Introduction to Human-Robot Interaction

91.550 Human-Robot Interaction

Prof. Yanco

Fall 2007

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 Borenstein, University of Michigan

Robotic Walkers

Walkers from Haptica, Inc., Ireland

Left photo courtesy of Gerard Lacey, Haptica

Robotic Wheelchairs

Wheelesley, MIT AI Lab

Hephaestus Smart Wheelchair, AT Sciences

Independence Enhancing Wheelchair, ActivMedia

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, Carnegie Mellon University

NurseBot

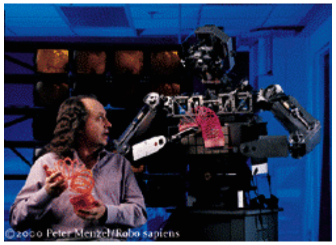
Nursebot Pearl

Assisting Nursing
Home Residents

Longwood, Oakdale, May 2001
CMU/Pitt/Mich Nursebot Project

Multi-Agent Robotics: Soccer

Humanoid Robots



MIT's Cog

Photo courtesy of Rod Brooks, MIT

Humanoid Robots: Robonaut

Courtesy of Rob Ambrose, NASA JSC

Humanoid Robots: Robonaut

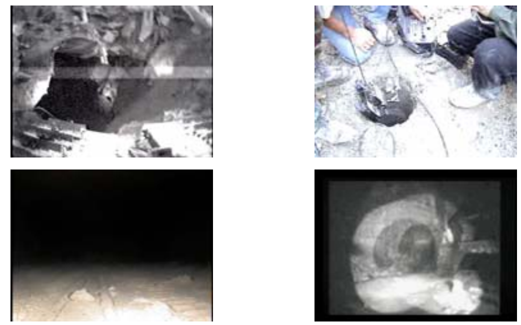
Courtesy of Rob Ambrose, NASA JSC

Robotic Systems from Search and Rescue Competitions

Photos are by permission of RoboCup 2003 teams

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 “telepresense” 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*

Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 33

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%.

Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 34

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%.

Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 35

Taxonomy Classifications for Team Composition

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

Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 36

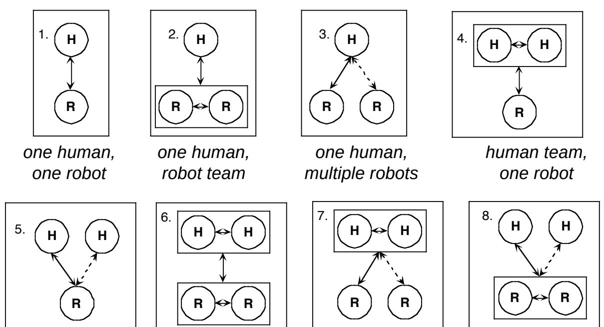
HUMAN-ROBOT-RATIO

- 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



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*

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,
    {{sonar,ladar}→map}

PRE-PROCESSING

- The amount of pre-processing of sensors for decision support.
- Possible values:
  - Denoted in a list of functions.
  - For example,
    {{sonar→map}, {video→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

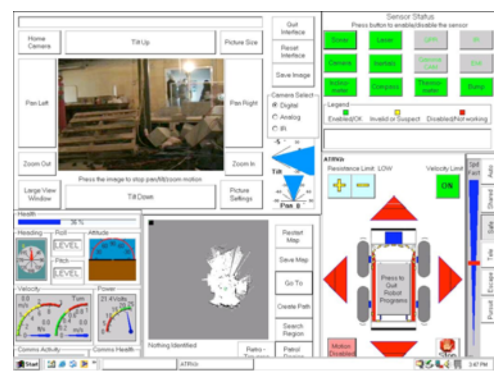
HRI Design Guidelines

- 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 award 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?

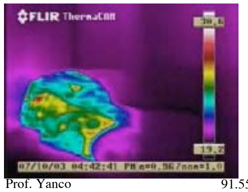
Sensors for Locating Victims

- 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

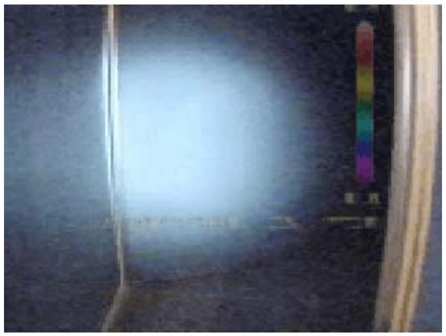
Fusing Information

- Victims can be missed in video images

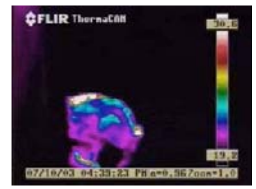
Fusing Infrared and Color Video



Fusing Infrared and Color Video



Fusing Infrared and Color Video



Other Sensor Modalities for USAR

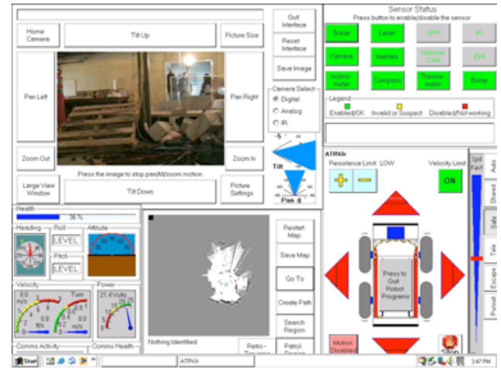
- CO_2 detection
- Audio

Overlay of four sensor modalities

Overlay of four sensor modalities

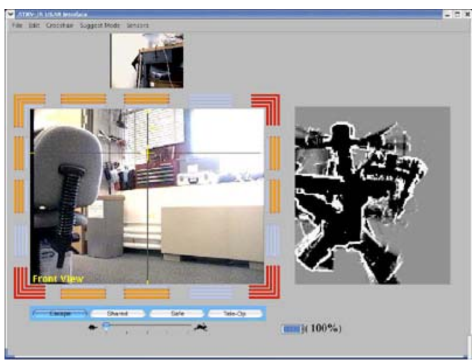
Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 77

Redesigning INEEL's Interface



Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 78

Redesigning INEEL's Interface



Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 79

Your Chance to Try

- You can try to drive our USAR system with its new interface, either tonight or tomorrow

Prof. Yanco | 91.550 Human-Robot Interaction, Fall 2007 | Lecture 1, Slide 80