeV 25 MeV 800MeV 350MeV/u 900MeV 400MeV/u 2.2 GeV	2 ❍A 50 ❍A 100 ❍A 0.1 mA	(2kW) (3 kW) (50 kW) 80 kW 400kW 4 MW
Neutrino/ Muon	Neutrino Factory (USA) NuMI (FNAL, USA) MLF (JPARC, Japan) Neutrino target (JPARC)	Under study Existing Under study Under study	Ta C C C	16 GeV 120GeV 50GeV	 15 ❍A	4 MW 0.4 MW 1 MW 0.75MW
Hadron	Hadron target (JPARC)	Under constr	Ni	50GeV	15 ❍A	0.75MW

Remote Handling Needs at High Power Target Stations

- High power particle accelerators require remote handling systems for service and repair, because of
  - high level of radioactivity
  - frequent maintenance cycle
- Target maintenance, replacement, handling and disposal must be addressed in collaboration with the remote handling system design.
- Areas of the target station that require remote handling;
  - the target and target material processing/supply system,
  - the shielding components,
  - the cooling systems
  - the beam dumps (periodic non-contact servicing)
  - other subsystems - vacuum, magnet, and inert gas distribution
- Affordable remote maintainability can only be met if sufficient attention is given to all aspects of remote handling in early stages of component design

Target system designs and remote handling

- Target system designs for remote handling

Target Module Type	Neutron Beam Facility	RIB Facility		
		ISOL	In-flight Frag.	ISOL / In-flight
Vertical Shielding Plug	TRIUMF, LANCE, SINQ			
Large Horizontal Trolley	**ISIS**, SNS, MLF, ESS	(SIRIUS)		RIA(?)
Large Vertical Shielding Plug		**ISAC**, (SIRIUS)		RIA(?)
Small Target Module		ISOLDE, SPIRAL, HRIBF		RIA(?)
Others	IFMIF, APT		MSU, GANIL, RIKEN	RIA(?)

- Remote handling of core components
- Remote handling for servicing cooling water, liquid target loop, vacuum and inert gas distribution system

Comparison of Two Target Module Designs

- **Large Trolley Type (ISIS, SNS)**
  - The remote maintenance of the TRAM involves the replacement of individual components rather than large modules
  - Pros:
    - *Flexibility (straightforward to deal with unexpected)*
    - *Less costly to maintain spare*
    - *Easier to maintain small clearance between components*
  - Cons:
    - *Individual component replacement requires the whole facility to be shutdown while remote handling tasks are undertaken*
- **Large Vertical Shielding Plug Type (ISAC)**
  - Larger target system that is self-shielded to the extent that some of the servicing activities can be performed manually
  - The target can be replaced in a hot cell with manipulators

***Both Remote handling not verified for Liquid metal target maintenance**

Challenges in RIA Target Remote Handling

- High radiation environment
- High power liquid target
- Potential loose contamination
- Require precise alignment
- Complex facility/system components

Design Guidelines :

- **Component/Layout design for easy remote maintenance**
- **Efficient and Precise remote handling system**

  -> integrate robotic & automated systems
- **Flexible and Reliable remote handling system**

  -> man-in-the-loop control (teleoperation)
- **Incorporate remote handling at early design stage**

Remote Handling Technology Options

- **Teleoperation is versatile, but slow and inefficient. So its use is validated only in very high radiation environments, or entirely remote places.**
- **Automation is inflexible, and unreliable due to the lack of adoptability to changes in task conditions**

- **Semi-automatic Teleoperation technologies:**
  - Combine teleoperation and automation for flexibility, efficiency and precision
  - Need to adopt innovative Robotics technology

What is difficult:
the innovative edges of robotics technology to look for

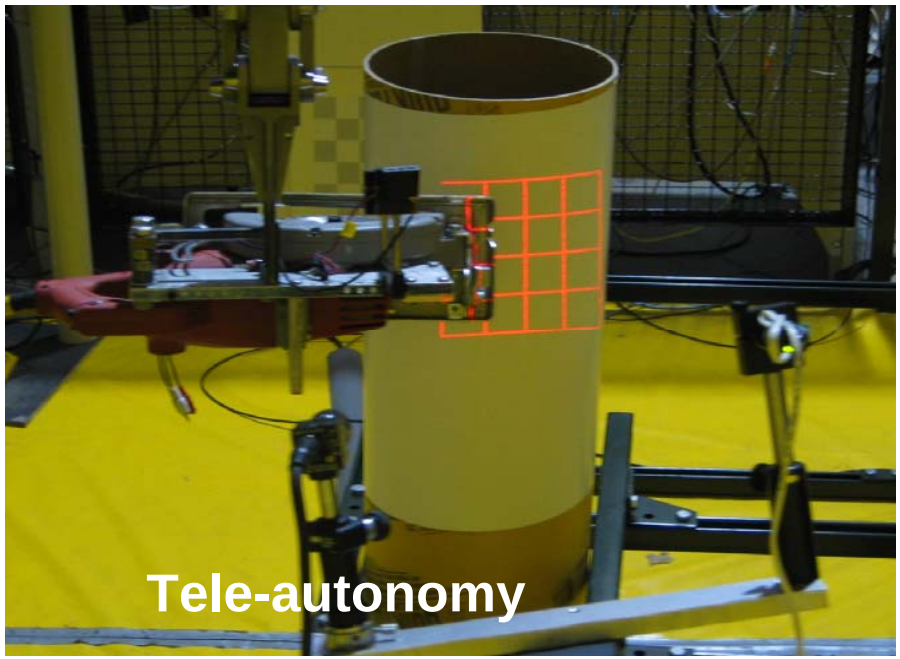
- **Recent Hypes in Robotics Technologies innovations emphasis on mobility and intelligence, thus adds on 'flexibility' and 'efficiency',**
  - e.g. emergency response, battlefield, service, silver, entertainment, exploration,
  - Non-contact tasks / or pick-and-place tasks – sensing, calibration, and manipulation/navigation at coarse level (easier)
- **But Not on 'Precision'**
  - e.g. remote maintenance, some D&D, manufacturing
  - Contact tasks
    - *Precise sensing and calibration on-the-fly is difficult*
    - *Point-to-point motion vs. trajectory motion*
- **Payload capacity is another bottleneck, but not much we can do about it.**

Some Enhanced Teleoperation Approaches
(Argonne National Laboratory / DOE-EMSP)

- **Tele-autonomous Operation**
- **Virtual Fixture**

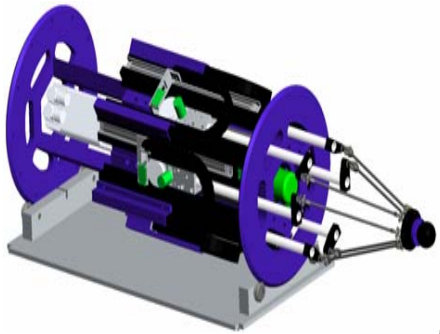
Tele-autonomous Operation

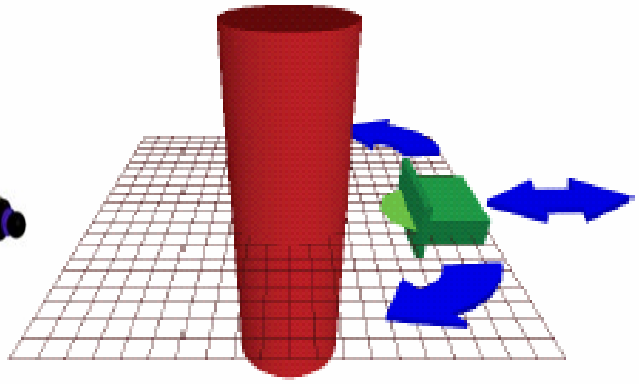
- **Blending human and robot automation**
  - Robot performs precise manipulation based on sensing
  - Human operator performs high-level decision making
- **Analogy: Cruse control, Airplane autopilot in landing**

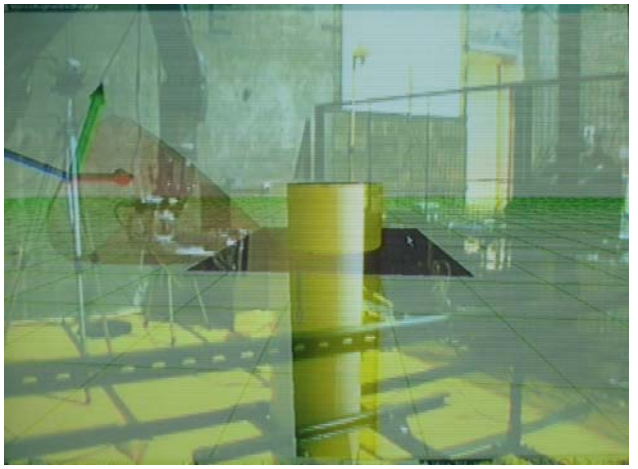


Virtual Fixture

- 'Virtual Fixture':
  - Computer generated surface that can assist teleoperation
- Approach similar to 'Navigation' in computer assisted orthopedic surgery
- Haptic display
- Other displays (auditory, visual) can also be beneficial







Summary of Advantages
(of Enhanced Teleoperation Approaches)

- **Teleautonomy: Bottom-up approach to automation**
  - Not trying to automate too much
  - But define a few elementary motor behaviors and provide robotic architecture that blends with human operation
- **Virtual fixture provides passive (safe) and precise manipulation**
- **Take advantage of known geometry of unstructured environment and/or simple and effective sensing methods to provide for 'precision' manipulation**
- **Motor behavior and Virtual Fixture**
  - Relationship exist between them (trajectory and path behavior)
  - Synergy can be accomplished
    - *For different tasks*
    - *For complementary roles in a same task*

Gaps to be filled

- Adopt the enhanced teleoperation technologies for the RIA Target environment:
  - Sensing and Environmental Modeling on-the-fly
  - Virtual fixture that simplifies operator task
  - Autonomy
  - Demonstrate effectiveness for critical tasks:

    e.g. handling for connections for liquid and vacuum
- Target design which facilitates efficient assembly and disassembly of lithium target and loop components
- Payload issue: Use of Advanced Electro-mechanical Manipulators

Conclusion

- RIA target remote handling involve difficult manipulation tasks, that require both reliability, flexibility and precision
- Some recent enhancements in telerobotics technologies may be leveraged to accomplish such requirements
- Such critical issues in remote handling system for RIA must be adequately addressed :
  - Detailed review of target system remote handling requirement, and identification of development needs
  - Verification of applicability of enhanced telerobotics
  - Target design for easy maintenance
- It is important to address these R&D issues at early stage of RIA target system design