User-Centered Robot Head Design: a Sensing Computing Interaction Platform for Robotics Research (SCIPRR)

Anthony M. Harrison
Naval Research Laboratory
anthony.harrison@nrl.navy.mil

Wendy M. Xu
Oregon State University
xuwe@oregonstate.edu

J. Gregory Trafton
Naval Research Laboratory
greg.trafton@nrl.navy.mil

ABSTRACT

We developed and evaluated a novel humanoid head, SCIPRR (Sensing, Computing, Interacting Platform for Robotics Research). SCIPRR is a head shell that was iteratively created with additive manufacturing. SCIPRR contains internal scaffolding that allows sensors, small form computers, and a back-projection system to display an animated face on a front-facing screen. SCIPRR was developed using User Centered Design principles and evaluated using three different methods. First, we created multiple, small-scale prototypes through additive manufacturing and performed polling and refinement of the overall head shape. Second, we performed usability evaluations of expert HRI mechanics as they swapped sensors and computers within the the SCIPRR head. Finally, we ran and analyzed an experiment to evaluate how much novices would like a robot with our head design to perform different social and traditional robot tasks. We made both major and minor changes after each evaluation and iteration. Overall, expert users liked the SCIPRR head and novices wanted a robot with the SCIPRR head to perform more tasks (including social tasks) than a more traditional robot.

KEYWORDS

Human-Robot Interaction, Mechanical Robot Head Design, User Centered Design, 3D Printing, Animation, Projection

ACM Reference format:
Anthony M. Harrison, Wendy M. Xu, and J. Gregory Trafton. 2018. User-Centered Robot Head Design: a Sensing Computing Interaction Platform for Robotics Research (SCIPRR) . In *Proceedings of HRI'18, March 5th–8, 2018, Chicago, IL, USA, ,* 9 pages.
DOI: 10.1145/3171221.3171283

1 INTRODUCTION

In the field of robotics, there seem to be two kinds of robots, regardless of their outward appearance. One robot type, the *task-oriented non-social robot*, focuses on performing tasks in the best, most efficient manner possible. The second robot type, the *social interactive robot*, focuses on collaborating or working with people in the best social manner possible. Task-oriented robots include autonomous cars, the HUBO platform [17], the Mars rover [2], and many others. These task-oriented robots typically have state-of-the art sensors and computers when they are built, and interaction usually occurs through a computer interface, not in a collaborative, peer-to-peer setting. Some robots with interactive heads include Kismet [3, 4], the MDS platform [20],the iCub [9], SnackBot[8], and Furhat [11]. Social interaction robots typically have sensors for detecting people and a face to encourage and enable interaction with people. Interestingly, there are relatively few robots that have both strong functional task capabilities and strong social interaction capabilities.

Why does this dissociation exist? We believe that this dissociation exists because most interaction design work has focused on people in supervisor, peer, and even operator user roles, but not the people who actually build and maintain the robots, the mechanic user [19]. To explore this dissociation and to create a possible solution, we applied user-centered design (UCD) approaches to focus on the personas we call "Expert HRI Mechanic" which is based off of Scholtz' mechanic role and the "Novice User" which generally refers to the other roles defined by Scholtz [19].

To preview our design goals generated from our UCD approaches, we found two primary concerns: the ability to easily change existing sensors and computers on the robot and the desire for strong interaction capability through visual design and social affordances. Because the head and face is a primary interaction method (nods, shakes, communication, emotional expressions, etc.) and sensors are typically needed in the head, our focus will be on the design of a humanoid robot head that will meet both functional and interaction goals.

We begin with a description of user-centered design, describe the generation of the two personas and the results of those user interviews. We report on the final solution we developed for the head but also, true to the user-centered design (UCD) approach, we share the feedback and critique of the iterations that came with it. The feedback and data were gained through multiple different user-centered research methods allowed us to keep the focus on the user personas that we developed and evaluate the solution based on our multifaceted design goals and requirements.

2 ABOUT THE USER-CENTERED DESIGN PROCESS

User-Centered Design (UCD) is an iterative design process that allows a designer to create solutions based on the needs and impressions of potential users [1, 14, 15]. Highlights include:

- Users are consulted throughout the design process.
- Design needs and requirements are gathered from the users.
- The design team includes multidisciplinary skills and perspectives.

HRI'18, March 5th–8, 2018, Chicago, IL, USA

DOI: 10.1145/3171221.3171283

- Designs are iteratively refined based on user-centered evaluation.
- Solution is grounded in the understanding of the tasks and environments of users.

Part of UCD is relying on what is learned about users as the research is being done, instead of referencing pre-established experiences or a certain unifying perspective [15]. Therefore, we gathered a design team that consisted of four core members, encompassing fields including, computer science, mechanical engineering, user experience design, and cognitive science to create a multifaceted team with different perspectives and levels of familiarity with both functional and interaction robots. In the following we describe how our team interviewed users and created personas using user research based on the mechanic user's interaction with a robot, ran multiple user studies and research sessions, and aggregated the feedback to inform critical design iterations [19].

3 PERSONA DEVELOPMENT AND DESCRIPTION

We developed an Expert HRI Mechanic persona to ground our design and allow us to empathize with a specific user group's interaction needs. Studying the tasks and difficulties of the persona through structured interviews allowed us to come up with our UCD goals.

3.1 Mechanic User Role

The first user we focused on was the mechanic user role. This role, as suggested by Scholtz, is an individual who focuses on repairing, updating, and debugging hardware and/or software aspects of a robot [19]. The mechanic needs a way to take the robot "off-line" for testing. The mechanic also needs to be able to increase the robot's capabilities to accommodate a new task, computer, or sensor.

Interestingly, the mechanic is a user role often overlooked when we consider robot interaction, but it is nonetheless a critical user role. If robot mechanics can not easily update or maintain a robot, the usability of the entire robot enterprise decreases a great deal. It is not uncommon to see "robot graveyards" in the labs of robot researchers after robots just can not keep current with fast pace of technological development.

3.2 Models of the Expert HRI Mechanic persona

To create a user-centered persona, we needed to find several people that fit the mechanic user role to develop into a persona. We focused on engineers that work with robots specifically intended for use in social environments where they may need to interact with non-mechanic users. We also wanted people who could speak from their personal experience about the tasks they performed and the difficulties that come along with it. Therefore, we looked for engineers with at least 5 years of direct interaction with fixing, repairing, building, and generally maintaining robots.

We interviewed three people who fit the Expert HRI Mechanic user role. All three people had extensive experience working with robots and 5 to 10 years experience with humanoid robots. One was female and two were male. Their self identified specialties included computer vision, human computer interaction, mechanical design, software development, and cognitive modeling, all areas one would associate with a person working as an HRI Mechanic.

3.3 Procedure

The participants were individually asked to fill out general demographic and professional surveys about themselves and robot projects they worked on. We then had an open ended interview about their experience maintaining, repairing, and replacing robots and robot components. In our interviews, we looked for tasks and difficulties that were common to all of them. These common difficulties defined the rest of the HRI Mechanic persona and identified issues and concerns they had. They also were consulted through out the design process.

3.4 Results and Discussion

The interviews yielded a great deal of qualitative data. While there are many ways to use and reduce this data (e.g., protocol analysis [5, 22]), we used a traditional UCD approach here. After the mechanic defined their responsibilities and daily roles, we used the commonalities in anecdotes and shared experiences to create driving characteristics of the persona. Here we share some of their more influential anecdotes that started to reveal a design need. These anecdotes highlighted two primary tasks: (1) the re-occurrence and necessity of making modifications to the robot sensors and computing technology and (2) the importance of how the robot appears (visual aesthetics).

User stories on making modifications to the robot:

- *"On many occasions we have made modifications to install sensors for specialized tasks. These have included adding a special sensor in the front ... to detect fire... which wasn't included in the original design."*
- *"Changes to [the] robot or sensor are [meant to be] permanent but they end up short term."*
- *Since there was no established way to attach new equipment, they had figured out"hacky things like put holes in robots to accommodate sensors or glue or tape them onto robot."*

User stories on how the robot looks (visual aesthetics):

- *"Also, most of our robots are too scary for little children so such communities would be avoided."*
- *"It's difficult to install new sensors without having it look 'obnoxious'"*
- *"Making it look good for interaction was hard"*
- *"The world is made for things with two arms, two legs, and a head... not a sensor stick"*
- *"I just duct tape everything so it was quite unsightly"*

These tasks and user testimonies helped us develop design priorities that we knew would directly address their concerns. This also helped identify another user role that was being inherently prioritized in their work; the novice robot user that interacts with the robots they work on.

3.5 Novice Robot User Persona

In an untraditional way, we developed a general persona of the testimonies and interviews done for the Expert HRI Mechanic person. Naturally, their tasks involved heavily considering the impact and interaction of everyone else who might use the robots they work on. These include the peers, the supervisors, operators, and even bystanders. We refer to this general inclusive persona as the novice robot user role. The novice user is the most common user role studied in human robot interaction. The novice user typically does not have a strong understanding of the current capabilities of robots; their knowledge comes from direct experience (e.g., the EV3 or the roomba), news media, and cinema. We further developed the novice robot user persona based on the extensive empirical work on novices (both qualitative and quantitative; [10, 21].

Novice User primary tasks and needs:

- User needs the robot to be functional for the tasks the user wants performed.
- User needs to be able to interact comfortably and naturally with the robot with little training.

Through our analysis of the Expert HRI Mechanic perspective, many of these novice user's task needs will be met through affording the interaction and visual aesthetic tasks of a mechanic. The following design goals aim towards a solution that will allow both the Expert HRI Mechanic persona and Novice User to better perform the task they need to.

Specifically, these interviews have allowed us to identify the needs of the expert HRI mechanic (the ability to easily swap new sensors in an aesthetically consistent manner) and the needs of the novice robot user (functional and easy to use).

4 DESIGN GOALS

The interviews allowed us to constrain the design space and focus on three primary goals that the expert HRI mechanic and the novice user wanted. We also recorded some more general priorities that were inherent to convenient functional robot head design. This included having an outer shell that protected the inner components, having easy access to wires and switches, and integration into the robot body (in this case, the DRC HUBO). While these are integral to the existence of the head platform and were at times intricate to design for, those findings were not novel realizations or surprising requirements unique to this problem area and user group.

Recall that our focus here is on the head because many sensors are placed in the highest spot on a robot and a head with a face affords a great deal of interaction. The three priorities we focused on mirrored the concerns of the expert HRI mechanic and the novice user: (1) Making it easy to modify or change the sensors and associated computers; (2) Enabling an approachable visual aesthetic to fit different situations; and (3) Enabling natural robot interaction with human novices.

4.1 Technology Configurability

Every mechanic discussed the difficulty with changing sensors and computers. Typically, a robot comes with a set of sensors that work well with the robot and match the general aesthetic. If someone needs to use the robot in a different context than what the head and sensor package was not already designed for, they will need to spend a great deal of time and effort. This is inevitable, as the robot ages, more state-of-the-art sensors, computers and other equipment are developed. The robot's components become outdated and need to be swapped out to keep up with advancing technologies. Even if the robot head can be modified with a better or more powerful sensor, the form factor may no longer match and the robot can look unsightly and/or unapproachable.

For example, the Mobile, Dextrous, & Social (MDS) robots [4] have mechanically articulated faces with 17 degrees of freedom. The MDS face is extremely expressive, allowing the robot to nonverbally communicate internal states and emotions. Similarly, the MDS head's design is very cohesive with respect to the rest of the robot. However, with its eyes and head designed around the RGB and depth sensors installed, the MDS is very limited in terms of sensor expansion: the cameras are in the eyes, which greatly limit the size and power requirements of adding or changing a sensor. In addition, replacing one of the cameras in the eye is a time-consuming and non-trivial task.

Thus, our priority is to create a robot head that will the mechanic user role to easily change-out sensors that may have different form factors without interfering with the visual aesthetic.

4.2 Approachable Visual Aesthetic

The expert HRI mechanics all recognized that having duct tape on a robot was unsightly and awkward. They also saw the benefits of having a visually appealing facade. A complex, convoluted, or mismatched visual facade could dissuade a potential novice user from interacting with the robot or make necessary interactions more difficult because the user could be fearful or untrusting.

The HUBO robot, for example, has a standard sensor stalk. The sensor stalk can accommodate virtually any sensor, but the sensor is not only exposed to the environment, but has no aesthetic cohesiveness with the rest of the robot. The unfamiliar jutting wires and flashing black boxes do not encourage eye contact or communication from a novice user, all aspects important to social interaction.

Therefore, our priority for enabling a visual aesthetic was to allow our design to both holistically integrate into the rest of the robot and have an approachable exterior.

4.3 Encouraging Social Interaction

The robot mechanics highlighted that they wanted the robot to have strong interaction potential. Similarly, the novice robot user persona suggests that novices would like to be able to interact with the robot in a natural, comfortable manner

Many researchers have shown that robots that look like or act like people in some manner typically have better interaction potential than robots that do not. Systems that sound like a female are given female traits [13]. Robots that take the human's perspective into account are considered better interaction partners than ones that do not [6, 7]. Robots that use referential gaze are more effective communicators than robots that do not use referential gaze [12]. Robots that show emotion are more likely to be better interaction partners [18].

Given this background, we set a design goal to create a humanoid head and face that would afford strong interaction potential.

Thus, we focused on these three design goals: enabling technology reconfigurability; creating an approachable visual aesthetic; and enabling social interaction potential.

Figure 1: Design solution for a technology adaptable and social interaction affording robot head. The SCIPRR's visor surface allows sensor penetration and facial expressions or data projection (Figure 2). The inner hex shaped scaffolding and easy access panels allows for easy configuration.

5 OUR DESIGN SOLUTION OVERVIEW

Our design solution is an actuated humanoid head shaped casing that is functionally and visually integrated with the HUBO platform (our target robot platform, though this design can be modified for other platforms or aesthetics). The case holds scaffolding that accommodates the various sensors, microphones, and computers one might need for a robot. We created a polycarbonate surface front visor that allows sensor functionality and a back-projection system that affords a display of an animated face. The case opens up via hinged doors making it easy to access and modify the internals. The inside scaffolding is made of hexagonal bolt holes for easy configuration. The entire head platform is 3D printed and treated for a smooth finish. We call our solution the Sensing Computing Interacting Platform for Robot Research or SCIPRR. In the following we detail the three main aspects of the design solution.

5.1 Actuated Humanoid Case

Based on previous insights and our interviews, we recognized that having a human shaped head would enable stronger social interactions. The head is the source of visual first impressions when interacting with the robot. Users are familiar with the head shape, cuing users where to look and providing an interface for communication. SCIPRR is actuated with a neck connector which attaches the head to the rest of the body and allows for four degrees of freedom. This allows the robot to communicate through expressive motion. Head gestures including nodding the head up and down or tilting to one side can help a novice user understand that the robot is in agreement or confused, for example. Further, the case is intentionally visually designed to integrate into the rest of the body. We considered boxy to flat options (see figure 5) and finally by mimicking the design language of long rectangular foundations and rounded accents, we gave the robot head a professional and finished appearance.

The versatile head case also serves a functional purpose: protecting the sensors and computers inside from debris. It was also designed so that if the robot falls, the casing will take the brunt of the impact. Further, the entire shell has good airflow to offset heat emitted by multiple sensor and devices in a small space. This is accomplished by venting through the exterior side "ear" mounts and by providing optional mounting for fans.

5.2 Visor and Projection System

Our expert users lead us to some opposing design preferences that we solved through a creating a visor with clear polycarbonate (e.g. Lexan™) and a back projected surface. They wanted to enclose and protect sensors, yet still allow for sensing through the front of the robot head, and reserve front facing space for an interface for novice users to interact with. So, we fit both the projector and the sensors needed with simple and robust connectors that allowed them to sense and project forwards through the a polycarbonate visor. Polycarbonate is clear, durable, and also transmits a broad spectrum of light. The surface can also be used as a projection display because the material supports chemical bonding of tints, addition of appliqué, and sand-blasting. With these techniques, we made the bottom half of the visor surface semi opaque allowing us to project onto it from the inside. The upper-third of SCIPRR's visor is dedicated to sensors, while the lower-thirds can be shared by the projected display or more sensors.

The back projection system uses a cell-phone sized laser HD projector. We use two mirrors to create the correct size face given tight space inside and the surface area of the visor facade. Because the laser projector only casts hard shadows, there is virtually no light spill-over for collocated sensors as seen in Figure 1. We can render images, videos, remote desktops, arbitrary webpage content, and an animated face. We developed a ROS based rendering application that controls the components of the facial expression that SCIPRR can use when interacting with humans. This involved positioning visual sprites and timing them to follow with speech and facial patterns.

5.3 Scaffolding and Hexagonal Patterning

We used 3D design and simulation software to design the inner structure that would house the sensors and equipment. Using a hypothetical load of 5kg (the mass of a MultisenseSL™ and computer) the strength of the printed nylon models were tested in simulation and with drop-tests. Initial strut and conduit designs (see figure 4, sketches), while using a minimal amount of material, required complex brackets in order to mount sensors to the frame. We used 1/4"-20 standard nuts and bolts and created corresponding perforations all throughout the structure so that bolts could be attached anywhere. The 1/4"-20 standard is available on most optical sensors for broad tripod compatibility. By using a tessellated hexagonal pattern, we could reduce the amount of material used without weakening the frame and provide a convenient support for the hex shape of bolt heads(see figure 1, right). Now sensor brackets merely need to enclose the sensor and provide hex-plugs to mount anywhere within the inner-frame. This means a mechanic user could mount sensors and equipment everywhere in the scaffolding using the bolt holes and hexagonal pattern.

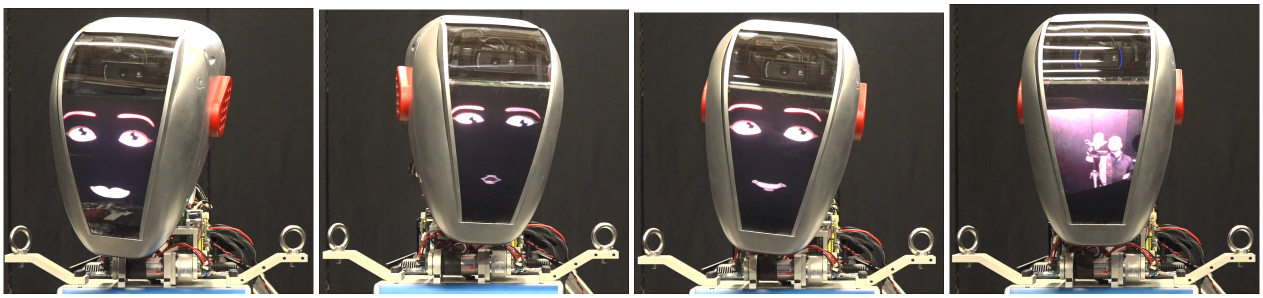

Figure 2: Stills from demo video shown to usability study participants highlighting the animated expression, actuated head, and projection display.

While the robotic platform is responsible for providing power, internally the head provides sufficient space between the outer-shell & inner-cage for wire routing, which can be further augmented by passing through hex-mounts.

6 EVALUATIONS AND RESULTS

Since the design solution was multifaceted and addressed multiple design goals, we developed multiple types of user-centered evaluations. Here we highlight three different styles of UCD evaluations: 1) expert HRI Mechanic usability test, 2) head shape prototyping poll, and 3) Amazon Mechanical Turk (AMT) perceived capabilities survey. We choose to emphasize these three methods as they each evaluate the three main design goals, respectively. Together, these three evaluations examine the configurability of sensors and equipment, the quality of the visual design, and the social interaction impact of the SCIPRR.

6.1 Usability Test for Technology Configurability

Figure 3: Usability test of SCIPRR by people representing the Expert HRI Mechanic persona. Subjects were given the head arrangement shown in the upper left and then directed to assemble into the new sensor configuration shown in the upper right.

A usability test allows user-centered researchers to examine the quality of a design by having the end users try out the interaction design. The users are selected to match the end user persona, typically given a specific task that exploits the purpose of the design, asked to externally express their thought process, and researchers observe and record the tasks[15]. Often the usability test will be paired with debriefing surveys or other quantitative surveys. In our case we recruited the same three users we based the Expert HRI Mechanic persona on. The limited sample size is based on the need for experienced experts that have both worked on the robot mechanics and use their robots for social interaction. They took the usability test and were given a survey of their experience afterwards.

6.1.1 Method. Users were invited into a side room and seated in front of a table with the SCIPRR head placed on a stand to the side of the table. Since this evaluation was meant to replicate the maintenance of the head specifically, the robot head was isolated from the rest of the HUBO robot body. The user was introduced to SCIPRR and given the general purpose of the head design 1) sensor and equipment configurability and 2) HRI affordance. To show the design in action, the user was shown a 53 second video clip of the head moving, face animating, and verbally describing its functionality, including the ability to display what the camera sensor is seeing. Stills of the video are shown in figure 2.

Then we explained the task scenario:

> *Imagine that you just used this robot head as shown in the video to give a demo of the head's capabilities and engage with the people visiting your booth. As you can see, it has a webcam sensor on top and a projection surface to display a friendly face. Now you need to prep this robot for a very different situation, bomb disposal. In this environment, there will be minimal human interaction and an emphasis on having high precision sensors. Please reconfigure this robot head into the new sensor configuration.*

The user was then shown an image of the new sensor configuration similar to the one on the top right of figure 3 along with a few basic descriptions of the inner structure. This description was provided so the user would be more familiar with the platform. They were also provided a box of standard and relevant tools typically used in this situation, a different visor type with no devoted projection area which allows for more sensor space, and the two new sensors. To finish the task, the user needed to take apart the head, remove the camera, find a way to attach the stereo vision

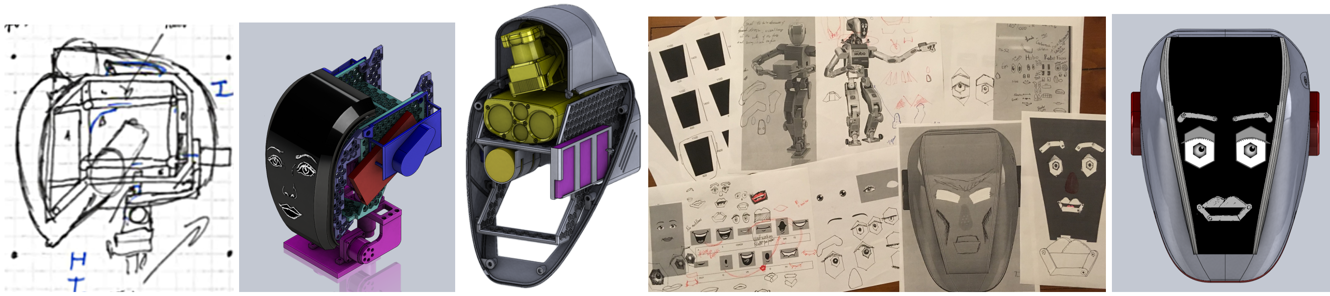

Figure 4: Examples of the ranges in designs of the head structure and face animation. Iterations progressed from paper sketches to software renderings and small 3D printed prototypes and were informed by user input. Such feedback resulted in the ideation of a more robotic face (furthest right) which is different from the face shown in Figure 1.

system and LIDAR devices, swap out the visor types, and assemble it back together.

6.1.2 Feedback and Results. Through this exercise we found small features to improve upon but a generally positive reaction to the design solution. It took about 29 minutes for an internal design team member to complete the full task while the 3 experts spent an average of about 38 minutes. Below we share the common thread in their feedback that we addressed.

In referring to the use of the visor with the shared projection surface and transparent sensor space, one user exclaimed *"How clever is that!"* Another, also before actually taking it apart, demanded that we *"Change the face on the projection ... it is too realistic, makes it look weird."* We gathered similar comments from other sources and iterated through a series of new, more mechanically inspired faces for evaluation; an example can be seen on the far right of figure 4.

One surprising but logical re-occurrence from all of our users was the commentary and concern about the nuts and bolts. One user, after finding the inset and hex shaped spaces, celebrated saying *"Proper holes for screws, woo!"*. Otherwise, the commentary or focus was punctuated with "Oops" and the clatter of nuts and bolts dropping. There were a few instances of users arbitrarily deciding to unscrew a nut or adding bolts to provide additional stability. They concluded with writing *"lock nuts in so they do not fall out."*, *"It would be nice if the nuts stayed put once inserted so maybe slightly tighter holes."*, and *"Nuts falling out was a bit surprising... I was glad to see that most bolts were the same size though."* One benefit to this head is that it can be removed from the robot and brought off to the side, but if mechanics can not remove it they would be dropping pieces of metal into the body of the robot. To address this concern, we created a new design for the hex holes to have lips that slightly cover the nuts and hold them in place more firmly.

When users got enough of the head's outer shell taken apart, they started to notice the unique hex-filled patterning of the equipment scaffolding. They commented out loud, *"Might do well, due to the multiple mounting options inside"* and *"Lot-o-mounting holes inside, this is good."* One user reflect in the ending survey that *"Sensor packages are improved regularly and it's nice to not be reliant upon one type of sensor, just swap it."* Another commented both on the space for sensors and overall hex patterning saying that the *"advantage here is that the sensors can be added and secured easily [...] anywhere. It's relatively easy to add a sensor to [a] robot (e.g., putting a tray on the front), but securing it has always been a problem. It's nice that it's part of the process here."*

One user did say that, although it *"requires only [a] basic wrench, but since bolts can [only] go into specific holes, locations are limited unlike with duct tape."* But, they all acknowledged that this contained solution was much better than other unsightly solutions as *"the looks are preserved."*

After hearing multiple people being surprised that the top lid came off so easily, we changed the hinged lid to a tight panel that needs to be slid off intentionally. Conversely, the users found the visor too hard to remove so we developed an easier way to slide it out.

Overall, we found this design solution to be a viable as one user wrote that *"It's very interesting to be able to swap out sensors in this manner. The head is relatively easy to put back together and intuitive enough to be figured out without any written instructions. "*

This analysis lead to several design changes. First, while the nuts and bolts were appreciated, they needed tightening, based on user comments. Second, the top was changed from a hinge to a lid to allow easier access. Third, the visor itself was found to be a bit difficult to remove so a simpler solution was developed.

6.2 Prototype Polling for Visual Aesthetic

Brainstorming visual form factors of the head shape and internals took a lot of creativity, collaboration, and iteration as shown by a few examples in figure 4. We used many user-centered design methods to help us along the way including informal critiques, focus groups, and surveys. From the initial focus interviews, sketches were generated of different heads and visor shapes to help stimulate brainstorming. Each of these variants considered the general pros and cons of the respective design decisions like issues of visor shape, sensor visibility range, and suitability with the HUBO robot's design language. Going forward, we performed multiple evaluations as the fidelity of the designs increased from sketches in the hallway, emailed electronic renderings, and physical 3D printed prototype ballots. In the following we detail one design survey.

6.2.1 Method. Novices and experts (our expert HRI Mechanics) were presented with seven different design proposals and asked to rank their preferences *based on their requirements* (i.e., optical

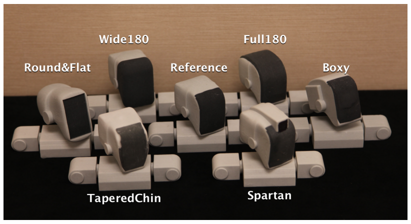

Figure 5: Examples of high fidelity rapid prototypes of the robot head design. Participants were given ballots to rank heads in order of their preference and solicit feedback.

sensor expert focusing on visor reflections, novices just on visual features). Each design proposal highlighted one or two particular set of features of interest (discussed below). Design proposals were presented as renderings and 3D printed miniatures (see figure 5) with a description of the relative affordances of each design. Participants were given a week to review all the models and submit their rankings and any additional comments or questions.

6.2.2 Prototype Variants. The series of prototype heads were generated focusing on both the form of the shell and the display-visor. Each of which was a variant of the Reference design. Shell variations included rounded organic forms (i.e., *Round&Flat*), strict rectilinear shapes (i.e., *Boxy*), combinations of the two, and forms for extra large sensors (i.e., *Spartan.*) Visor variations were examined for sensing utility and potential for the display surface. Variants included flat (for minimal distortion,) tapered-chin (to provide a more humanoid front profile,) full and wide (for broader field-of-views.)

6.2.3 Results. Participants showed a consistent preference for the *spartan* (35%) and the *tapered-chin* (25%) visors. The comments support the notion that these were selected for sensor compatibility (the spartan can accommodate large form-factor sensors) and general aesthetics (participants noted some designs were too literal or "too square".) They seemed to expect the head to reflect the same rectangular design style of the HUBO and confessed most of them looked discordant when mounted on the HUBO. We combined these preferences into the current design iteration. The exterior shell incorporates both curved and linear forms for the front and back of the head, respectively. While mostly boxy, the Hubo uses a rounded wedge design for motor covers. These have been adapted as SCIPRR's ear mounts for improved cohesiveness (see figure 1, left.)

This analysis allowed us to determine the type of head shape that users preferred. Users seemed to mix both functional concerns (the spartan design had the space for one of the biggest sensors available) and aesthetics (curved and linear to match the Hubo aesthetic).

6.3 Perception Survey for Social Interaction

Our goal in this experiment was to explore whether the use of the new SCIPRR head increased novices' perception of what capabilities they would want a HUBO robot to perform. Affording social interaction for novices was an important design requirement for the Expert HRI Mechanic persona and depending on the simple existence and the visual aesthetic of a humanoid head and facial expression. Therefore, we focused on comparing the impact of having a HUBO with the standard preexisting sensor stick head versus our SCIPRR head solution.

6.3.1 Method. We set up an Amazon Mechanical Turk (AMT) study to see if there would be an impact on a novice user's interest in having a robot perform certain social and function tasks. We captured static pictures of the HUBO robot with the SCIPRR head and with the standard HUBO sensor stick as presented in figure 6. Rather than just wanting a visual comparison between the two, we were interested in whether the SCIPRR head would be perceived as especially relevant or useful for social interactions or more traditional robot tasks. We therefore asked novice participants whether they preferred the robot with either the SCIPRR head or the sensor stick to perform a series of social and traditional tasks. The design was a mixed 2 (Between: SCIPRR head vs sensor stick) x 2 (Within: Social vs Traditional) experiment.

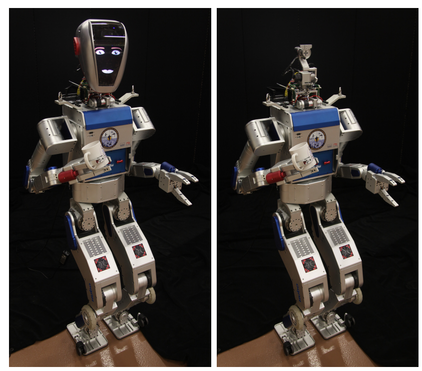

Figure 6: For our study, a portion of the participants evaluated the robot's capabilities using the picture on the left of HUBO robot with the SCIPRR head and the others referenced the HUBO robot with the sensor stick head.

6.3.2 Participants. Sixty-one participants completed the study for monetary compensation ($1 for the study; (for an evaluation of the validity of this method, see [16]). All the participants stated that they were native English speakers; there were 29 females and 32 males; their average age was 35 years old and ranged from 22 - 60. 29 participants were in the SCIPRR condition and 32 participants were in the Sensor Stick condition. Participants were shown one image throughout (SCIPRR/sensor) and asked the questions. Participants responded yes/no.

6.3.3 Materials. The participants were shown one of the images in Figure 6 and asked a series of questions in a random order. Each question was of the form "Would you want this robot to..." Each participant saw 12 "Social" questions and 12 "Traditional" questions presented in a random order. Social questions contained explicit social interaction either in play or information or learning, while traditional questions contained non-social behavior with a focus on physical tasks that robots could potentially perform. Social questions included questions like "Play a game of hide and seek" or "Rearrange living room furniture with you" or "Build a pillow fort with the kids." Traditional questions included questions like "Mow the lawn" or "Carry the laundry up the stairs" or "Rake leaves in the back yard."

6.4 Results

We computed averages for each participants on whether they wanted the presented robot to perform each social or traditional robot tasks; results are shown in Figure 7. As suggested in Figure 7, participants wanted both robots to perform traditional tasks more than social tasks, $F(1, 59) = 39.4$, $MS_e = 1.6$, $p < 0.05$. Participants also reported wanting the robot with the SCIPRR head to perform more tasks in general (social and traditional) than the robot with the sensor stick $F(1, 59) = 4.3$, $MS_e = .49$, $p < 0.05$. There was no interaction between the two factors $F(1, 59) = .2$, $MS_e = 0.007$, $n.s.$. Finally, a planned comparison showed that marginally more people wanted the robot with the SCIPRR head to perform social tasks than with the sensor stick, t(59) = 1.9, p = .06.

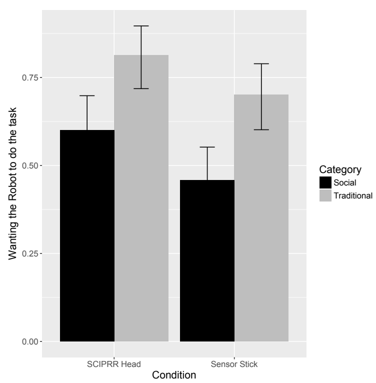

Figure 7: Mean ratings by participant by condition. Error bars are 95% confidence intervals.

6.4.1 Experiment Discussion. First, participants wanted a a humanoid robot to perform traditional, manual, tasks more than social tasks. This is somewhat surprising because people have relatively little experience with robots and robots are depicted in the popular press and the movies as being capable both physically and socially. Perhaps people are (appropriately) skeptical about today's robots to be able to interact in socially robust manners because there are so few actual examples, while there are actual examples of robots performing traditional physical tasks (e.g., the roomba). People could also just have a personal preference for a non-robot performing the social and often relational tasks.

Second, the SCIPRR head seemed to cause an overall halo effect: participants who saw the SCIPRR head wanted that robot to perform more tasks overall than a robot with 'just' a sensor stick. It is unclear, of course, whether any head on any robot would cause the naive person to believe the robot could perform more tasks, but at the least it is clear that participants wanted and felt more comfortable with the robot with the SCIPRR head on the HUBO body to perform more tasks.

Finally, participants wanted the robot with the SCIPRR head to perform marginally more social tasks than the robot with the sensor stick. This effect needs to be replicated, but at the least it is suggestive that the SCIPRR head provides some social affordances that could encourage people to interact with it.

7 GENERAL DISCUSSION

Most robots in use today are either task-oriented or socially interactive. Task oriented robots typically do not have strong interactive capabilities (e.g., they do not have a head or a face or may not be able to gesture well). Conversely, socially interactive robots typically do not have strong functional capabilities (e.g., their sensors are not usually state-of-the-art or configurable). We used User-Centered Design approaches to identify problems and evaluate associated solutions that could help make a robot that is both functional and interactive.

SCIPRR (Sensing Computing Interacting Platform for Robotics Research) is a head that attaches to a humanoid robot. SCIPRR was iteratively created with additive manufacturing and contains convenient scaffolding to accommodate various sensors and small-form computers and microphones. The platform takes advantage of a clear visor and a back-projection system with a series of mirrors to present an animated face.

We evaluated SCIPRR using three different UCD methods. First, we created multiple, small-scale prototypes through additive manufacturing and performed polling and refinement of the overall head shape. Second, we performed evaluations of how expert HRI mechanics could swap and change sensors and computers within the SCIPRR head; changes were again made based on their performance and comments. Finally, we executed a formal experiment to evaluate how much people would like a robot with our head design to perform different social and traditional robot tasks. We found that participants wanted the robot to perform more tasks (including social tasks) with the SCIPRR head compared to a robot with a sensor stalk.

The SCIPRR head now resides on our current HUBO platform and has been used for different experimental and demonstration purposes. The SCIPRR head itself has gone through both major and minor changes due to the UCD approach we used. Both 3D printer ready and model files are available for download from Thingiverse.com, keyword: SCIPRR.

8 CONCLUSION

SCIPRR represents a tool for roboticists in general, and HRI mechanics in particular, to maximize the use of sensors over the lifespan of a given robotic platform. Our work will continue to adapt and improve SCIPRR by broadening its sensor compatibility with new mounting options, as well as its aesthetic with alternative cosmetic shell designs.

9 ACKNOWLEDGEMENTS

We thank the previous reviewers of this manuscript as well as our expert HRI mechanics. This work was supported in part by ONR to GT. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the US Navy.

REFERENCES

[1] Chadia Abras, Diane Maloney-Krichmar, and Jenny Preece. 2004. User-centered design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications* 37, 4 (2004), 445–456.

[2] J. Bares, M. Hebert, T. Kanade, E. Krotkov, T. Mitchell, R. Simmons, and W. Whittaker. 1989. Ambler: an autonomous rover for planetary exploration. *Computer* 22, 6 (June 1989), 18–26. DOI: http://dx.doi.org/10.1109/2.30717

[3] Cynthia Breazeal and Brian Scassellati. 1999. A Context-Dependent Attention System for a Social Robot. In *Proceedings of the Sixteenth International Joint Conference on Artificial Intelligence (IJCAI '99)*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1146–1153. http://dl.acm.org/citation.cfm?id=646307.687601

[4] Cynthia Breazeal, Michael Siegel, Matt Berlin, Jesse Gray, Rod Grupen, Patrick Deegan, Jeff Weber, Kailas Narendran, and John McBean. 2008. Mobile, dexterous, social robots for mobile manipulation and human-robot interaction. In *ACM SIGGRAPH 2008 new tech demos*. ACM, 27.

[5] Karl Anders Ericsson and Herbert Alexander Simon. 1993. *Protocol analysis*. MIT press Cambridge, MA.

[6] Laura M Hiatt, Anthony M Harrison, and J Gregory Trafton. 2011. Accommodating human variability in human-robot teams through theory of mind. In *IJCAI Proceedings-International Joint Conference on Artificial Intelligence*, Vol. 22. 2066.

[7] Laura M Hiatt and J Gregory Trafton. 2010. A cognitive model of theory of mind. In *Proceedings of the 10th International Conference on Cognitive Modeling*. 91–96.

[8] Min Kyung Lee, Jodi Forlizzi, Paul E. Rybski, Frederick Crabbe, Wayne Chung, Josh Finkle, Eric Glaser, and Sara Kiesler. 2009. The Snackbot: Documenting the Design of a Robot for Long-term Human-robot Interaction. In *Proceedings of the 4th ACM/IEEE International Conference on Human Robot Interaction (HRI '09)*. ACM, New York, NY, USA, 7–14. DOI: http://dx.doi.org/10.1145/1514095.1514100

[9] Giorgio Metta, Giulio Sandini, David Vernon, Lorenzo Natale, and Francesco Nori. 2008. The iCub Humanoid Robot: An Open Platform for Research in Embodied Cognition. In *Proceedings of the 8th Workshop on Performance Metrics for Intelligent Systems (PerMIS '08)*. ACM, New York, NY, USA, 50–56. DOI: http://dx.doi.org/10.1145/1774674.1774683

[10] Lilia Moshkina, Susan Trickett, and J Gregory Trafton. 2014. Social engagement in public places: a tale of one robot. In *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction*. ACM, 382–389.

[11] SAMER AL MOUBAYED, Gabriel Skantze, and Jonas Beskow. 2013. The furhat back-projected humanoid head–lip reading, gaze and multi-party interaction. *International Journal of Humanoid Robotics* 10, 01 (2013), 1350005.

[12] Bilge Mutlu, Fumitaka Yamaoka, Takayuki Kanda, Hiroshi Ishiguro, and Norihiro Hagita. 2009. Nonverbal leakage in robots: communication of intentions through seemingly unintentional behavior. In *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*. ACM, 69–76.

[13] Clifford Nass, Jonathan Steuer, and Ellen R Tauber. 1994. Computers are social actors. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 72–78.

[14] Don Norman. 2013. *The design of everyday things: Revised and expanded edition*. Basic Books (AZ).

[15] Donald A. Norman and Stephen W. Draper. 1986. *User Centered System Design; New Perspectives on Human-Computer Interaction*. L. Erlbaum Associates Inc., Hillsdale, NJ, USA.

[16] Gabriele Paolacci, Jesse Chandler, and Panagiotis G Ipeirotis. 2010. Running experiments on amazon mechanical turk. (2010).

[17] Ill-Woo Park, Jung-Yup Kim, Jungho Lee, and Jun-Ho Oh. 2005. Mechanical design of humanoid robot platform KHR-3 (KAIST Humanoid Robot 3: HUBO). In *5th IEEE-RAS International Conference on Humanoid Robots, 2005*. 321–326. DOI: http://dx.doi.org/10.1109/ICHR.2005.1573587

[18] Rosalind W Picard. 2003. Affective computing: challenges. *International Journal of Human-Computer Studies* 59, 1 (2003), 55–64.

[19] J. Scholtz. 2003. Theory and evaluation of human robot interactions. In *36th Annual Hawaii International Conference on System Sciences, 2003. Proceedings of the*. 10 pp.–. DOI: http://dx.doi.org/10.1109/HICSS.2003.1174284

[20] Mikey Siegel, Cynthia Breazeal, and Michael I. Norton. 2009. Persuasive Robotics: The influence of robot gender on human behavior. In *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 2563–2568. DOI: http://dx.doi.org/10.1109/IROS.2009.5354116

[21] JaYoung Sung, Henrik I Christensen, and Rebecca E Grinter. 2009. Robots in the wild: understanding long-term use. In *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*. ACM, 45–52.

[22] SB Trickett and J Gregory Trafton. 2009. A primer on verbal protocol analysis. *The PSI handbook of virtual environments for training and education* 1 (2009), 332–346.