Teleoperation and autonomy

Thomas Hellström
Umeå University
Sweden

Slide material contributions from Robin Murphy, Jussi Suomela

How is a robot controlled?

1. By the human operator
2. Mixed human and robot
3. By the robot itself

Levels of autonomy!

Levels of autonomy

1a. Remote control
   - Visual contact / no sensor feedback
1b. Tele-operation – OCU provides sensor data
   - Simple t-o: control of individual joints, motors etc.
   - User space t-o: motion primitives e.g. internal closed loop velocity control of vehicle
   - Safety-guarded t-o: e.g. emergency stop
2. Semi-autonomous (supervisory) control
   - Shared control
   - Trusted control
3. Autonomous robots – not here yet

Remote control

- Not only toys
- The operator has most of the time straight visual contact to the controlled target
- Control commands are sent electrically by wire or radio

Components of a Teleoperated system

OCU = Operator's Control Unit

Remote
- Sensor
- Mobility
- Effector
- Power

Local
- Display
- Communication

Teleoperation Applications

Space
- Perfect for teleoperation: safety and costs
- Problems with very long delay

Lunokhod 1 (Луноход) “moon walker”
First t-o vehicle on the Moon 1970

Sojourner, first t-o vehicle on another planet. Landed on Mars 1997
Teleoperation Applications

- Military
  - underwater
  - ground
  - air
  - semiautonomous / internal closed loop control
- Anti terrorist
  - typically internal closed loop control

Medical
- Endoscopic surgery
  - Surgery through small incisions or natural body openings
  - minimal damage, smaller risks
- Telesurgery
  - Surgeons can work over distances

Teleoperation Applications

- Mining
  - Unsafe areas
  - Cheaper operation

USAR robots
(MURC Scenario by Hunt)

- "Remote" robot
- "Local" operator
- "Local" feedback

Problems with Tele-operation

- Lighting conditions
  - High variation in ambient light makes computer vision tasks difficult
- No "tactile" feedback
  - Couldn't really tell when the robot was stuck or when it was free
  - Robot didn't have proprioception (internal sensing)
  - Operator didn't have an external view of the robot itself
- Communications
  - High dropout rate after about 10 feet away

All images from http://crasar.csee.usf.edu/pics/allpics/Pictures chosen for pedagogical purpose. Two different robotic systems are shown
Simulator Sickness

- Common in Teleoperation
- Similar to motion sickness, but can occur without any actual motion of the operator
- Symptoms: apathy, general discomfort, headache, stomach awareness, nausea...

Simulator Sickness

- Caused by cue conflict
- In cue conflict different nerves get different information from the environment
- Typically conflict between visual and vestibular inputs
- Especially when HMD is used and the time lags in vision and control

Delays

- Acceptable control loop times
  - Nyquist sampling theorem: measuring frequency > 2 x system frequency
  - In practise (mobile machines):
    - < 0.1 s: perfect
    - < 0.5 s: ok
- Delays depend on
  - Transmission speed (max. 300 000km/s)
  - System delays
- Long delays cause Cognitive fatigue

Not really unmanned...

- 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

Long delay teleoperation

- Earth-Moon-Earth: 2 seconds
- Earth-Mars-Earth: 37 seconds
- No possibilities for external closed loop control with a moving robot
- Instead: "move and wait" teleoperation

Tele-operation

+ Doesn’t depend on machine intelligence
+ Doesn’t depend on a present operator
- Depend on good communication
- Hard for the operator ⇒ Cognitive fatigue
  Simulator sickness
  Many operators required
Tele-systems Best Suited for Tasks:
- that are unstructured and not repetitive
- that require dexterous manipulation, especially hand-eye coordination, but not continuously
- that require object recognition or situational awareness
- that don’t require display technology that exceeds bandwidth and time delays limitations of the communication link
- where the availability of trained personnel is not an issue

Ways to improve Tele-operation
- Improve the HRI ⇒ less demanding for operator: TELE-PRESENCE
- Make the robot more intelligent ⇒ less demanding for operator and communication system: SEMI-AUTONOMY

Tele-presence (remote presence) "Virtual reality”
Provide sensory feedback such that the operators feel they are “present” in robot’s environment
- Ideally all human senses transmitted
  - Vision, hearing and touch
  - Smell and taste
  - Balance, motion
- Demands higher bandwidth
- Less problems with Cognitive fatigue and Simulator sickness

Vision
- Humans get 90% of their perception through vision
- “To see is to believe”
- Eyes are very complex opto-mechanical systems
  - FoV is (H)180 deg x (V)120 deg
  - Focused area only few degrees
  - Movements over whole area
  - Extremely difficult system to be imitated

Interface with Vision
- Head tracking
- HMD ⇒ relatively good feeling of presence

Hearing
- Human range 16 – 20000Hz
- Important in telepresence
- Noise can be filtered out
Touch & Force

- Tactile information ("touch")
  - mechanoreceptors – activated by pressure on the tissues
- Kinesthetic information ("force")
  - sense of position and motion of limbs and associated forces conveyed by receptors in the skin around the joints, tendons, and muscles, together with neural signals

Interface with Haptic feedback

- tactile sensing of the robot manipulator is fed back to the fingers of the operator

Interface with kinesthetic (force) feedback

- Force is fed back to the operator
- Generates a real response in gripping and manipulation tasks
- Also in virtual environments

Vestibular sensors

- Located inside the inner ear
- Responds to
  - Angular acceleration (and thus rotation)
  - Spatial orientation
  - Linear acceleration in the horizontal and vertical plane, i.e. to gravity
- ⇒ pose and movements of the head are detected

Vestibular feedback

- Usually not needed in teleoperation
- Expensive to implement
- Usually in simulators to create presence
- If vision and vestibular sensors mismatch ⇒ simulator sickness

Better than the real thing: Augmented reality

- Real information (usually image data) is mixed with additional virtual information
- Numerical information, real-time models, etc.
Tele-presence applications

- Lawn mower
- Tele conferences
- "Taking care of" elderly
- Baby sitters
- Home robots
- Security
- Garden clubs

Ways to improve Teleoperation

- Improve the HRI => less demanding for operator: TELE-PRESENCE
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Semi-autonomous control

- General idea:
  - Teleoperation for hard tasks
  - Autonomy for simple tasks
- Reduces cognitive fatigue/simulator sickness
- Demands lower bandwidth
- Less sensitivity to delays

Two major types:
- Shared control
- Traded control

Shared control

Example (space robotics)
Task: Release the bolts on shield H34.

- Autonomous motion to shield H34.
- The human monitors and may interrupt if the situation becomes unsafe.
- The human releases the bolts by tele-operation

Note: Constant monitoring needed

Traded control

- The human operator
  - Initiates action
  - Neither monitors nor interrupts
- If the operating conditions go outside the abilities of the robot, control is transferred to the human
- When the human takes over, she has to quickly acquire situational awareness
- When the robot takes over, it has to quickly acquire situational awareness
Situational awareness

Most often refers to the operator’s perception of the world.

Important for:
- pure teleoperation
- operator take over in semi autonomous systems:
  Low awareness ⇒ longer take-over time

Three levels of situation awareness (Endsley 2000):
1. there is perception of the relevant status information
2. there is comprehension of the status information
3. there is prediction, i.e. the ability to use this comprehension to consider future situations

Experiences of robotic rescue researchers at the World Trade Center (Casper 2002):

- 54% of the time spent was reported to have been wasted trying to determine the state of the robot
- The operator gets confused by the egocentric camera view regarding Attitude (roll, pitch)

Traded control - Sojourner

11.5 kg
630 x 480 mm
worked by Teleoperation and semi-autonomous control

Example: "DRIVE TOWARD THAT STONE"
Sojourner avoids obstacles on the way

Dante I

Dante I on the rim of Erebus.

Dante II

Mt. St. Unam, Alaska.

Dante II

Photo by Bill Ingalls/NASA
Interface design

Between the operator and robot/vehicle
- Strong connections with HMI and HCI, but additional problems
- As usual:
  The user interface is absolutely critical
  - make up 60% of commercial code

Interface layout

- The level of autonomy
- The level of sensing/perception

Interface - Remote control

- No sensor feedback
- Low bandwidth

Levels of autonomy (again)

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Interface – Simple Tele operation

- "Direct" tele-operation
- Same view as onboard
- External closed loop control of motor speeds, height, ...
- Operator controls with hand controllers (like onboard)
- Realtime operator decision making is necessary
- High bandwidth, low delay communication
Interface – User-space Tele operation

- Multimodal/multisensor
- Integrated display with combined sensor information
- Internal control-loops for speed, height, ...
- (Autonomous safety functions)

Interface – Semi-autonomous Control

Support for
- high-level commands
  - Move to …
  - Grip
  - Look for …
- monitoring of success/errors
- Interruption of tasks

Control methods (Sheridan 2003)

Novel interfaces

- "novel" is relative
- gestures
- gazes
- brainwaves
- muscle movements
- WEB interfaces
  - multimodal
  - supervisory

The Black Knight

- Objects that are detected are overlaid on the driving map enabling drivers to maneuver around them
- Can plan paths to be manually driven by its operator
- Guarded teleoperation: The vehicle stops when it detects lethal obstacles in its path.

The Black Knight’s OCU

http://www.youtube.com/watch?v=HRDs__6dFsElfeature=related
The Remote Robotic Reconnaissance Vehicle (R3V)

- Enhanced situational awareness using fused sensors

The robotic vehicle with a FLIR (forward looking infrared) and a low-light camera

Operator Control Unit (OCU), for control and display

OCU – Operators Control Unit

- Vehicle status and remote video via a 1024x768 LCD display
- Vehicle control: Speed, Steering
- Camera control: zoom camera, fader controls and camera tilting, manual iris, focus and gain control.

Fusion of IR and camera

- Low-light image
- IR image
- Fused low-light and IR image

Assessing the usability of a HRI

- Effectiveness: the percentage of a task that the user is able to complete
- Efficiency: depends on the time needed to complete a given task
- User satisfaction: subjective

The three measures are weighted:
- Life critical applications: more weight to the effectiveness
- Time critical applications: more weight to efficiency
- Entertainment: more weight to user satisfaction

Camera display modes

Three basic ways to monitor a robot’s location, orientation and the world around it

- **Egocentric**: Inside-out perspective; “Through the windshield”
- **Exocentric**: Outside-in perspective; Radio-controlled planes.
- **Mixed perspective**: Inside-out perspective but includes information about orientation, e.g. artificial horizon displays

(Wang, Levis, Hughes 2004)

Camera display modes

Problems:
- Exocentric views hard to achieve
- A fixed camera on the vehicle may give an illusion of flatness
- The angle of the horizon line gets confused with the roll of the vehicle; the “graveyard spiral” (Roscoe 1999)
- Gravity referenced display with the tilted vehicle’s chassis improves situational awareness
Gravity referenced display

- Fixed Camera (note the roll display in lower left corner)
- Gravity Referenced Display (note the indication of roll provided by the tilt of the robot's body)

Pictures: Jijun Wang

Predictive Displays

- Predicts 5 seconds ahead by simulation based on user actions and vehicle velocity
- Superimposed information on the display:
  - The length of the lines: Indirect velocity information
  - An arrow describing the vehicle's predicted position and heading
  - A representation of the vehicle body

Predictive Displays

(Kim and Bejczy, 1993)

- The operator can manipulate a computer graphics simulation of the slave robot.
- This simulated robot can be superimposed over the video returning from the remote site

Predictive Displays

- “Time Clutch”: a foot pedal which, when pressed allows the simulated robot to move without the physical robot moving. The operator's inputs are held in memory until the simulated robot "comes back" to the current physical robot state

Predictive Displays

- “Position clutch”: disengages the operator's commands entirely from the physical robot so that the operator can fine-tune positioning in the simulator.
- “Time brake”: emptying out the command memory until the simulated robot "comes back" to the current physical robot state
References

S. Lichiardopol, A Survey on Teleoperation, Technische Universiteit Eindhoven, 2007
