Teleoperation

History and applications
Notes

- You always need telesystem or human intervention as a backup
  - at some point a human will need to take control
  - embed in your design

- "Roboticists automate what is easy and leave the rest to the human" - Don Norman

- The user interface is absolutely critical
  - User interface make up 60% of commercial code
  - Useful = is the program purpose useful?
    - usually given to designer via specifications and requirements
  - Usable = can a human use it efficiently?
    - designer must conduct usability studies
    - avoid "if I can use it, some one else will"
Definition

- *Teleoperation* means simply to operate a vehicle or a system over a distance.
- Distance can vary from tens of centimeters (micro manipulation) to millions of kilometers (space applications).
The 1st mobile machines without human onboard were teleoperators → the first pre-stage of a robot

How to control a vehicle over a distance?

Phased development from mechanical manipulation to high level supervisory control

Today both closed loop teleoperation and high level communication are needed
Robot teleoperation

- Basically every mobile robot is a teleoperated machine and most of the teleoperated machines are mobile robots, only level of autonomy varies

- \[ \rightarrow \text{HRI} = \text{teleoperation interface} \]

- Autonomous robots??
Definition - consideration

- The earliest type of teleoperation?
- What is the difference between using a tool and teleoperation (remote manipulation)
Tool or Teleoperation

- Tool – to improve the work task, to make something possible
- Teleoperation – to avoid hostile environment, usually neither the quality nor the efficiency of the work is improved
- To move operator quickly to the operation site
Development

- manipulation
- vehicle (submarine) control
- space
- Semiautonomous vehicles
- Autonomous vehicles (no closed-loop teleoperation needed)
Vision - forestry

MAN & HORSE

MAN & wheel/track based harvester

man & walking harvester

teleoperated wheel/track or leg based harvester

autonomous forwarder

semi-autonomous remote operated multi-machine forest harvesting worksite

autonomous thinning and brushing robot societies

remote operated multi-machine forest harvesting worksite

autonomous forwarder

teleoperated wheel/track or leg based harvester

man & walking harvester

MAN & wheel/track based harvester

MAN & HORSE

1950 1970 2000 2010

autonomy/intelligence

MAN & HORSE
Terminology

- **Teleoperation**: to operate a vehicle or a system over a distance

- **Operator**: human operator is the person who monitors the operated machine and makes the needed control actions

- **Teleoperator** is the teleoperated machine. A sophisticated teleoperator can also be called as *teлерobot*

- In *supervisory control* remarkable part of the control is delegated to the teleoperator end (compare coordinated teleoperation)
Terminology

*Robot:* Any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner. The term is derived from the Czech word robota, meaning “forced labor.” [Encyclopedia Britannica]
Definitions (way to control)

- Mechanical manipulation
  - The control commands are transmitted mechanically or hydraulically to the teleoperator. Visual feedback can be straight or via monitor.
  - This is typical for manipulation of dangerous materials as well as micro manipulation
Definitions (way to control)

- Remote operation/control:
  - The operator has most of the time straight visual contact to the controlled target. Control commands are sent electrically by wire or radio.
Definitions (way to control)

- "Normal or standard teleoperation"
  - Wireless control and visual feedback via camera - monitor system
Definitions (way to control)

- semi- or full autonomy
  - robot is controlled when needed
  - Visual feedback through the robot’s eyes (camera-monitor)
  - ex. Sojourner with different modes, Automine
  - human doesn’t have to do everything
- Supervisory control
Definitions

- **Closed loop control (Direct teleoperation):** The operator controls the actuators of the teleoperator by direct (analog) signals and gets real-time feedback. This is possible only when the delays in the control loop are minimal.

- **Coordinated teleoperation:** The operator again controls the actuators, but now there is some internal control - remote loop - included. However, there is no autonomy included in the remote end. The remote loops are used only to close those control loops that the operator is unable to control because of the delay.
Definitions

- In *supervisory control* [Sheridan, 1992], the remarkable part of the control is to be found in the teleoperator end (compare coordinated teleoperation). The teleoperator can now perform part of the tasks more or less autonomously, while the operator mainly monitors and gives high-level commands. The term *task based teleoperation* is sometimes used here, but it is more limited than "supervisory control".
Closed loop/Supervisory control

OPERATOR

display controls
HMI computer

transmission

teleoperator’s computer
sensors actuators

TASK

OPERATOR

display controls
HMI computer

transmission

teleoperator’s computer
sensors actuators

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TASK
History
The first *modern* master-slave teleoperators were mechanical pantographs.

These manipulators were developed by the group of R. Goertz in the late 1940s at the Argonne National Laboratory where Enrico Fermi developed the first nuclear reactor.
History

- The mechanical manipulators were soon replaced by electro mechanical servos.
- In 1954 Goertz’s team developed the first electro mechanical manipulator with feedback servo control.
- After this the teleoperation of manipulators and vehicles spread out rapidly to new branches where advantages of teleoperation techniques could be utilized.
Applications

- Submarines (ROV)
Applications

- Space
  - Perfect for teleoperation: safety and costs
  - Problem very long delay => “move and wait”
Applications

- Military
  - underwater
  - ground
  - air
  - semiautonomous / closed loop control

- Anti terrorist
  - typically closed loop control
Applications

- **Medical**
  - Endoscopic surgery
    - ~ (micro) mechanical manipulation (is this teleoperation??)
    - minimal damage, smaller risks
  - Telesurgery
    - Specialists can operate over distances
Applications

- Industrial – Mining
  - Resque operations
  - Mining in unsafe areas
Industrial applications

- Why to teleoperate if there is no danger??
- Semiautonomous work machines with part time teleoperation!!
- All possible work is done autonomously
- Difficult tasks and exceptions are teleoperated
- This will be the future
Components [Uttal 89]

- **Local**
  - display
  - Local control device
- **Communication**
- **Remote**
  - sensor
  - mobility
  - effector
  - power

![Diagram showing components]
Technology

- Mechanical manipulators, (good feedback)
- Electrical servos – TV, (closed loop)
- Radio control – Video, (closed loop, supervisory)
signal speed max. $\sim 300\ 000\text{km/s}$

Shannon theory: measuring frequency
$> 2 \times \text{system frequency}$

In practise (mobile machines) $< 0,1\text{s}$
$\Rightarrow$ perfect, $< 0,3 - 0,5\text{s} = \Rightarrow$ easy

In long delay systems “move and wait”
task based teleopration
Delay

- There are always delays in a teleoperation loop.
- Every part of the system has some delays.
- Digital systems increased the delay.

Diagram:

- Teleoperator delay
- Transmission delay
- Feedback delay
- Control delay
Long delay teleoperation

- No possibilities for closed loop control
- because of the mission it’s difficult to increase the autonomy
- => move and wait teleoperation
- models of robot and environment, operator loop in control
Problems

- cognitive fatigue
- communications dropout
- communications bandwidth
- communications lag
- too many people to run one robot (hidden cost)

Predator: 7:1 Human robot ratio
4 people to control it (52-56 weeks of training)
- one for flying
- two for instruments
- one for landing/takeoff
- plus maintenance, sensor processing and routing

lack of self-awareness— in Kosovo, come along side in helicopter and shoot down
Teleoperation best suited for

- the tasks are unstructured and not repetitive
- key portions of the task require dexterous manipulation, especially hand-eye coordination, but not continuously
- key portions of the task require object recognition or situational awareness
- the needs of the display technology do not exceed the limitations of the communication link (bandwidth, time delays)
- the availability of trained personnel is not an issue
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