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I Want What You've Got: Cross Platform Portability And Human-Robot Interaction Assessment

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Performance Metrics For Intelligent Systems

I want what you've got: Cross platform portability and human-robot interaction assessment.

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ABSTRACT: Human-robot interaction is a subtle, yet critical aspect of design that must be assessed during the development of both the human-robot interface and robot behaviors if the human-robot team is to effectively meet the complexities of the task environment. Testing not only ensures that the system can successfully achieve the tasks for which it was designed, but more importantly, usability testing allows the designers to understand how humans and robots can, will, and should work together to optimize workload distribution. A lack of human-centered robot interface design, the rigidity of sensor configuration, and the platform-specific nature of research robot development environments are a few factors preventing robotic solutions from reaching functional utility in real word environments. Often the difficult engineering challenge of implementing adroit reactive behavior, reliable communication, trustworthy autonomy that combines with system transparency and usable interfaces is overlooked in favor of other research aims. The result is that many robotic systems never reach a level of functional utility necessary even to evaluate the efficacy of the basic system, much less result in a system that can be used in a critical, real-world environment. Further, because control architectures and interfaces are often platform specific, it is difficult or even impossible to make usability comparisons between them. This paper discusses the challenges inherent to the conduct of human factors testing of variable autonomy control architectures and across platforms within a complex, real-world environment. It discusses the need to compare behaviors, architectures, and interfaces within a structured environment that contains challenging real-world tasks, and the implications for system acceptance and trust of autonomous robotic systems for how humans and robots interact in true interactive teams.

KEYWORDS: *robots, human-robot interaction, cross-platform compatibility, usability, mixed-initiative.*

1. INTRODUCTION

True human-robot teaming requires that team members be aware of and capable of working toward their goal, and work toward that goal with or without input from the other members. Belbin defined a team role as:

> *"… a pattern of behaviour characteristic of the way in which one team member interacts with another where performance serves to facilitate the progress of the team as a whole. The value of team-role theory lies in enabling an individual or team to benefit from self knowledge and adjust according to the demands being made by the external situation."* [1, see also 2]

For a robotic system to be to become a team-member, the control architecture and human-robot interface (HRI) must allow the human team member to build trust in the system, regardless of the level of intelligence inherent in the robotic system. Humans are inherently distrustful of events that are unpredictable, as can often be seen in various superstitious behaviors that we all have. System trust is enhanced when the system performs and fails predictable, and when it is designed to meet the actual users' needs, abilities, and limitations within the constraints of the task. That the human team member has limitations, such as boredom or limited short-term memory, is frequently overlooked in the design of robotic architectures. Human-centered design requires true user testing, not just designer evaluation to build trustworthy systems and to overcome the known and measurable limitations of the human team members. Different approaches to control architectures and interface design must be compared to determine which enhances the efficacy of the human-robot team.

This paper discusses the challenges inherent to the conduct of human factors tests of robotic control architectures within a complex, real-world environment. It discusses the challenges that must be addressed to compare the efficacy and usability of behaviors, architectures, and interfaces within a structured environment that contains challenging real-world tasks, and the implications for system acceptance and trust of autonomous robotic systems for how humans and robots interact in true interactive teams.

2. HUMAN-ROBOT TEAMING

Human-robot interaction is a subtle aspect of design that must be investigated during the creation of both the human-robot interface and robot behaviors if the team is to effectively meet the complexities of the real world.

Usability testing is one tool available to help roboticists design systems to meet these goals. The goal of testing is not only to determine whether the system can achieve the goal for which is has been designed; more importantly the purpose of testing is for the system creators to learn how humans and robots can, will, and should work together in the complex, real world to achieve their goals. The presence of reliable, transparent to the user robot systems in the field of Human Robot Interactions (HRI) is lacking. This lack of reliable technology has led to the majority of HRI studies to be performed in a simulated environment. In the few cases where real robot systems have been used, the lack of scientific controls in robot behavior implementation from one system to another has reduced experiment results to subjective observations.

Often, research in human-robot interaction has assumed that the human will always be the ultimate decision maker and the goal seeker, while the robot is seen as a tool that is not aware of the task goal. In the near-term, this may be true. But we are designing and researching for the long-term; that is, when robots will be equally capable of providing leadership on those tasks for which they are better suited. One aspect of incorporation of autonomous robots into tasks such as search and rescue or remote characterization of high radiation environments is that use of these robots will change how the task *must* be performed. Robots are desired for tasks that are dull, dirty, or dangerous to humans. For example, a human entering a high rad environment has significant limitations to her exposure time. This exposure limit may not be as low for a robot designed for this task. Therefore, dwell times in certain areas may be increased, and the selection of routes may not come under the same scrutiny. In other words, there are rules that drive the paradigm for the performance of tasks by humans. Robots may not have to play by these rules, but the rules that they have to obey may reflect characteristics of the design of the control architecture, the platform selected, or the information presented on the interface.

As such, robots are substitute task performers under some level of supervision by the human. The robot may be designed to meet the physical requirements of the task, but the complexity of the task when it is transformed into a monitoring task for the human also yields changes to the task paradigm, requirements, constraints on human interaction with the system that are often neglected altogether when human-robot testing is ignored. When human-robot interaction is considered, often it has not been possible to make comparisons architecture to architecture or interface to interface between systems because differences in platforms could not be controlled. Therefore, it has been difficult to assess whether performance was a function of the interface, control architecture or the suitability of the platform to the environment.

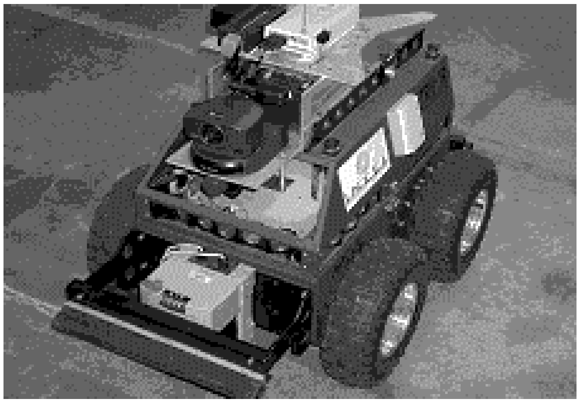


Figure 1. The ATRV Jr. and component sensors

3. HUMAN CENTERED INTERFACE DESIGN AND TESTING

The lack of human-centered robot interface design, the rigidity of sensor configuration, and the platform-specific nature of research robot development environments are a few factors preventing robotic solutions from reaching functional utility in real word environments. Often the difficult engineering challenge of implementing adroit reactive behavior, reliable communication, trustworthy autonomy that combines with system transparency and usable interfaces is overlooked in favor of other research aims. The result is that many robotic systems never reach a level of functional utility necessary even to evaluate the efficacy of the basic research, much less result in a system that can be used in a critical, real-world environment.

Yanco, Drury, and Scholtz [3] have identified two major shortcomings in prior HRI evaluations. First, robotic system evaluations typically fail to test the expected end user of the system; rather, the designers of the system are also the test users. Such evaluation is flawed, because system designers possess a much broader and higher-level system understanding and proficiency than would the end users of that system. In short, system designers have a unique "mental map" of the interface that is based on how the system works --- a level of understanding that the typical end user may never need or want to derive. For example, most people do not fully comprehend *how* the engine in their car works; however, these same people may be very highly capable drivers, who are able to navigate complex environments, such as Boston in a snowstorm, because the control of the car does not depend on understanding how the engine works. When design robotic architectures and interfaces assume a high level of system insight, usability of the system decreases for the presumed system end-user. Thus, due to their specialized insight, designers represent an upper bound of expected performance, and so these evaluations fail to identify the difficulties that an actual HRI user might experience.

The second shortcoming noted by Yanco et al. [3] is that HRI evaluations are commonly informal, precluding careful empirical control. As a consequence, most HRI evaluations fail to provide objective or conclusive results. Yanco et al. do not dismiss the value of current robotic system evaluation methods. Rather, they aim to point the way toward more effective evaluation that yields the critical information that designers need.

The information derived from true usability experiments can help to realize the broad use of robotic systems in hazardous environments, by identifying the shortcomings in robot interfaces, control system configurability, human-information processing and overall usability. The Idaho National Engineering and Environmental Laboratory (INEEL) has made a concerted effort to build a foundation of well-engineered communication, perception and autonomous behavior, robust to changing, unstructured environments and which could be reused across different robot geometries and sensors [4].

At present, the INEEL has performed several formal and semi-formal usability tests of our HRI and behavior control architecture. These studies are discussed more fully elsewhere see [4, 5, 6]. These tests have examined the role of prior experience with remote systems on usability and interaction with the system, the effects of age, gender, and more simply, users' expectations for system performance and robot behaviors.

As suggested by Yanco et al. [3], in tests of our interface and architecture, we have avoided evaluating the interface with system designers or seasoned operators. Instead, we enlisted novice users of robotic systems in our evaluation. First, we are designing for multiple applications, including countermine operations, remote characterization of high radiation environments and military reconnaissance. We believe that by opting for novice users, we maximized both the relevance of our study to multiple applications and our evaluation's sensitivity to interface shortcomings.

Second, because we believe that incorporation of autonomous robots into these types of tasks will inherently change not only the structure of the task, but the humans' role in these tasks, we must design the HRI to support novice users. For example, use of autonomous robots may eliminate the need for humans to enter high radiation environments; therefore, the rules that keep the human safe in the high rad environment may no longer apply. If we design a system that plays by rules that serve no purpose, we limit the system. Evaluation with novice users does not preclude the necessity of further evaluation with the actual target users when the system is devoted to a single task domain. An evaluation of novice users does, nonetheless, provide a baseline performance measure using a greater number of participants than would otherwise be possible.

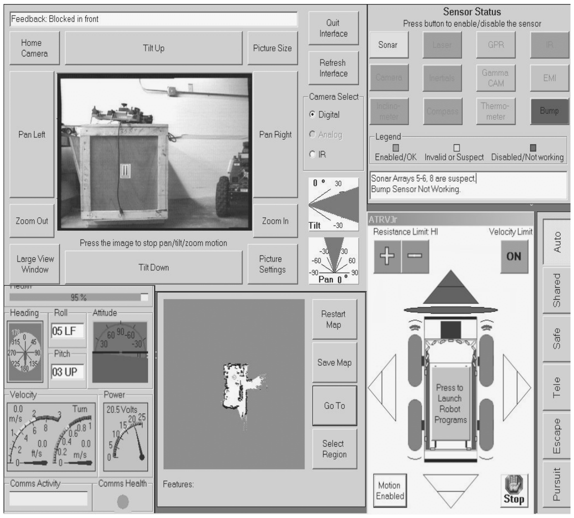
With this distinction aside, we believe that we have much more in common with Yanco et al. than not. Like Yanco et al., we firmly believe that robotic systems must be designed with as much environmental, and task realism as possible. Furthermore, we also believe that formal, iterative system testing is the only route that ensures a system the supports the capabilities and needs of the users. There are several aspects of testing that must be considered: 1) the validity of the test to the application or the fidelity of the task; 2) the fidelity of the test participants to actual end users; 3) unbiased task design; and 4) fidelity of test environment. In previous work, we proposed the following set of guidelines for usability testing of a single interface or architecture.

2.1 Guidelines for testing usability of a human-robot interface or architecture [7]

1. Simplification of the environment to allow problem solution can corrupt the ability of the human-robot system to achieve its goals; therefore, the system must be tested in real world conditions to determine if it accurately meets these real world needs.
2. The test environment must reflect the complexities of the real-world environment in which it will be used.
3. The test environment must incorporate uncertainty regarding the environment or the goal that will be seen in the true task.
4. Robotic systems will be effective only if the behaviors they use to achieve task goals are comprehensible and predictable to the human team members; therefore, system design must assess how the human will work with the system.
5. The task cannot be designed to exploit the capabilities of the robot; rather the robot's capabilities must be designed to exploit aspects of the environment and the task should emphasize the complexities encountered in the real world.
6. To accurately reflect the complexity of the task, testing must involve users who are similar to those who will put the system to actual use, not only those operators who are most familiar with the control architecture.
7. Testing must incorporate the need for an operator to maintain a level of awareness in more than one environment (proximal, proximal', and/or distal), as would occur during real-world deployment.
8. Issues of teaming and the ability of the human to trust the robot enough for effective teaming must be addressed and assessed in the testing.
9. Tasks constraints may dynamically change with the incorporation of human-robot teams. However, these constraints may still shape how the human expects the system to behave.

4. CROSS-PLATFORM COMPATIBILITY

The above guidelines, as are apparent from reading, focus on usability testing of a single system. They do not provide guidance for making comparisons *between* interfaces or control architectures. Comparison of the sufficiency of interfaces between designers, or the comparison of control architectures between platforms, is inherently complex. How is one to assess the performance of a control architecture separate from the advantages yielded by the mobile platform itself? Did failure occur because the interface did not provide the user sufficient information to maintain situation awareness or did failure occur simply because the platform selected is not agile enough or the size is incompatible for the environment or task?


Feedback: Blocked in front

Sonar Arrays 5-6, 8 are suspect.
Bump Sensor Not Working.

Figure 2. The INEEL human-robot interface.

In previous work, the INEEL has focused on the need to increase human- centered design and usability through an emphasis on consistency, simplicity, and low bandwidth communication. A human-centered approach requires that robot interface, behaviors and perceptions be designed such that the robot's particular characteristics are transparent to the user. To support this aim, the INEEL has developed a control system that uses a level of middleware abstraction to support robust perception and autonomous behavior for a wide variety of robotic systems. The abstractions allow for the easy addition of new robot systems as well as providing a method for developing behaviors on one platform that transfer with no source code changes to all other platforms, despite differences in size, bounding shape, or sensor configuration.

Recently, the INEEL team incorporated several major systemic changes to the robot control architecture. The first was to completely abstract all data and function calls with respect to robot specific geometry, sensor suite, and development environment from the robot control architecture. Doing so required funneling all robot sensor data into standard constructs. The constructs contain robot sensor information in a form generic to ground vehicles enabling the easy addition of future platforms into the INEEL architecture. Additionally all evidence of proprietary robot development environments (i.e., iRobot's 'Mobility,' ActivMedia's ARIA) have been removed from the behavioral content of the control architecture. The combination of these efforts resulted in a system capable of being transferred from one robot to another with out the need of porting or compiling the robot control architecture. The added benefit of this effort is the ability to develop and modify behaviors in complete abstraction allowing for behavior modification and development that applies the each platform in the INEEL control architecture as well as robots owned by other institutions. Recently, the INEEL has ported the "universal" architecture to unmanned systems owned and operated by the Army, Navy, and DOE as well as robots used at other research institutions.

The sensor abstractions ensure not only that code can be ported from one robot to another, but also provide a means for a standardized, custom communication protocol over a reliable, low-bandwidth communication architecture. The information sent to and from the interface is not dependent on a particular sensor configuration or robot geometry, allowing novice users with no knowledge of robot size, capabilities and sensors to accomplish complex tasks. In order to support different levels of operator trust and skill, the interface is designed with several distinct modes of operator intervention that complement scalable levels of robot autonomy. The system also provides continuous sensor analysis and allows for dynamic sensor reconfiguration, which allows the human to reconfigure the sensor suite when there are indications that sensors have failed during operation.

The technologies recently developed under the Advanced Robotic Control Architecture initiative at the INEEL provide such a structured test environment because they allow for the easy porting of robot behaviors from one robotic system to another. The net result is the ability for different robot systems to utilize the same algorithms for control. Additionally, the Advanced Robotic Control Architecture is of particular interest to the HRI community because the interface is entirely decoupled from the robot behaviors. That decoupled aspect of the Control Architecture makes it possible for multiple interfaces to be developed utilizing the same control intelligence setting the stage for a truly first-of-its-kind HRI study: A study in which all robots utilize the same behaviors, wherein it can be determined if an interface implementation is beneficial or a coping mechanism for a previously poor robot control behavior.

We believe that this type of cross platform, experimentally controlled, usability study will allow researchers to determine those aspects of their system that meets users' needs, and to assess areas in which their system behavior can be improved. We invite the opportunity to explore this area of research with other researchers.

5. REFERENCES

[1] Belbin, M. (1981). *Management Teams: Why They Succeed or Fail.* Butterworth Heinemann

[2]Belbin, M. (1993). *Team Roles at Work* Butterworth Heinemann.

[3] H. A. Yanco, J. L. Drury, and J. Scholtz, "Beyond usability evaluation: Analysis of human-robot interaction at a major robotics competition," *Journal of Human-Computer Interaction*, Vol. 19, pp. 117-149, 2004.

[4] Few, D., Bruemmer, D., & Marble, J. (2003). Usability and Portability Lessons Learned from the 2003 AAAI Robot Rescue Competition. In *Proceedings of the Eighteenth International Joint Conference on Artificial Intelligence (IJCAI-2003)*, AAAI Press.

[5] Marble, J. L., Bruemmer, D. J., & Few, D. A. (2003). Lessons learned from usability tests with a collaborative cognitive workspace for human-robot teams," *IEEE Conf. on Systems, Man, and Cybernetics*.

[6] Bruemmer, D., Boring, R., Few, D., Marble, J., & Walton, M. (in press). "I Call Shotgun!": An Evaluation of Mixed-Initiative Control for Novice Users of a Search and Rescue Robot. To appear in *Proceedings of the IEEE 2004 Conference on Systems, Man & Cybernetics.*

[7] Marble, J., Few, D., Bruemmer, D., & Dudenhoeffer, D. (2004). Challenges in the Design and Conduct of Usability Testing of Human-Robot Control Architectures. In *Proceedings of the ANS 10th International Conference on Robotics and Remote Systems for Hazardous Environments*, Gainesville, FL.