

Topic Paper

HRI Theory and Evaluation

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Abstract:

Human-robot interaction(HRI) is the study of interactions between humans and robots. HRI Theory and evaluation deals with the evaluation of human-robot interaction and proposes the interactions and information needed by both humans and robots for different level of interactions. It also provides the evaluation methodology based on the situations. This is related to HCI but has some key differences such as HRI concerns systems which have complex, dynamic control systems, exhibit autonomy and cognition, and which operate in changing, real-world environments. As there is predominant increase in capabilities of robots they are able to perform more tasks in an autonomous manner. So we need to think about the interactions that humans will have with robots and what software architecture and user interface designs can accommodate the humans to interact with such robots. Despite of many theories and policies that determine the interactions between humans and robots still, there are some crucial issues pertaining to different levels of interaction which would be discussed in this paper.

1. Introduction:

The main goal of researchers in this area is to create humans and robots that are efficient , effective and take advantage of the skills of each other through effective interaction. This can be achieved by increasing the number of robotic platforms that can be handled by individuals. In order to accomplish this goal we need to examine the types of interactions that will be needed between humans and robots, the information that humans and robots need to have desirable interchanges, and to develop the software architectures and interaction architectures to accommodate these needs. Human -robot interaction deals with the interactions at different levels. There are different dimensions that determine the interactions such as physical nature of robots, the number of systems a user may interact simultaneously and the environment in which the interactions occur.

The first dimension is the physical nature of mobile robots. Robots need some awareness of the physical world in which they move. Every robot build up its own world model where it needs to interact with humans by conveying the information using sensors but it may not convey the real world exactly due to the limitations of the sensors and the algorithms. The second dimension is the environment in which the interactions occur. Robots may have to work in dynamic and harsh conditions such as dust, noisy and low-light conditions. For example search and rescue robots may encounter more building or tunnel collapses during the operation and in military environment, explosions may drastically change the environment during the mission. Not only will the robot have to function in these conditions but the user interacting with the robot may be co-located as well. The third dimension is the number of independent systems the user needs to interact with. Typical human-computer interaction assumes one user interacting with one system. Even in collaborative systems we usually consider one user to one system with the added property that this user-computer system is connected to at least one other such system. This allows interaction between users and computers. In the case of humans and robots, there will be a person interacting with a number of heterogeneous robots.

Generally the interactions are well defined based on the types of users and their roles. Most prominent users of robots would be supervisor, operator, mechanic, bystander and teammate. Supervisory and teammate roles imply the same relationships between humans and robots as they do when applied to human- human interactions. An operator is needed to adjusting various parameters in the robot's control mechanism to modify abnormal behavior, to change a given behavior to a more appropriate one, or to take over and operate the robot. The mechanic type of interaction is undertaken when a human needs to adjust physical components of the robot, such as adjusting the camera or

adjusting various mechanisms. A bystander is generally another robot which does not explicitly interact with a robot but needs some model of robot behavior to understand the consequences of the robot's actions. For example a bystander might be able to cause the robot to stop by walking in front of the robot using perception.

Along with the development of the robot interfaces there has been significant increase in the evaluations of these systems. The two main evaluation styles in evaluation of the human-robot interactions are *summative* approach which is done after the fact i.e after the development of the system and the other is *formative* approach which is done simultaneously during the development of the system. But relatively the two classes of evaluation styles, formative and the low-cost techniques have been extensively used to evaluate the systems. The low-cost techniques used in the formative approach can be most effective as they deal with both major and minor issues in the early stages of the development. One of the popular low-cost technique for formative approach is Heuristic Evaluation. Heuristic Evaluation is popular due to its low-cost and its applicability to almost all systems. However, the application of Heuristic Evaluation to a system depends on the set of heuristics that are applicable to the system domain.

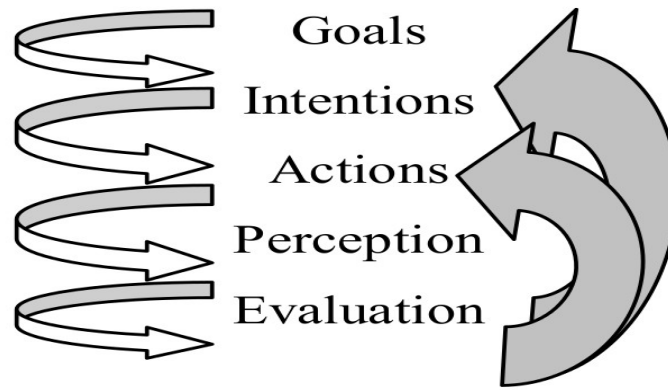
2. HRI Theory:

The first stage in development of a frame work for the HRI is to determine if any of the interactions used in HCI are applicable to your HRI system as both of them has similarities except for some differences. The most popular model of human-computer interaction is Norman's seven stages of interactions.

1. Formulation of the goal – think in high level terms of what it is you want to accomplish.
2. Formulation of the intention – think more specifically about what will satisfy this goal.
3. Specification of the action – determine what actions are necessary to carry out the intention. These actions will then be carried out one at a time.
4. Execution of the action – physically doing the action. In computer terms this would be selecting the commands needed to carryout a specific action.
5. Perception of the system state – the user must then assess what has occurred based on the action specified and execution. In the perception part the user must notice what has happened.
6. Interpretation of the system state – having perceived the system state, the user must now use her knowledge of the system to interpret what has happened.
7. Evaluation of the outcome – the user now compares the system state (as perceived and interpreted by her) to the intention and to decide if progress is being made and what action will be needed next.

These seven stages are iterated until the intention and goal are achieved.

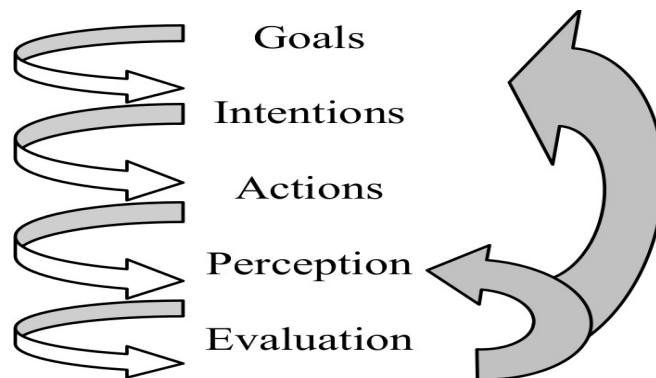
Norman defines two issues with these seven stages: the gulf of execution and the gulf of evaluation. The gulf of execution is a mismatch between the user's intentions and the allowable actions in the system. The gulf of evaluation is a mismatch between the system's representation and the user's expectations. These correspond to four critical points where failures can occur. Users can form an inadequate goal or may not know how to specify a particular action or may not be able to locate an interaction object. These result in a gulf of execution. Inappropriate or misleading feedback from the system may lead the user to an incorrect interpretation of the system state resulting in a gulf of evaluation.



Norman's HCI Model

Then in the development of HRI we should make necessary changes to the HCI model such that the developed model describes the HRI system accurately. As the interactions between human and robots is at different level they are well described using the different users and their roles which we specified earlier.

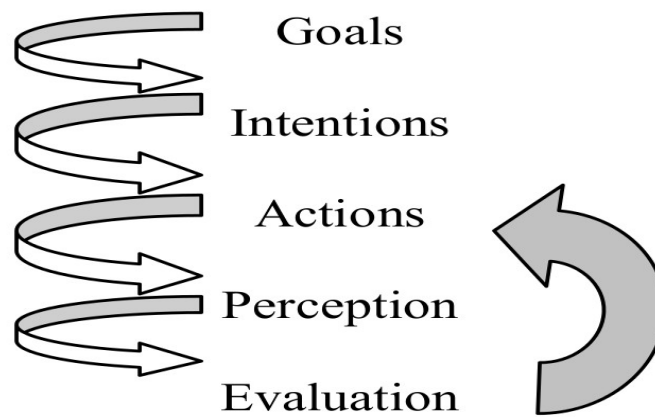
1. *Supervisor Interaction*: A supervisor monitors and controls the overall situation i.e the supervisor would monitor all the robots in particular environment in a manner to achieve the goals. Every robots in the environment possess planning systems, the goals and intentions have been given to the planning system, and the robot software is generating the actions based on a perception of the real world. The supervisor can step in and specify an action or modify plans.



Supervisor Interaction Model

The above figure shows a proposed model for the supervisor- robot interaction. The main loop is the perception/evaluation loop as most of the actions are automatically generated by the robot software. Supervisor interactions at the action and intention level must be supported as well. The human-robot interaction for the supervisor is heavily perceptually based, and that interactions need to be supported on both the action and intention level.

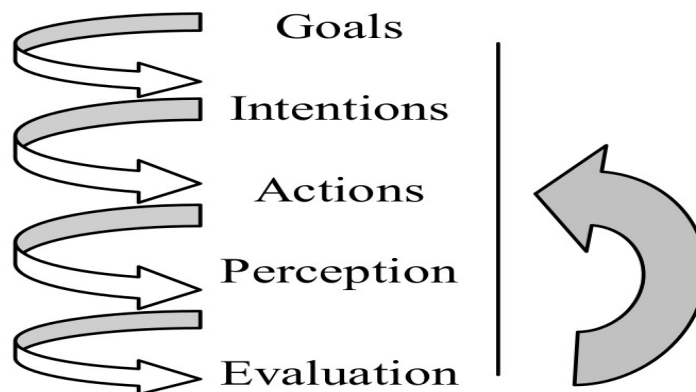
2. *Operator Interaction*: An operator deals with the modification of internal software or models when the robot behavior is not acceptable. The operator will interact with the robot at the action level. It will be necessary to then determine if these actions are being carried out correctly and if the actions are in accordance with the longer term goal.



Operator Interaction Model

The above figure shows a proposed model for the operator-robot interaction. It specifies that an operator can only have interaction with the robot at action level. By this operator can check the correctness of the actions of system.

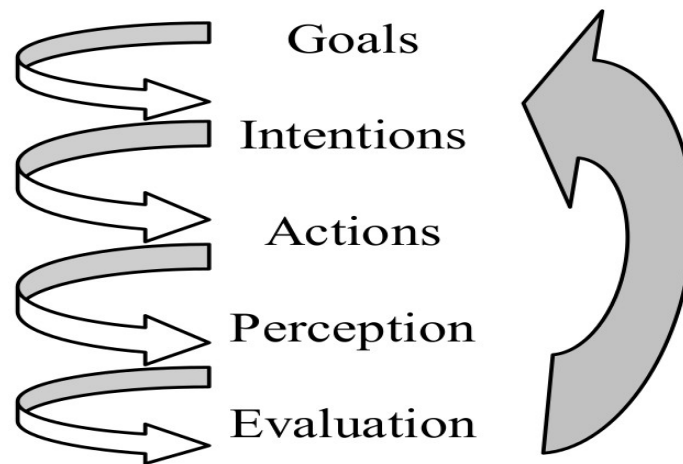
3. *Mechanic Interaction*: The mechanic deals with physical interventions, but it is still necessary for the mechanic to determine if the interaction has the desired effect on the behavior. So, the model looks similar to the model for the operator interaction. However, the difference is that while the modifications have been made to the hardware, the behavior testing needs to be initiated in software and observations of both software and hardware behavior are necessary to ensure that the behavior is correct.



Mechanic Interaction Model

The above figure shows the proposed model for the mechanic-robot interaction. It specifies the interactions should be both hardware and software as the changes made in hardware should reflect to correct working of the software.

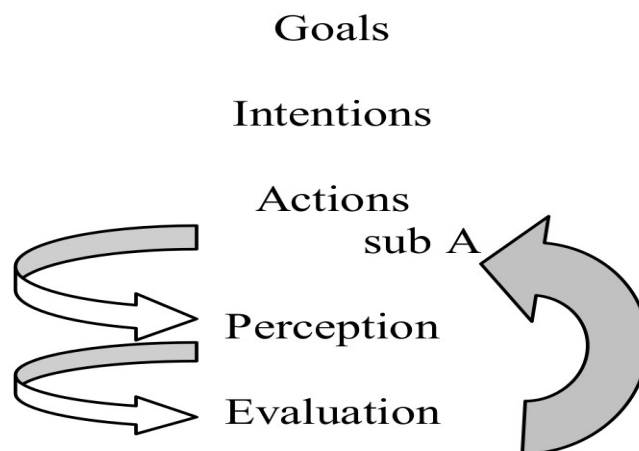
4. *Teammate Interaction*: Teammates of the robots can give them commands to either perform sub goals or to change the larger goals. Even with good user interfaces, teammates may not have the necessary time to perform these interactions. If they do, they can certainly switch to the supervisory role if appropriate.



Teammate Interaction Model

The model in figure shows the interaction model proposed for teammate interactions. We propose that this interaction needs to occur at a higher level of behavior than the operator interactions allow. Human team members talk to each other in terms of higher level intentions – not in terms of lower level behaviors. Terms such as follow me, make a sharp left turn, wait until I get there would be reasonable units of dialogue between a robot and a human team member in the peer role. In this case, direct observation is probably the perceptual input used for evaluation. In the case that the behavior is not correctly carried out, the peer has the choice of switching to the operator model or handing off the problem to someone more qualified as the operator.

5. *Bystander Interaction*: A bystander deals with assisting the robot using perception by locating itself in the same environment as of the robot. For example, the bystander might be able to cause the robot to stop by walking in front of the robot. In this interaction, the bystander has only a subset of the actions available. Bystander is not able to interact at the goal or intention level. The largest challenge pertaining to bystander interaction is how to advise the bystander of the capabilities of the robot that are under its control.



Bystander Interaction Model

The above figure shows the model proposed for bystander and robot. Bystander only interacts with the subset of actions which are declared to it.

There are many other theories to develop Human-robot interactions such as conversational policy of Joint Intention Theory which uses speech recognition, body language in the form of gestures, and observation and interpretation of the use of space and body language of the users being communicated with. There are even some common metrics to measure the performance of different types of HRI.

3. HRI Evaluation:

HRI evaluation is generally done using two approaches; summative and formative. Summative evaluations that are applied on an implemented design product to judge how well it has met design goals; in contrast formative evaluations are applied to designs or prototypes with the intention of guiding the design or implementation itself. The focus on summative applications seems to come at the expense of formative evaluations in the development of most HRI systems. Also, a contributing factor to this paucity is a lack of evaluation methods that are both suited to formative studies and have been successfully demonstrated on HRI applications specifically.

3.1 Heuristic Evaluation Process:

Discount/low-cost evaluation techniques are used in formative approach of evaluations. These methods are designed explicitly for low cost in terms of manpower and time. Because of these properties, discount evaluations are often applied formatively. One such popular method is Heuristic Evaluation. Heuristic Evaluation is a type of usability inspection method, which is a class of techniques involving evaluators examining an interface with the purpose of identifying usability problems. It is advantageous as it is applicable to a wide range of prototypes, ranging from detailed design specifications to fully functioning systems. Heuristic Evaluation was developed by Nielsen and Molich. In accordance with its discount label, it requires only a few (three to five) evaluators who are not necessarily HCI or HRI experts. The principle behind Heuristic Evaluation is that individual inspectors of a system do a relatively poor job, finding a fairly small percentage of the total number of known usability problems. However, Nielsen has shown that there is a wide variance in the problems found between evaluators, which means the results of a small group of evaluators can be aggregated to uncover a much larger number of bugs. The Heuristic Evaluation process in general consists of the following steps :

1. The group that desires a heuristic evaluation performs preparatory work, such as:
 - Creation of problem report templates for use by the evaluators.
 - Customization of heuristics to the specific interface being evaluated. Depending on what kind of information the design team is trying to gain, only certain heuristics may be relevant to that goal. In addition, since canonical heuristics are (intentionally) generalized, heuristic descriptions given to the evaluators can include references and examples taken from the system in question.
2. Assemble a small group of evaluators to perform the Heuristic Evaluation. These evaluators do not need any domain knowledge of usability or interface design.
3. Each evaluator independently assesses the system in question and judges its compliance with a set of usability guidelines (the heuristics) provided for them.
4. After the results of each assessment have been recorded, the evaluators can convene to

aggregate their results and assign severity ratings to the various usability issues. Alternatively, an observer (the experimenter organizing and conducting the evaluation) can perform the aggregation and rating assignment.

3.2 Standard Heuristics:

Yanco, acknowledges Heuristic Evaluation as a useful HCI method, but rejects its applicability to HRI because Nielsen's heuristics are not appropriate to the domain. There are many issues listed as differentiating factors between HRI and HCI/HMI, including complex control systems, the existence of autonomy and cognition, dynamic operating environments, varied interaction roles, multi-agent and multi-operator schemes, and the embodied nature of HRI systems. But the new heuristics can be developed and validated in accordance to the system domain based on the standard heuristics. Some of the standard and fundamental heuristics are

1. Sufficient information design

The interface should be designed to convey “just enough” information: enough so that the human can determine if intervention is needed, and not so much that it causes overload.

2. Visibility of system status

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time. The system should convey its world model to the user so that the user has a full understanding of the world as it appears to the system.

3. Appropriate information presentation

The interface should present sensor information that is clear, easily understood, and in the form most useful to the user. The system should utilize the principle of recognition over recall.

4. Match between system and the real world

The language of the interaction between the user and the system should be in terms of words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

5. Synthesis of system and interface

The interface and system should blend together so that the interface is an extension of the system itself. The interface should facilitate efficient and effective communication between system and user and vice versa.

6. Help users recognize, diagnose, and recover from errors

System malfunctions should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution. The system should present enough information about the task environment so that the user can determine if some aspect of the world has contributed to the problem.

7. Flexibility of interaction architecture

If the system will be used over a lengthy period of time, the interface should support the evolution of system capabilities, such as sensor and actuator capacity, behavior changes and physical alteration.

8. Aesthetic and minimalist design

The system should not contain information that is irrelevant or rarely needed. The physical

embodiment of the system should be pleasing in its intended setting.

3.3 Heuristic Development and Validation:

The general process of heuristic process follows steps such as:

- Create an initial list of HRI heuristics via brainstorming and synthesizing existing lists of potentially applicable heuristics.
- Modify the initial list based on pilot studies, consultation with other domain experts, and other informal techniques.
- Validate the modified list against existing HRI systems, hypothesizing that a small number of evaluators using the heuristics will find a large percentage of known usability problems, and that evaluators find more usability problem using the HRI heuristics than another set of heuristics. In addition, we might compare the performance of inspectors who are robotics experts but HCI novices against HCI experts who are robotics novices.

4. HRI Challenges:

The study of HRI has a wide variety of challenges some of them are of basic research nature and exploring concepts general to HRI, and others are of domain-specific nature, dealing with direct uses of robot systems that interact with humans in particular contexts. Some of the major challenges of HRI are multi-modal sensing and perception, design and human factors, developmental and epigenetic robotics, social, service, assistive robotics and robotics for education.

4.1 Multi-Modal Perception:

Real-time perception and dealing with uncertainty in sensing are some of the most enduring challenges of robotics. In HRI, the perceptual challenges are particularly complex, because of the need to perceive, understand, and react to human activity in real-time.

The range of sensor inputs for human interaction is far larger than for most other robotic domains. HRI inputs include vision and speech which are both major open challenges for real-time data processing. Computer vision methods that can process human-oriented data such as facial expression and gestures must be capable of handling a vast range of possible inputs and situations. Even the language understanding and dialog systems between human users and robots remain an open research challenge. The major challenge is to obtain understanding of connection between visual and linguistic data and combining them toward improved sensing and expression.

Even in the cases where the range of input for HRI specific sensors is tractable, there is the added challenge of developing systems that can accomplish the sensory processing needed in a low-latency time frame that is suitable for human interaction. For example, Kismet, an animated robotic head designed for infant-like interactions with a human, using object tracking for active vision, speech and prosody detection and imitation, and an actuated face for facial expressions, required several computers running in tandem to produce engaging if non-sensical facial and speech behavior.

Researchers need to develop algorithms for integrating multi-sensor multi-modal data inherent to HRI domains in addition to develop new and improving existing sensors. Multi-modal sensing has also been used for a robot to detect the attention of human users in order to determine if a user is

addressing the robot, integrating person tracking, face recognition, sound source localization and leg detection all of which are under research.

4.2 Design and Human Factors:

The design of the robot, particularly the human factor concerns, are a key aspect of HRI. The robot's physical embodiment, form and level of anthropomorphism and simplicity or complexity of design, are some of the key challenges which are still being explored.

Work by Bartneck claimed that robotic embodiment has no more effect on people's emotions than a virtual agent. Compelling recent work used three characters, a human, a robot, and an animated character, to verbally instruct participants in a block stacking exercise. The study reported differences between the embodied and non-embodied agents: the robot was more engaging to the user than a simulated agent. Woods studied perception differences between live and video recorded robot performances. They proposed using video recordings during system development as a complementary research tool for HRI.

HRI studies have verified that there are differences in interaction between anthropomorphic and non-anthropomorphic robots. For example, children with autism are known to respond to simple mobile car-like robots as well as to humanoid machines. However, pilot experiments have suggested that humanoid robots may be overwhelming and intimidating, while others have shown therapeutic benefit. Biomimetic, and more specifically, anthropomorphic form allows human-like gestures and direct imitation movements, while non biomimetic form preserves the appeal of computers and mechanical objects.

4.3 Development/Epigenetic Robotics:

Development/Epigenetic Robotics deals with the cognitive development of robots. Developmental robotics are focused on creating intelligent machines by endowing them with the ability to autonomously acquire skills and information. Techniques for automated teaching and learning of skills has direct applications for algorithm development for education robotics. This work involves estimating behavior from human actions. In the broader field of robot learning, a variety of methods are being developed for robot instruction from human demonstration, from reinforcement learning and from genetic programming.

4.4 Social, Service, Assistive Robotics and Robotics for Education:

Service, assistive, educational robotics include a very broad spectrum of application domains, such as office assistants, autonomous rehabilitation aids and educational robots. Socially assistive robotics is a growing area of research with potential benefits for elder care, education, people with social and cognitive disorders and rehabilitation, among others. Socially assistive robotics is the intersection of assistive robotics, which focuses on robots whose primary goal is assistance, and socially interactive robotics, which addresses robots whose primary feature is social interaction. Educational robots have shown to be better for instruction than people in some specific domains. While some automated systems are used for regular academic instruction, others are used for social skill instruction. In particular, robots can be used to teach social skills such as imitation, self-initiation of behavior and are being explored as potentially powerful tools for special education.

5. Conclusion:

This paper gives the basic idea of the Human-Robot Interaction and the evaluation of such systems. It summarizes the general processes of development of HRI and the methods of evaluation. It also describes the some of the popular processes and methods of evaluation such as Heuristic Evaluation. It also lists the challenges of the HRI.

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