Human-Robot Interaction

91.451 Robotics II
Prof. Yanco
Spring 2005
What is Human-Robot Interaction (HRI)?
Current State of the Art: Some Examples

- Healthcare and Assistive Technology
  - Aids for the Blind
  - Robotic walkers
  - Robotic wheelchairs
  - Companion robots

- Robot Soccer

- Humanoid Robots

- Wide variety of ways to interact with a robot!
Aids for the Blind

GuideCane, UMich

NavBelt, UMich

Photos courtesy of Johann Bernstein, University of Michigan
Robotic Walkers

Walkers from Haptica, Inc., Ireland

Left photo courtesy of Gerard Lacey, Haptica
Robotic Wheelchairs

Whelesley, MIT AI Lab

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Hephaestus Smart Wheelchair, AT Sciences

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Independence Enhancing Wheelchair, ActivMedia

HRI Lecture, Slide 6
Robotic Arms

Raptor Arm,
Advanced Rehabilitation Technologies
Stroke Therapy

MIME, VA Palo Alto Rehabilitation Research and Development Center
Therapy for Autistic Children

CosmoBot, AnthroTronix
NurseBot

NurseBot, developed at Carnegie Mellon University, interacting with residents of an assisted living facility

Photos courtesy of Sebastian Thrun and Carnegie Mellon University
NurseBot

Nursebot Pearl

Assisting Nursing Home Residents

Longwood, Oakdale, May 2001
CMU/Pitt/Mich Nursebot Project
Multi-Agent Robotics: Soccer

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HRI Lecture, Slide 12
Humanoid Robots

MIT’s Cog

Photo courtesy of Rod Brooks, MIT
Humanoid Robots: Robonaut

Courtesy of Rob Ambrose, NASA JSC
Humanoid Robots: Robonaut
Robotic Systems from Search and Rescue Competitions
Urban Search and Rescue
Urban Search and Rescue
What is Human-Robot Interaction (HRI)?

- Only recently (past 5 years or so) have researchers begun to study HRI
- Before this, robots were not developed enough to consider interaction with people
Roles of Interaction

- Supervisor
- Operator
- Teammate
- Mechanic/Programmer
- Bystander
Supervisor

- Oversees a number of robots
- May or may not have time to help one out
- May have to hand off to an operator
- Needs global picture of all robots/mission
- Needs to understand when a robot is having a problem, the seriousness of the problem, the effect on the mission

- Challenge: How many robots can a supervisor effectively monitor?
Operator

- Needs to have “teleprense” to understand where robot is and what must be done
- Interactions depend on level of autonomy
- Can vary from complete teleoperation to giving new way points to giving high level task to specifying a mission
- Needs awareness of robot health, awareness of environment and awareness of what robot is to be doing to support task/mission

- Challenges:
  - How to maintain awareness despite communications limitations
  - How to control multiple robots
Teammate

- Robot is a member of the team
- Teammates can give commands within the scope of the task/mission
- Interactions such as gestures and voice may be helpful here
- Need to understand any limitations robot has in capabilities

- Challenge: Can the robot understand the same interaction vocabulary as other team members?
Mechanic/Programmer

- Comes into play if the operator cannot resolve the issue
- These interactions could happen within a task or mission
- Given that a hardware/ software change is made, then the mechanic/programmer must have a way of interacting with the robot to determine if the problem has been solved.

- Challenges:
  - How much self diagnosis can the robot do?
  - Have to determine when to move from operating in degraded capability to pulling robot off task and attempting to fix problem
Bystander

- No formal training using robot but must co-exist in environment with robot
  - Consider health care situation; floor cleaning robots; robot pets; on-road driving
- In military situations, could be a friendly, a neutral or an enemy
  - The robot should be able to protect itself from an enemy

- Challenges:
  - How can a bystander form a mental model of what the robot’s capabilities are?
  - Should a bystander have a subset of interactions available?
  - What type of social interactions come into play?
Caveats to Roles

• One person might be able to assume a number of roles for a particular robot (excluding the bystander role)

• A number of people might be interacting with one robot in different roles; these people may have to be aware of the different interactions happening as well as other information they need.

• Assuming we can determine information/ interaction needs for different roles, then we could use that information to
  – Design a user interface to support a given role
  – Determine whether multiple roles could be supported in one user interface
Awareness in HRI

• Awareness is used frequently in CSCW

• Definition [Drury 2001]
  – Given two participants p1 and p2 who are collaborating via a synchronous collaborative application...
  – ...awareness is the understanding that p1 has of the
    • presence,
    • identity and
    • activities of p2

• But HRI is different due to
  – Single or multiple humans interacting with a single or multiple robots
  – Non-symmetrical relationships between humans and robots; e.g., differences in
    • Free will
    • Cognition
HRI Awareness Base Case

• Given one human and one robot working on a task together...
• ... HRI awareness is the understanding that the human has of the
  – location,
  – activities,
  – status, and
  – surroundings of the robot; and
• the knowledge that the robot has of
  – the human’s commands necessary to direct its activities and
  – the constraints under which it must operate
A General Framework for HRI Awareness

- Given n humans and m robots working together on a synchronous task, HRI awareness consists of five components:
  - Human-robot awareness
  - Human-human awareness
  - Robot-human awareness
  - Robot-robot awareness
  - Humans’ overall mission awareness
Details

- Given \( n \) humans and \( m \) robots working together on a synchronous task, HRI awareness consists of five components:
  - **Human-robot**: the understanding that the humans have of the locations, identities, activities, status and surroundings of the robots. Further, the understanding of the certainty with which humans know this information.
  - **Human-human**: the understanding that the humans have of the locations, identities and activities of their fellow human collaborators
Details, Continued

- **Robot-human**: the robots’ knowledge of the humans’ commands needed to direct activities and any human-delineated constraints that may require command noncompliance or a modified course of action.

- **Robot-robot**: the knowledge that the robots have of the commands given to them, if any, by other robots, the tactical plans of the other robots, and the robot-to-robot coordination necessary to dynamically reallocate tasks among robots if necessary.

- **Humans’ overall mission awareness**: the humans’ understanding of the overall goals of the joint human-robot activities and the measurement of the moment-by-moment progress obtained against the goals.
HRI Taxonomy

• Why classify?
  – Way to measure properties of systems
  – Easier to compare systems

• Classification categories
  – Autonomy Level
  – Team Composition
  – Presentation of Sensor Data
  – Task Specification
Taxonomy Classifications for Autonomy Level

• AUTONOMY
• INTERVENTION
AUTONOMY

• Measures percentage of time that robot carries out task independently.

• Possible values
  – Single value from 0 – 100% if fixed level.
  – Range specified if autonomy level is adjustable.
  – Together with INTERVENTION, sums to 100%.
INTERVENTION

• Measures percentage of time that human operator needs to control robot.

• Possible values
  – Single value from 0 – 100% if fixed level.
  – Range specified autonomy level is adjustable.
  – Together with AUTONOMY, sums to 100%.
Taxonomy Classifications for Team Composition

- HUMAN-ROBOT-RATIO
- INTERACTION
- ROBOT-TEAM-COMPOSITION
**HUMAN-ROBOT-RATIO**

- Measures the number of robot operators and the number of robots.
- Possible values:
  - Non-reduced fraction of the number of humans over the number of robots.
  - If the number of humans or robots is variable within a system, the numerator or denominator of the fraction may be expressed as a range.
INTERACTION

- Measures the level of shared interaction between the operator(s) and robots(s).
- Possible values:
  - one human, one robot
  - one human, robot team
  - one human, multiple robots
  - human team, one robot
  - multiple humans, one robot
  - human team, robot team
  - human team, multiple robots
  - multiple humans, robot team
INTERACTION

1. \( H \rightarrow R \)
   one human, one robot

2. \( H \rightarrow \begin{array}{c} R \leftrightarrow R \end{array} \)
   one human, robot team

3. \( H \rightarrow \begin{array}{c} R \leftrightarrow R \end{array} \)
   one human, multiple robots

4. \( H \leftrightarrow H \rightarrow R \)
   human team, one robot

5. \( H \rightarrow \begin{array}{c} H \leftrightarrow H \rightarrow R \end{array} \)
   multiple humans, one robot

6. \( H \leftrightarrow H \rightarrow \begin{array}{c} R \leftrightarrow R \end{array} \)
   human team, robot team

7. \( H \leftrightarrow H \rightarrow \begin{array}{c} R \leftrightarrow R \end{array} \)
   human team, multiple robots

8. \( H \leftrightarrow H \rightarrow \begin{array}{c} R \leftrightarrow R \end{array} \)
   multiple humans, robot team
**ROBOT-TEAM-COMPOSITION**

- Specifies if all robot team members are the same or different.
- Possible values
  - *Homogeneous*
  - *Heterogeneous*
  - May be further specified with a list containing the types of robots in the team and the number of each type of robot used in the team
Taxonomy Classifications for Presentation of Sensor Data

- AVAILABLE-SENSORS
- PROVIDED-SENSORS
- SENSOR-FUSION
- PRE-PROCESSING
AVAILABLE-SENSORS

• List of sensor types available on the robot platform (repeated for each type of robot on the team).

• May also contain the location of the sensors (not required).
PROVIDED-SENSORS

- Lists the sensor information provided to the user through the interface.
- Subset of AVAILABLE-SENSORS, listing only sensors displayed in some form on the user interface.
SENSOR-FUSION

• Lists any sensor fusion that occurs for the user interface.

• Possible values:
  – Specified as a list of functions from sensor type to result.
  – For example,
    
    \{\{\text{sonar}, \text{ladar}\} \rightarrow \text{map}\}

PRE-PROCESSING

• The amount of pre-processing of sensors for decision support.

• Possible values:
  – Denoted in a list of functions.
  – For example,
    
    \{\text{sonar} \rightarrow \text{map}, \text{video} \rightarrow \text{mark-red-areas}\}
Taxonomy Classifications for Task Specification

• CRITICALITY
• TIME
• SPACE
CRITICALITY

• Measures the potential for harming humans or environment in a particular domain given a failure.

• Possible values:
  – High
  – Medium
  – Low
TIME

• Specifies if operator and robot function at the same or different times.
• Possible values:
  – Synchronous
  – Asynchronous
SPACE

• Specifies if operator and robot function in the same space or different space.

• Possible values
  – Collocated
  – Non-collocated
Studying Human-Robot Interaction

• Much research to date has been devoted to robot technology but little on human-robot interaction (HRI)
• Interfaces are often afterthoughts or just a tool for the robot developers
• Human-computer interaction (HCI) has been studied for many years, but tools and metrics do not directly transfer to HRI
HCI vs. HRI

• Need to test robots in degraded conditions
  – Environment (noise, no comms, poor visibility)
  – Sensor failures

• Repeatability
  – No two robots will follow the same path
  – Testing can not depend on any two robots (or the same robot at different times) behaving in an identical fashion
HCI vs. HRI

- Different roles of interaction are possible
- Multiple people can interact in different roles with same robot
- Robot acts based on “world model”
- Degraded state of operation of robot
- Physical world – air, land, and sea
- Intelligent systems, learning, emerging behaviors
- Harsh environments
Evaluation of HRI

- Field work (e.g., USAR competitions)
  - See many different user interfaces but have no control over what operator does
  - Difficult to collect data
  - Can see what they did – but there isn’t time to determine why
  - Best used to get an idea of the difficulties in the real world
  - Can identify “critical events” but don’t know for certain whether operator was aware of them
Evaluation of HRI

• Laboratory studies
  – Take what we learned in the real world and isolate factors to determine effects
  – Repeatability is still difficult to achieve due to fragile nature of robots
Some Metrics for HRI

- Time spent navigating, on UI overhead and avoiding obstacles
- Amount of space covered
- Number of victims found
- Critical incidents
  - Positive outcomes
  - Negative outcomes
- Operator interventions
  - Amount of time robot needs help
  - Time to acquire situation awareness
  - Reason for intervention
What is “awareness”?  

- Operator made aware of robot’s status and activities via the interface  
- HRI awareness is the understanding that the human has of the  
  - location,  
  - activities,  
  - status, and  
  - surroundings of the robot; and  
- And the knowledge that the robot has of  
  - the human’s commands necessary to direct its activities and  
  - the constraints under which it must operate
Studying Robotics Designed for Urban Search and Rescue

• **USAR task is safety-critical**
  – Run-time error or failure could result in death, injury, loss of property, or environmental harm [Leveson 1986]

• **Safety-critical situations require that robots perform exactly as intended and support operators in efficient and error-free operations**
Urban Search and Rescue Test Arena

- Locate as many victims as possible while minimizing penalties
- Arena used in AAAI and RoboCup competitions
- Also available for use at NIST
Example Study: AAAI-2002

• Observed and videotaped all participating robots, interfaces, operators
• Systems also tested by a Fire Chief
• Analyzed HRI of top four teams
• Coded activities
• Isolated “critical incidents” and determined causes
Examples of Critical Incidents

- Team A deployed small dog-like robots (Sony AIBOs) off of the back of a larger robot
- One AIBO fell off and became trapped under fallen Plexiglas but operator didn’t know this

Lack of human-robot awareness of robots’ location
Examples of Critical Incidents

- Operator using Team B’s robot in “safe” mode became frustrated when robot would not move forward
- Operator changed to “teleoperate” mode and drove robot into Plexiglas
- Plexiglas was sensed by sonar and indicated on a sensor map, but map was located on a different screen than video
- Operator did not take his attention away from video to check

Lack of human-robot awareness of robots’ surroundings
Examples of Critical Incidents

- Operator using Team B’s robot moved the video camera off center for a victim identification
- Robot maneuvered itself out of tight area in autonomous mode
- Upon taking control of robot, operator forgot that camera was still off-center
- Operator drove robot out of arena and into the crowd

Lack of human-robot awareness of robots’ status
Discussion of AAAI-02 Study

• All critical incidents were due to a lack of awareness of the robot’s situation
• Problems arise due to interface design and operator’s almost singular reliance on video images
• Based upon this study and others that we’ve performed, have developed design guidelines for HRI interfaces
Usability Testing

• Tested four USAR experts (not roboticists) on two different robot systems at NIST in January 2004
• Allows us to determine how easy it is for a non-developer to use a system
Some Results from Usability Testing

- 12 – 63% of each run was spent acquiring SA to the exclusion of all other activities
- Two subjects panned the robot more often than the camera to acquire SA
- Directional SA
  - Robot bumped obstacles an average of 2.6 times/run
  - Of all hits during all of the subjects’ runs, 41% of the hits were on the rear of the robot
- Again, we saw a heavy reliance on video
HRI Design Guidelines

• Enhance awareness
  – Provide a map of where the robot has been
  – Provide more spatial information about the robot in the environment to make the operators more aware of their robot’s immediate surroundings

• Lower cognitive load
  – Provide fused sensor information to avoid making the user fuse data mentally
  – Display important information near or fused with the video image
HRI Design Guidelines

• Increase efficiency
  – Provide user interfaces that support multiple robots in a single window, if possible
  – In general, minimize the use of multiple windows and maximize use of the primary viewing area

• Provide help in choosing robot modality
  – Give the operator assistance in determining the most appropriate level of robot autonomy at any given time
Presentation of Sensor Information
Presentation of Sensor Information

• In prior slide, interface displays video in the upper left, sensor information in the lower right
• User needs to switch video window to FLIR if that view is desired
• Too much information spread over the interface
• How could sensor data be combined for a more effective display?
Sensors for Locating Victims

• Many sensor types used for victim location and safe navigation
  – Color video cameras
  – Infrared video cameras
  – Laser ranging and other distance sensors
  – Audio
  – Gas detection

• Few systems use more than two sensor types

• None of the systems in our studies fuse information effectively, resulting in poor situation awareness
Fusing Information

- Victims can be missed in video images
Fusing Infrared and Color Video
Fusing Infrared and Color Video
Fusing Infrared and Color Video

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HRI Lecture, Slide 74
Other Sensor Modalities for USAR

- CO$_2$ detection
- Audio
Overlay of four sensor modalities
Overlay of four sensor modalities
Redesigning INEEL’s Interface
Redesigning INEEL’s Interface
Your Chance to Try

- You can try to drive our USAR system with its new interface, tonight at 7:15ish