Preliminary system and hardware design for Quori, a low-cost, modular, socially interactive robot

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ABSTRACT

This paper presents progress on Quori, a low-cost socially interactive robot platform comprised of an upper-body humanoid with a rear projection head and two gesturing arms on a mobile base. The robot's hardware is introduced and features are explained. The modularity, expandability, customizability, and affordability of the design are discussed. The information provided in this paper is meant to generate feedback for the final design of the robot, which will be used to produce and award copies of the robot to select research groups for both in-lab and "in the wild" deployments.

KEYWORDS

socially interactive robots, non-contact HRI, low-cost hardware

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1 INTRODUCTION

Hardware platforms for socially interactive robotics can be limiting because of its cost or lack of functionality. This paper presents the hardware for "Quori", a novel, affordable, socially interactive robot platform for enabling non-contact human-robot interaction (HRI) research in both in-lab and "in the wild" experimental settings. In its final form, the platform will be a complete package with all necessary hardware and software to provide a ready, "out of the box" experience. Our hope is that Quori will provide a hardware platform that will enable computing researchers to enter the field of HRI and develop and test algorithms, as well as conduct statistically significant user studies by deploying systems in the real world and collecting user data to inform further computing research in HRI.

By working with the HRI community to identify the most important hardware capabilities for a socially interactive robot, some optimization can be achieved to lower cost and maximize functionality. The input of the HRI community on Quori's design process was collected via on-line surveys, hosted workshops, and conference presentations. The data collected from our quorum (a diverse group of researchers in the broader HRI community) directed our design decisions for Quori's hardware and software. This paper introduces the hardware and possible functions and uses of Quori. The analysis and discussion of survey data and the design process, as well as the integration of the hardware and low-level software, are beyond the scope of this paper.

The goal of this paper is to capitalize on a unique interaction with the HRI community to receive our final round of feedback on the hardware direction and robot capabilities. This work is part of a National Science Foundation Computing Research Infrastructure grant that will be awarding Quori robots to eight university researchers with releavnt HRI research plans.

2 SYSTEM OVERVIEW

Quori consists of an expressive upper body attached to a omnidirectional mobile base (Figure 1). Each part of the system is described in detail in Section 3. We included design considerations for sensors needed for HRI (Figure 1, right), including sensing the robot's internal state via motor encoders, as well as a laser range finder, camera, and microphones to sense the environment and user(s). An example networking diagram for controlling the robot is shown in Figure 2.

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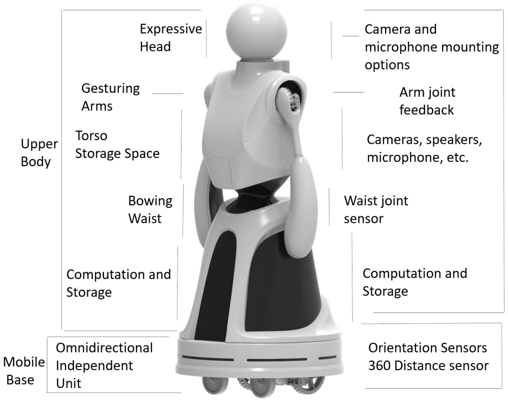

Figure 1: Overview of Quori's components (left) and sensing capabilities (right).

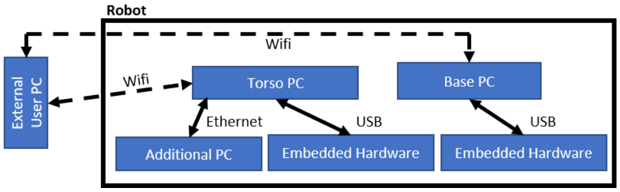

Figure 2: Simple network diagram for Quori.

3 HARDWARE OVERVIEW

Our hardware design approach consists of three key aspects: 1) verified utility through iterations with the HRI community to identify desired features; 2) capability using recent technology breakthroughs for low-cost and targeted feature inclusion; and 3) longevity of impact through development of modular interface standards. This section covers the current state of the robot's design, leading into the final iteration, which will take place in Summer 2018. At that time, we will begin to produce multiple copies of the robot for distribution to the HRI research community.

3.1 Spherical Projection Head

To maximize flexibility, both in the style and apparent motion of the robot's head, we exploited the relatively recent availability of low-cost portable projectors in a retro-projected animated face (RAF). RAFs have been shown to be highly expressive, such as in Lighthead [3], Mask-Bot [10], Furhat [8], and Engineered Arts' Socibot[1].

The RAF consists of a small projector, a lens or mirror, and a projection surface. Quori's head module utilizes a domed mirror and pico projector to warp a projected image onto a specially coated sphere (Figure 3). A rigid connection between the projector and projection surface has been designed to keep the projector and mirror aligned and minimize noise caused by the robot's vibration. These components fit within a compact space approximately the size of an adult human head. The RAF yields an expressive, customizable, and natural for human-robot interaction [2].

Figure 3: Quori's head hardware CAD (left) and finished head module (middle). Sample warped image to be sent to the projector (top-right) and the final product displayed on the sphere (bottom-right).

Software to map the spherical surface to the projected image and an intuitive interface for researchers to program and control the face is needed to display faces properly on the sphere or another surface. Our mapping algorithm maps pixels on the sphere to pixels in an image to be sent to the projector (Figure 3, bottom). This is used to create expressive faces.

The projector is an AXAA P5 currently (2017) priced at $290USD. It was selected because of its relatively low cost, brightness, small achievable image size, about 3x5 inches at a short distance of 8 inches, and other properties[2]. The resolution of the sphere's surface is not uniform; it is dense near the top and sparse toward the neck. To provide an idea of the resolution available, the least dense equatorial line is about 200 pixels. The projector is able to create a color image that is visible in most illuminated indoor environments where there is no sunlight saturation (Figure 8). This module is easily detachable by its four mounting holes and can be replaced, as discussed in Section 3.4.

3.2 Gesturing Arms

Gestures are a key part of natural communication in social interaction. Our arm design is low-cost, modular, safe, and expandable. Our 2-DOF shoulder module (Figure 4) is based on a design by Whitney and Hodgins [12]; however, our design differs in that we use 3D-printed bevel gears instead of a capstan cable drive, and we chose to not gravity-compensate the arm as we expect extra DOFs to be added, reducing the effectiveness of the design. The arm is driven by anti-cogged brushless DC motors[3] [9] through a transmission consisting of a friction wheel pair and a timing belt speed reduction. The whole arm module mounts the the spine via fasteners. The electronic diagram for this module is defined in Figure 10.

Notable features of the arm design include access to and resolution of the joint positions, drive motor abilities, and general safety considerations. The approximate resolution of the joint position

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[1] https://www.engineeredarts.co.uk/socibot/

[2] The projector is rated to provide 300 lumens, last 20,000 hours, and have native 1280x720 HD resolution; however, there are only 132 lumens available to the spherical surface since the only image reflected to the spherical head is a circle inscribed inside the projection rectangle.

[3] http://iq-control.com/

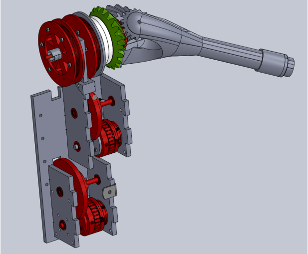

Figure 4: Arm module CAD showing inside view of the transmission; belts not shown.

sensors are 0.022 degrees and 0.075 degrees for the shoulder joint and the drive motors, respectively. Access to both positions allow us to check for slippage in the friction wheel or timing belt stages, as well as perform automatic calibration on boot-up of the system. The arm motors can produce approximately 0.3 Nm torque and are able to rotate at approximately 16 revolutions per second, resulting in possible shoulder joint speeds of about 1.2 radians per second. The arm design is expandable; we designed access for power and communication for further joints in the arms, such as an elbow, while allowing the arm to rotate continuously.

We employed the following safety measures: setting a torque limit on the drive motors; a low-mass, inertial, and stiffness arm mechanism that is safer according to the Head Injury Criterion [13]; and a friction wheel designed to slip in case the motor generates too much torque. For safety purposes, the arms are programmed to stop and coast to prevent self-collision.

Our primary goals in arm design are to ensure safe and precise fluid motion at low cost. To achieve these goals, we used lightweight limbs with no payload capability and anti-cogging control to make low-cost motors usable [9]. Arms that would be expected to lift, push, or pull would need structural stability that typically leads to heavier and more expensive designs. Furthermore, a heavier arm requires larger, and thus more expensive, motors to move. Low-cost motors or servos could be used, though at the expense of precision, as noted in [9] for the case of brushless DC motors.

3.3 Holonomic Mobile Base

Our mobile base module (Figure 5) is holonomic and is inspired by the RAMSIS II design [5]. It is optimized for mobility using the design tools from Costa and Yim [1]. The base has three actuators (Figure 5) that generate base linear and angular velocities in the ground plane and orient the upper body of the robot. Two casters serve to support the weight of the robot and increase the support polygon. Power is delivered to the base via a slip ring between the turret and differential drive base. Communication and control of the base are achieved wirelessly via an Up Core single-board computer [4]. Space and USB ports are available for a laser scanner or camera. The electronic diagram for this module is defined in Figure 10.

The base measures 19 inches in diameter and 8 inches in height and complies with the 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design; it can traverse over 1/4-inch bumps (ADA 303.2), 1/2-inch floor gaps (ADA 302, 407.4.3), and 1:12 inclines (ADA 405.2), which are common in real world deployments. The max speeds the base is able to achieve are 0.8m/s in a straight line and 180 degrees per second with the turret. The field of view (FoV) of the laser distance scanner is shown in Figure 9 and was achieved by placing the sensor to maximize FOV, as shown in the plot. The on-board computer was selected to allow additional sensors to be added that may require substantial computational resources. Finally, the design allows the base to act as a stand-alone module independent of the upper-body humanoid torso.

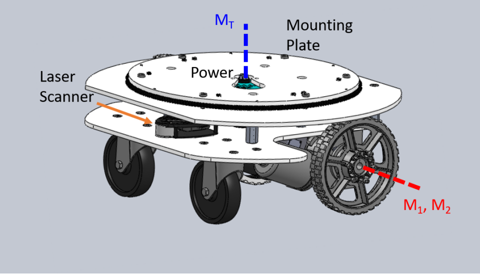

Figure 5: Holonomic base hardware schematic. Mounting is for upper body or customized hardware. DoF axes driven by the three actuators are highlighted, M_1 and M_2 are driven by the drive motors, and M_T is driven by the turret motor.

The choice of design for the holonomic base ensures notable cost reduction over other options. For example, with three motors, our base uses fewer actuators than other designs that require four or more motors [4]. Other holonomic designs may involve using an omniwheel or additional motors; however, they often suffer from performance drawbacks, such as vibration or complexity [5]. The manufacturing of the base is made more affordable by utilizing laser cut parts from sheet ABS and commercial off the shelf (COTS) parts for the majority of the components, requiring only one major 3D-printed part and two machined parts.

3.4 1-DOF Spine

The spine is designed to not only support the arms and head (Figure 6, left), but also to produce useful and natural forward/backward postural motion, (Figure 6, right). The spine's 1-DOF allows the robot to express levels of engagement or disengagement by leaning forward or backward. A secondary benefit of this design is its potential to minimize vibration generated during the motion of the mobile base, leading to fluid, natural, and appealing motion that can be tuned in a way similar to that of a metronome. The arm and head modules connect to the spine and swing with it. The batteries and main on-board computer are stored within the spine structure.

The spine allows for easy attachment of additional custom hardware, specifically, the arms and head. A new head module can easily be securely attached to the spine using the mounting holes provided. The arms have similar mounting possibilities with the ability to screw into the spine column. There are also considerations for shelves/ledges to be added to the spine for sensors, tablet, tray, container mounting, etc.

Considerable space is allotted for the batteries and computer, 6.75 x 6.0 x 8.4 inches and 8.0 x 8.0 x 2.9 inches, respectively. Currently,

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[4] https://up-shop.org/up-boards/140-up-core-4gb-32gb-emmc-memory.html

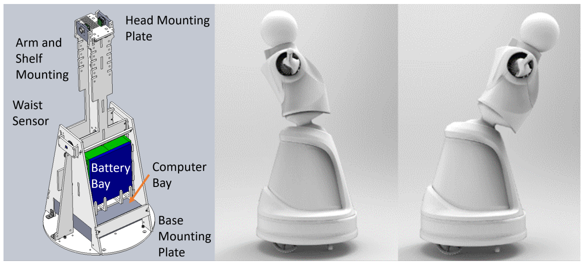

Figure 6: Upper torso and spine hardware schematic (left). Extreme positions the robot achieves by bowing forward 30 degrees (right) or leaning back 15 degrees (middle) which are mechanically limited to prevent collisions.

we fit 40-ampere-hours of sealed lead acid batteries that power the whole robot. While many options exist for small form factor computers, we have ensured sufficient space for a computer with considerable computational resources for in the wild operations, such as an Alienware Alpha R2 or NVIDIA Jetson Tk1.

The spine design is low cost because of its simple structure manufactured from laser cut sheet material and a handful of additional hardware. Cost, as well as weight, are saved by using the batteries as counter-mass for the spine.

4 DESIGN AND MANUFACTURING

4.1 Appearance Design

Physical appearance is a key attribute for a robot designed for social interaction. We continue to discover what modular appearance accessories and baseline physical characteristics address the needs of the HRI community (as indicated by community input) while also retaining stylistic consistency when appropriate. A sample design for Quori is shown in Figure 1.

Quori has undergone an "envelope" design development. The underlying robot and mechanical systems are clad with a panelized torso, base, and arms. This method allows for the working apparatus of the robot and the body to be separable. The design for each body part was tested to allow for local freedom of movement. For example, the torso was designed with collision detection for the movements of the arm at the shoulder as well as for the rotations at the waist. Each panel was considered not only in appearance, fit, and finish, but also in terms of easy disassembly for access to the robot. The base panel curves are designed to increase the distance between the user and the robot for both safety and social proxemics [6].

Significant attention was given to the holistic appearance of Quori. The torso, arms, and base were designed to be an identifiable, self-consistent whole: color, seaming, and surface curvature are continuous among the parts. These features (seaming, curvatures, etc.) of the body were designed to address specific community-identified HRI issues of gender, the Uncanny Valley [7], and acceptance. The gender identity is meant to be dampened without being generic, the size and appearance is slightly abstract to not mimic human physiognomy and therefore avoid the Uncanny Valley, and the geometry of the robot is meant to be recognizably friendly — we avoided sharp corners or threatening musculature in favor of softly curved surfaces and eased edges that facilitate acceptance. The overall form is a body, or envelope, that is made of large parts with consistent features: the spherical head is connected to the rounded torso by a stalk. The outsized and softly curved forearms meet the torso by a slender femoral shaft. The upper body is supported over the base by a geometrically simple waist. This yields a perception of a network of discrete, soft spheroids connected by simple masts, rather than a body that is blob-like or mechanical across its surface.

4.2 Manufacturing Panels

We are currently working from the principles mentioned in Section 4.1 toward an attainable price point for fabrication that also allows user choice in the robot embodiment details. Our panels are designed to be swappable for different colors or materials (Figure 7). The panels are easily removed or replaced via the magnetic and mechanical alignment and securing features, avoiding visibly mechanical buttons or fasteners on the surface. Users also have the option to perform more involved exterior design changes similar to ONO [11], such as completely changing the style of the robot. We used 3D printing, manufacturing customizable panels from CAD printable panels to fit the spine.

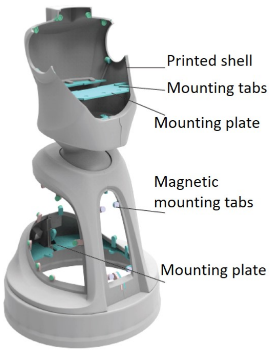

Figure 7: Basic design considerations and features for attaching Quori panels. Removable panels not shown to demonstrate ease of access to chest, battery, and computer areas.

4.3 Customization for Research Goals

The following is a list of possible Quori customizations.

- Replace head module with a tablet or place one in the chest
- Hold objects in the arms or on a tray attached to the spine
- Upgrade computation capabilities
- Remove or replace the arms
- Detach the mobile base, head, torso, or arm modules.

5 CONCLUSIONS

This paper introduced the design of Quori, a low-cost socially interactive robot platform. We described the features and utility of the four modules and identified decisions for ensuring a low-cost design. The modules are designed to assemble together into an aesthetic design that meets issues identified by the HRI community.

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A ADDITIONAL FIGURES

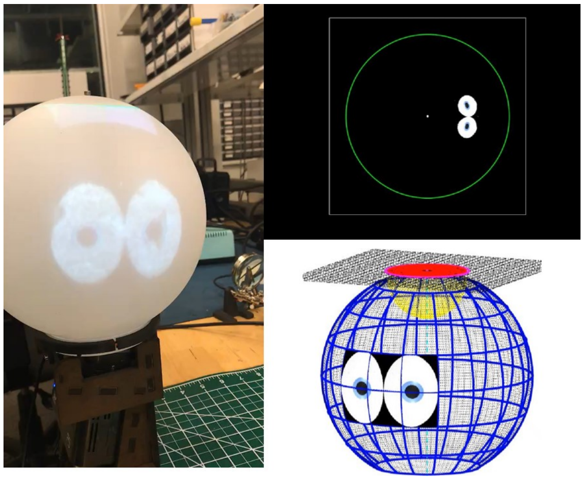

Figure 8: A sample set of eyes.

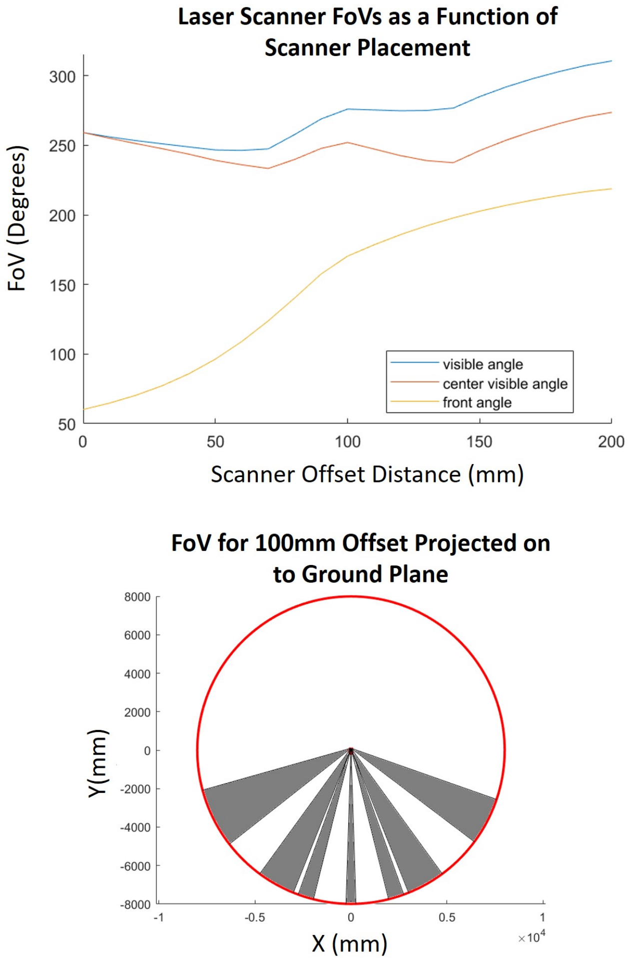

Figure 9: Top: plot showing the location required to have a maximum FOV as measured by: the largest continuous visibility (yellow), total visibility near the base (orange), and total visibility near the limit of the sensor (blue). Bottom: FOV of our current design with the sensor offset 100mm. Blind spots shaded in gray and the outer circle marking an 8-meter radius about the robot marked as the smaller inner circle.

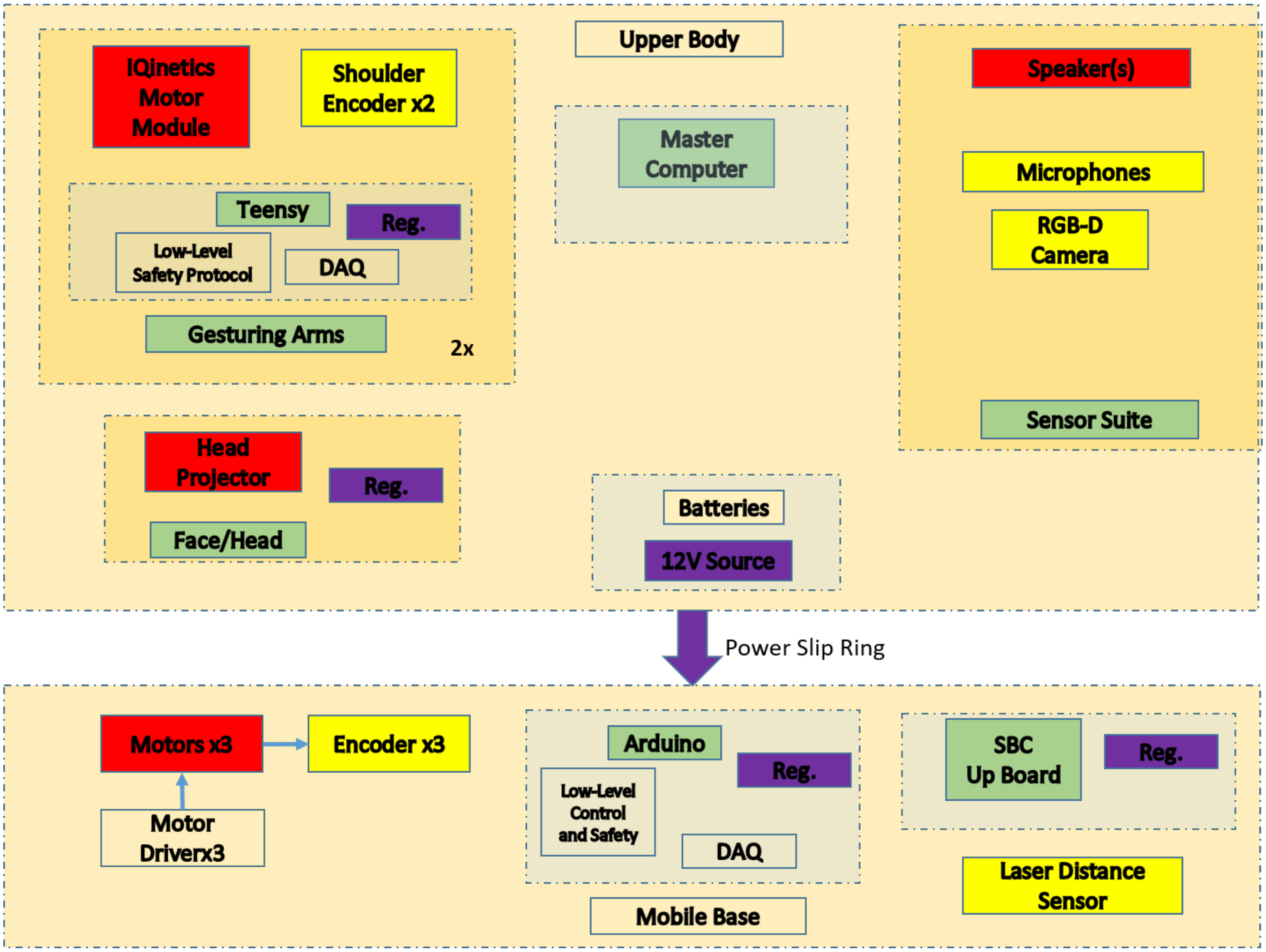

Figure 10: Power and electronic component diagram for Quori showing power (purple), actuation (red), computation (green), sensing (yellow).