Remote Technologies

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IAEA-ANL Training Course
on
Nuclear Facility Decommissioning & Environmental Remediation Skills
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Outline

• When to use remote systems and why
• Types of remote systems and what will be covered
• Early tools still work—long handled tools
• Early remote controlled techniques
• Servomanipulators
• Special tooling
• Robotics and telerobotics
• Example systems/projects and lessons learned

NOTE: Implementation guidelines discussed throughout
When to Use Remote Systems and Why

- Time/distance/shielding—radiation and contamination
- Use suited humans when it is safe because they are faster, but…
  - PPE can cause heat stress
  - Sometimes rad levels are just too high
  - Sometimes it’s too much trouble to deal with the contamination
- Remote systems are needed when human access is not possible or practical...often not used due to cost.
Limitations to Remote Systems

• They are expensive (but you can improvise by using throw away radio control vehicles with mounted cameras/sensors).

• Existing systems generally require custom tooling.

• Typically require training and experience (but we are working on this one).

• They can have reliability problems.

• They are hard to decontaminate.

• They can be slow.
## Remote System Time Efficiencies

<table>
<thead>
<tr>
<th>Manipulator type</th>
<th>Task completion time ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skilled human operator (unencumbered)</td>
<td>1</td>
</tr>
<tr>
<td>Suited human (air suit or equal)</td>
<td>8:1</td>
</tr>
<tr>
<td>Force-reflecting servomanipulator or master/slave manipulator</td>
<td>8:1</td>
</tr>
<tr>
<td>(i.e., through-the-wall type)</td>
<td></td>
</tr>
<tr>
<td>Non-force-reflecting electromechanical manipulator</td>
<td>20-50:1</td>
</tr>
<tr>
<td>(i.e., power-arm type)</td>
<td></td>
</tr>
<tr>
<td>Crane/impact wrench</td>
<td>50-500:1</td>
</tr>
</tbody>
</table>
Types of remote systems that will be covered

- Long-handled tools
- Crane tools
- Mechanical master/slave manipulators
- Power arms
- Servomanipulators
- Remote controlled platforms
- Telerobotics
- Special tooling
Long-handled tools in the 1940s

• State-of-the-art: Extended reach tools, and hot cells with crane hook-suspended impact wrenches

• ORNL (X-10) Graphite Reactor operated November 1943 until 1963
  • First Pu pilot scale production
  • First electric power from reactor
  • First key source of medical isotopes

ORNL Graphite Reactor
Extended Reach Tools: Old technology still commonly used today

- Long handled tools to place distance between worker and radiation source
- Direct tool handling and operation—manual
- Direct viewing usually although remote viewing was used as well
- Shielding material—water, concrete, steel
- Still used today—most economical
Remote Crane and Impact Wrench Tools
Early Large Facility Remote Handling

- One degree of freedom (up/down) plus X-Y resulting in large floor space requirements for equipment
  - Large envelope
  - Can only exert force in one direction

- Generate large handling forces with no force feedback requiring custom, robust process equipment
  - Necessary for the heavy lift tasks

- Low operating efficiency requiring up to 500 times longer than hands-on techniques
  - Slow end-effector speeds

- Still essential for heavy equipment handling and transport

- Can bring in portable cranes for D&D
  - Shears
  - Large impact wrenches
  - Custom tools
Master-Slave Manipulator (MSM)

- Ray Goertz, most significant pioneer and inventor
- Argonne National Laboratory (ANL)
- First demonstrated 1948 - 1949
Master-Slave Manipulator (MSM)

• Advantages
  – Highly dexterous
  – Force reflecting
  – Inexpensive
  – Reliable (HD models)
  – Work well with a shielding window

• Disadvantages
  – Limited reach
  – Small effective working volume
  – Require a shielding window workstation
  – Can be overloaded by operator
Power Arm Manipulators:
Substantial Improvement Over Crane and Impact Wrench Techniques

- Additional degrees of freedom improve manipulating capabilities, operating efficiency, and equipment layouts
  - Can exert force in all 6DOF
  - Relatively small work envelope
  - Good coverage if transporter deployment correct

- Generate large forces requiring custom, robust process equipment

- Operating efficiency an order of magnitude better than crane and wrench but still low (50:1 typical with rate control)
  - Slow end-effector speeds
  - Difficult operator interface
Bridge Mounted Power Arms

- **Advantages:**
  - Large lifting capacity (200 to 800 lbs)
  - Proven reliability
  - Stiff arm provides positioning accuracy in robotic (automated) ops mode

- **Disadvantages:**
  - Difficult to operate efficiently with limited dexterity
  - Not force reflecting
  - 50 X hands-on task times
  - Requires extensive and robust RH features on components
Servomanipulators:
Transportable Mechanical Master/Slave Manipulators

• Advantages:
  – Highly dexterous handling over large volumes, long distances
  – Force reflecting
  – 5 to 8 X hands-on task times
  – Reduces need and cost of special remote handling features on components
  – Moderately powerful
  – Can be equipped with an auxiliary hoist to assist with material handling

• Disadvantages:
  – Expensive
  – Complex and potentially unreliable
  – Mechanically compliant arm limits positioning accuracy in robotic mode

Telerob
EMSM-2B
ORNL / CRL Model M2 was the world’s first digitally controlled servomanipulator developed in the early 1980s. Its similar in design to the Telerob EMSM-2b used at SNS and is the direct ancestor of almost all of the world’s current computer controlled teleoperators.
• ORNL ASM was the world’s first (and only?) remotely maintainable servomanipulator for high radiation environments
ORNL Advanced Servomanipulator
ORNL D&D Manipulation

- High payload hydraulic manipulators to manage heavy, high reaction force cutting tools typical in D&D
- 6 DOF arms on 5 DOF torso
- Local hydraulics and controls

- Multiple Deployment Options
  - Overhead transporter
  - Crane hook
  - Remote Vehicle
CP-5 reactor D&D
CP-5 reactor D&D
SNS In-Cell Servomanipulator

- Telerob EMSM-2B
- 6 DOF arm + gripper (11 with bridge and interface)
- Replica master arms
- Dual arm, mirror configuration
- Digital Control
- Force Reflecting
- Force Ratio Control 2:1 up to 20:1
- 55 lbf continuous / 100 lbf peak capacity
SNS target cell remote systems

**Mobile Manipulator System**

**Pedestal Manipulator System**

**Remote Handling Control Room**
Remove Vehicle Platforms
Foster Miller and iRobot
Remotec Mobile Platforms

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY
Remote Vehicle Platforms
Telerobotic Small Emplacment Excavator
Autonomous and semi-autonomous robots for indoors and outdoor characterization
ORNL Gunite Tank Cleanup Project
Mobile Vehicle and Long Reach Manipulator Working Together

Tank Waste Retrieval at ORNL North Tank Farm

Robotics-based Radioactive Tanks Cleaning System

ORNL North Tank Farm
Gunite Tanks
ORNL integrated, tested, deployed, and operated a variety of remote systems, tools and processes for the ORNL Gunite Tanks Remediation (GAAT)
K25 site D&D

- ORNL managed systems integration and vehicle adaptation for dual arm manipulator systems, tooling support, and associated operator interfaces.

- RedZone Robotics was contracted for vehicle refurbishment and operations.
D&D Telerobotics

• A telerobot is an advanced combined teleoperated/robot system that can be accurately and efficiently commanded to perform specific functions automatically while maintaining the ability for high fidelity teleoperation.

• tR = make a robot a teleoperator
  – Tends to fall short on natural perception for the operator

• Tr = make a teloperator a robot
  – Tends to fall short on positional accuracy for autonomous motions

• While telerobots exist in many laboratories, minimal real world commercial capability exists at this time other than some virtual fixturing.
Telerobotic Test Bed

- Automation of tool tasks that are difficult for operators to complete in teleoperation.
- Use of a reciprocating saw to cut a pipe
- Use of an impact wrench/nut driver to remove bolts.
Not all remote systems are manipulators or vehicles
Stack Characterization System
Stack Characterization Sampling
GAAT tank waste retrieval tooling

- **Remote Cameras**
  - *Tank inspections and operations surveillance*

- **Sampling Tools**
  - *Tanks sampled at various locations*

- **Wall Coring Tool**
  - *Analysis of wall cores determines the depth and amount of contamination in the tank walls*

- **Saws an Hydraulic Shears**
  - *Removes obstructions in tank*

- **Pipe Plugging/Cutting/Cleaning Tool**
  - *Plugs interior tank pipes to improve tank vacuum and efficiency of air filtration system*

- **Feeler Gauge**
  - *Determines depth of wall degradation*
Tooling for sludge retrieval and wall cleaning

- Modified Light Duty Utility Arm
  - Deploys tools in tank
- Houdini Remotely Operated Vehicle
  - Deploys tools in tank
  - Plows and cuts sludge
- Confined Sluicing End-effector
  - Sludge/Supernatant mining and waste retrieval
  - Cleans tank walls
- Gunite Scarifying End-effector
  - Cleans tank walls
- Hose Management Arm
  - Supports the end-effectors and hoses
- Jet Pump
  - Conveys waste out of tank
- Flow Monitor and Sampling Device
  - Monitors waste flow and allows collection of waste slurry samples
Special tooling for D&D

- Tools must be adapted for grippers
- Parallel jaw grippers (2 finger) most common
- Power, control, and sensing need to be addressed separately
- Modifications are expensive!
Tooling Guidelines

• Tools must be as short coupled as possible.

• Depending on the tool process, the tool to manipulator interface may need to be compliant or rigid.
  - Saw = rigid
  - Impact wrench = compliant

• Designs need to ensure that parts will not come off in use (pin sockets/extensions)
Multi-fingered hands will someday allow use of non fixtured tools

- Multi-finger hands expensive, complicated, and not reliable for D&D use.
- Development in progress.
- Will allow the use of off-the-shelf tools.
Operator Interfaces and Cameras

• You need as many cameras as possible for remote work.
• Commercial security cameras can be adapted and work well.
• Rad-hardened camera are not necessary for most D&D operations
  – They do exist but are expensive
• Operator interface design does not have to be complicated or expensive but must be done well.
• Current trend is to use game controllers…workable but not optimal.
Operator Interface Design Issues
Summary

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Questions?