Therabot-An Adaptive Therapeutic Support Robot

Cindy L. Bethel, Zachary Henkel, Sarah Darrow, and Kenna Baugus
Department of Computer Science and Engineering
Mississippi State University
Mississippi State, USA
{clb821, zmh68, sd1209, kbb269}@msstate.edu

Abstract—**Mental health disorders are a prominent problem across the world. An effective treatment has been the use of animal-assisted therapy; however not everyone can interact with and/or care for a live animal. Therabot™ has been developed as an assistive robot to provide therapeutic support at home and in the counseling setting. Therabot™ is designed as a stuffed robotic dog and has adaptive touch sensing to allow for improved human-robot interactions. Through its touch sensing, it will determine if the level of stress of its users is increasing and adapt to provide support during therapy sessions and for home therapy practice. Over time, Therabot™ is expected to learn the preferences of its user and adapt its behaviors.**

Index Terms—**therapeutic social robot, socially assistive robot, social robot design**

I. INTRODUCTION

Therabot™ is an assistive-robot therapy system designed to provide support to people with mental disorders such as those with post-traumatic stress disorders during counseling and home therapy practice. Survivors of trauma can benefit from the use of stuffed animals not only as a means of comfort, but also as a grounding tool they can hold and interact with in a positive way [7]. The focus of this research effort has been on the development of a therapeutic social support companion for people dealing with post-traumatic stress and related mental health disorders.

An issue of growing concern in the United States is the prevalence of sexual victimization and violence. In the United States, as reported by the Center for Disease Control in 2012, one in five women (18.3%) and one in 71 men (1.4%) reported experiencing an attempted or completed rape in their lifetime [4]. An estimated 20% of college-aged females and 6% of college-aged men in the United States have experienced an attempted or completed rape at some point during their college careers [3], [4], [6], [8]. There is a need to develop effective methods of support, assistance, and therapeutic interventions for the populations who have experienced sexual victimization and violence as well as other related traumas.

When a victim of sexual violence initially comes into a crisis center or other related facility, they will typically be distressed or exhibiting symptoms of numbness and detachment. Therapists have found it helpful to provide these victims with stuffed animals not only as a means of comfort, but also as a tool to ground the victims by providing them with something they can hold, touch, pet, and cuddle. These stuffed animals are provided to both children and adults, as all people affected need assistance getting through the challenging process of recovery [7], [10], [15], [19].

A type of therapy technique that is growing in popularity is animal-assisted therapy. The use of animals in therapy has been shown to increase positive social behaviors, decrease behavioral problems, assist in enhancing the self-esteem of patients, decrease symptoms of depression and anxiety, and enhance general psychophysiological health and well-being. There are also limitations with this type of therapy, including the possibility that the animals used in treatment are not available for the patients to use in home therapy. If the patients want to continue their therapy at home, they must find an animal that they can have access to. There are also concerns of allergies to the animals, the necessary care and time commitment needed for the animals, and/or the transmission of possible diseases [2], [5], [12]. One proposed solution to these problems is a pet robot that does not have the dander of an animal and does not require the necessary care of a living pet. The owners of pet robots may enjoy the positive aspects of a pet without having to deal with the potentially negative requirements associated with caring for a live animal.

II. RELATED WORK

In assistive robot therapy, the primary objectives of the robot are assisting the therapist in the recovery process and establishing a positive, constructive rapport with the user or patient; however, these robots intermittently provide entertainment and companionship as well.

Studies suggest that a robot that interacts socially with users is more engaging than a stuffed toy alone [9]. Popular robot implementations confirming this are Huggable [9], a bear robot, and Paro, a seal robot [16]. Their form factors are designed to be comforting and reminiscent of plush toys; Huggable has been used to challenge users to play games to ease their nerves before surgery or during hospitalizations [9], and Paro has been incorporated into group settings as well as acting as an in-home companion, especially in eldercare facilities [16].

Several robotic systems are intended to be used continuously for weeks or months at a time. Snackbot, for instance, provides assistance in the workplace by utilizing natural language processing and fulfilling user requests [11]. Teo, the emotionally

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expressive, huggable, and autonomous robot used for treating developmental disabilities, allows a personalized experience with each user; a magnetic layer under the robot's covering and a set of magnetized facial features create an opportunity for young users to customize the robot's appearance and express their creativity. The robot also enhances the social and cognitive skills of users by playing learning games and interacting with them [1]. Teo's placement within facilities currently lasts for six months, but the robot is being improved to assist with everyday life. Several other robotic platforms have been studied for social therapeutic uses. For example, KASPAR is an interactive humanoid robot focused on assisting children with autism in social skills development [13]. Similarly, Probo, which was designed to be an imaginative entity that does not resemble a human or animal [18], has been studied in the realm of motivating play activities in children with autism spectrum disorders.

III. APPROACH

As part of the iterative design process for developing the Therabot™ robot, a requirements gathering approach was used. It was important for us to learn what was needed by patients and by the counselors that were interacting with these patients who had experienced trauma. As part of the initial design process for Therabot™, three different surveys were performed. The first survey was the *form factor* survey, which was made available online using Amazon Mechanical Turk and a hosted website. The other two surveys were for *survivors of past trauma* and the other for *clinicians who worked with patients who experienced trauma*. The surveys were designed to learn about their opinions of what would make a robot used in therapy more beneficial. Both of these surveys were hosted in a secure manner. Before distributing the surveys, they were approved by the Mississippi State University Institutional Review Board. Clinicians were asked to distribute the surveys to their patients to ensure that their patients were at a stage in their recovery process in which the questions would not trigger negative effects from their past trauma(s) (e.g., flashbacks).

A. *Requirements Gathering*

There are several important design concepts to consider when creating a robot that will interact with humans, especially in therapeutic applications. These design considerations include:

- The role of the robot, its personality, and user classification [14]
- Touch, appeal, and comfort of the robot
- A person's perception of whether the robot is judgmental
- Care and time requirements of the robot
- Simplicity and user-friendliness of the design

For humans, familiarity is a significant component of developing trust and attachment [20]. Humans prefer to interact with people they are familiar with and this familiarity grows as time is spent together. Touch is also an important promoter of relationships and trust between people, as it is a major form of non-verbal communication. These principles of human relationships can be applied to the interaction between a human and a robot. Humans develop trust with robots by familiarizing themselves with the robot and through different types interactions [17].

1) Form Factory Survey: The form factor survey was available online for approximately four months, hosted by Amazon Mechanical Turk. This survey was also hosted on a website by the university and advertised using university-wide announcements and social media. For the survey, ten different sketched forms were presented to participants: (1) floppy-eared dog, (2) cat, (3) bear, (4) frog, (5) short-eared dog, (6) monkey, (7) chipmunk, (8) elf, (9) dragon, and (10) puffball. Participants were requested to drag and drop the images into a ranked ordering of preference (most liked to least liked) based on the use of the forms as social companions for comfort and support (See Figure 1).

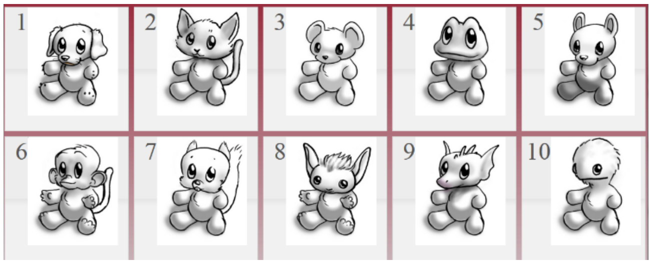

Fig. 1. Ten different animal forms shown in order of preference.

For each of the ten form factors, there were approximately seven different types of colored coverings. Participants were then presented their first choice from the form factor survey and requested to drag and drop in order of preference (most liked to least liked) the different covering options (the results from the most preferred form factor, the floppy-eared dog, are shown in Figure 2).

Fig. 2. The different color covering options for the floppy-ear dog.

The form factor survey, was administered to a total population of 1045 respondents (327 past survivors of trauma) of which 47% were female and 53% male. Votes in favor of the floppy-eared dog totaled 237, representing 22.7% of the total responses. The second most popular form was the cat, with 193 votes, or 18.5% of the total responses, followed by the bear in third place with 113 votes totaling 10.8% of all responses.

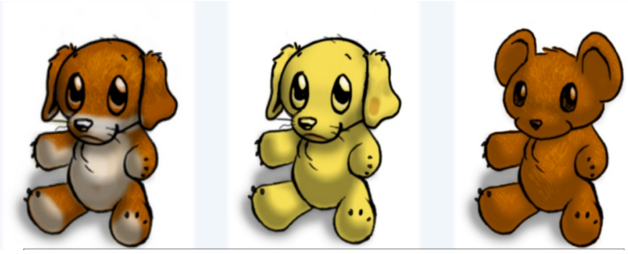

Fig. 3. The top three overall forms and coverings.

Of the 237 participants surveyed who chose the floppy-eared dog as their favorite form, 92 participants (38.8%) chose the ”Multi-colored” covering, shown on the left in Figure 3, as their favorite combination of form/covering. The ”Gold” color in the center of Figure 3, was the second most selected combination of form/covering with 46 (19.4%) votes. The third most popular form/covering (on the right in Figure 3) was the brown bear with 44 (18.5%) votes. These results informed the appearance for the Therabot™ initial design.

2) Past Trauma Survivor Survey: The past trauma survivor survey was created keeping in mind the feelings and experiences of past survivors, with efforts taken to make it appropriate for these survivors to complete. The survey asked for the survivors to complete their demographics, their use of comfort objects, and features they would like to potentially see included in an assistive therapy robot. They were asked if they had used any type of comfort objects or had any types of pets. They were also asked whether having comfort objects or pets helped during therapy or home therapy practice.

The survivors who took the survey were all in the recovery phase of their healing process. A total of 36 survivors of past traumatic experiences were surveyed to determine the prevalence of comfort objects, and the overall effectiveness of comfort objects in their experiences with therapy. The majority of the past survivors, or 31 of the 36 people (86.1%), indicated that they were *not* provided a comfort object as a part of their therapy. Of the 36 respondents, 30 of them (83.3%) indicated that they felt a comfort object would have been beneficial and helped them to feel more at ease when discussing the events of the incident.

Popular opinions, from the 36 survivors, as to what qualities a comfort object should have included: being ”huggable”, having multiple textures, having the capability of being manipulated, and having a generally soft feel. Without a comfort object, 25 of the past trauma survivors (69.4%) indicated that they were less likely perform home therapy exercises, suggesting that a comfort object would aid in therapy progress outside of the clinician’s office. Half of the survivors surveyed, or 18 (50.0%) of 36, also indicated that a robotic comfort object capable of giving hugs, patting for reassurance, or emitting nurturing sounds would be beneficial to therapy. A comfort object capable of responding to increased stress levels by providing calming support was also indicated by survivors as being potentially very helpful for therapy purposes. The responses from the surveys indicated that participants would prefer a robot that is the size of a larger stuffed animal, about the size of a pillow. Therefore, the robot is being designed to comfortably sit in a person’s lap. It is also designed to not be too heavy to be used by a child or an elderly person.

3) Clinician Survey: Clinicians could potentially use robots to aid not only during therapy sessions, but also to send home with their patients. It was important to understand clinicians’ thoughts and suggestions concerning home therapy robots, because they would be potential end users for the Therabot™. With help from the MSU psychology faculty, a survey was created for clinicians. All of the 13 clinicians surveyed had training or experience treating people with post traumatic stress and were considered subject matter experts. The clinicians were recruited from different sources, with a number of them being selected from a nationally recognized board of social work. The survey asked for the clinicians’ demographics, followed by questions concerning their use of comfort objects. The comfort objects section asked whether the clinicians had used comfort objects during therapy sessions in the past, and if so, what types of objects seemed to help their patients the most. This section also asked if their patients felt any positive or negative emotions after being given a comfort object. The last part of the survey asked what characteristics may be beneficial for the Therabot™ to have to support therapeutic treatment.

Clinicians were surveyed with anecdotal questions concerning the prevalence and effectiveness of comfort object use in therapy sessions. The 13 clinicians indicated unanimously that trauma or adverse incident survivors will frequently accept a comfort object offered to them. When asked whether it seemed that the comfort object calmed their patients when aggravated, 84.6%, or 11 of the clinicians indicated that it did. Giving a comfort object to survivors was also largely effective in increasing expressiveness when the survivors were unresponsive, as indicated by all 13 clinicians. When survivors were presented with a comfort object, the most common reaction was hugging the object, based on responses from three (23.1%) of the clinicians. Clinicians were also asked to indicate which actions directed toward the comfort objects used were most effective at relieving stress. Patting and hugging the objects were indicated as the most effective stress relieving actions.

From the clinician perspective, the most desired feature for a robotic comfort object was simulated breathing capabilities to be used for breathing exercises. They also selected the desire for some type of pressure sensor to detect stress from squeezing and recording capabilities. The majority of clinicians indicated that they would be willing to use a robot therapy comfort object in a stuffed animal form that had responsive and supportive qualities in their therapy practice and for home therapy practice.

4) Interactive Design Study: Once the first Therabot™ prototype was designed and constructed, it was important to obtain feedback from people who interacted with the robot. In addition to ongoing informal feedback received from students, researchers, and visitors interacting with prototype versions of Therabot™, a design evaluation study was conducted with the mid-2016 prototype. This prototype differed from the most recent version of the prototype in terms of its internal mechanical structures. Though the physical feel of the robot has changed slightly, its external appearance and functionality of the robot used in the evaluation did not differ from the current version of the prototype.

Study sessions were set up as a collaborative design process composed of paper surveys, interactions with two versions of the robot, and a semi-structured interview with a researcher. Each session was conducted in less than 60 minutes, and involved the following steps:

- **Explanation and Consent** *(10 minutes)* - the researcher verbally explained the steps of the session, provided the participant with a consent document, answered any questions, and obtained their consent.
- **Past Experiences & Attitudes Towards Comfort Objects Survey** *(10 minutes)* - participants responded to a paper survey, which inquired about their past experiences with trauma and the use of comfort objects.
- **Guided Interview** *(20 minutes)* - the researcher provided the participant with two versions of the robot (a stuffed version and a non-powered robotic version) and conducted a semi-structured interview about the current platform and its future development.
- **Experience Evaluation Survey** *(5 minutes)* - participants responded to a survey which measured participants' perception of the robot, beliefs about robots, and their experience during the session.
- **Demographics Survey** *(5 minutes)* - participants provided responses to a survey concerning their gender, age, formal education level, ethnic groups, experience with technology, and experience with pets.

During the interview participants were provided access to both a non-powered robotic version of Therabot™ and a "stuffed animal" version of Therabot™ (e.g., a version of the robot devoid of internal mechanical structure and electronics) and were encouraged to use them for illustration or exploration throughout the session. Participants were divided into two conditions, with the only difference occurring during the interview portion of the session. In the *sequential condition*, participants were provided the "stuffed animal" version of Therabot™, interviewed, then provided the robotic version of Therabot™, and interviewed further about any new thoughts brought about by the robotic version. In the *parallel condition*, participants were provided both the "stuffed animal" and the robotic versions of Therabot™ simultaneously while being interviewed.

Sixteen participants (9 female, 7 male, median age of 20) were recruited from the university's psychology recruitment program completed the study. All participants were currently undergraduates with 5/16 pursuing science or engineering degrees, 8/16 pursuing psychology degrees, and 3/16 not reporting their area of study. On average participants reported little experience with robots (M=2.25 of 5, SD=0.78) and high levels of experience with pets (M=4.63 of 5, SD=0.89). Of the two participants reporting receiving care for a past traumatic event, one indicated that a cat was part of his or her therapy.

Overall participants were not familiar with the use of a comfort object as part of therapeutic care (M=3.44, SD=1.9). Reported potential benefits of a robotic dog included encouraging play, providing comfort, and increasing coping abilities. Participant's speculated that drawbacks might include the robot breaking, the user becoming overly attached, and not being as comforting as a real animal. When discussing the robot's physical movements with the researcher, $8/16$ (50%) of participants emphasized that the robot's tail movements would be important in communicating with its user. Half of the participants ($8/16$) suggested that the robot should be able to either walk ($5/16$), jump ($3/16$), or stand ($2/16$). Additionally, participants suggested that the robot should have breathing-like movements ($3/16$). All participants ($16/16$) reported that the robot should make traditional dog sounds (e.g., barking, panting, etc.). None of the participants felt synthetic human speech should be incorporated for the robot to speak; however, $6/16$ thought passing actual human speech through the robot would be useful in some scenarios.

During the design sessions participants also provided feedback on features which were not currently part of the robot, but that they felt would be beneficial for it. One participant highlighted the importance of the robot working in multiparty settings, with multiple people and potentially other robots or animals. Several participants suggested that the robot should be customize-able through features like behaving like a specific breed of dog or responding to a user assigned name. Participants also mentioned adding more realism through a tongue, a wet nose, and heating the robot's body to mimic a real dog.

IV. THERABOT™ PLATFORM DEVELOPMENT

The development of Therabot™ required mechanical and electrical design efforts, covering and padding implementation, and the development of a software architecture. Each of these areas affected the others, meaning iterative changes originating in one area typically resultd in platform-wide alterations. For example, updating an actuator to provide higher torque may also require mechanical changes for mounting, padding changes for dissipating the heat, electrical changes for interfacing, and software updates for controlling the new actuator. This section briefly describes each area of the Therabot™ platform's development and how it has progressed over the project's lifespan.

A. Hardware

1) Mechanical Design: Therabot's internal mechanical structure has undergone three major revisions (see Figure 4) since the beginning of the project. The early version of the design consisted of two flat thin platforms attached with a thick rubber segment. The head structure was offset by a

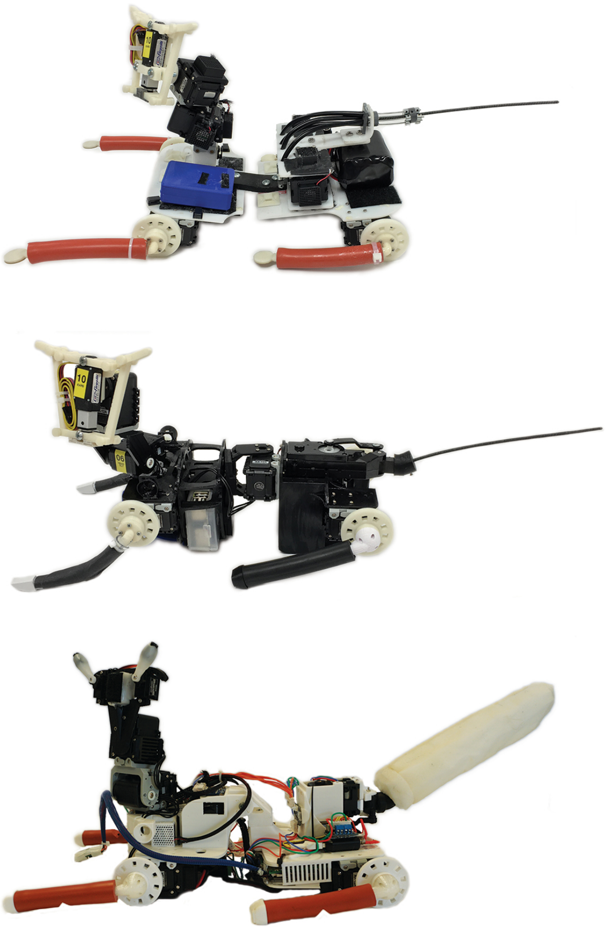

Fig. 4. Three major revisions to the robot's mechanical design, from earliest (top) to most recent (bottom).

plastic block attached to the surface of the front platform and consisted of motors functioning as mechanical links and a small 3D printed head outline to connect the robot's ear actuators. All electronic components were placed on the top portions of the platforms and encased in a fabric mesh. The first revision of the design incorporated more underlying mechanical structure, to better resemble the anatomy of an actual dog. However, this version distributed too much of the robot's mechanical structure to the underside of the dog, leading to difficulties with padding and covering the robot. The current mechanical design consists of two 3D-printed ABS plastic pieces which connect with a pivoting joint. The plastic pieces approximate the skeletal structure of a dog with modifications made to accommodate electronic components and the goal of keeping the robot's feel similar to that of a stuffed animal. The robot uses ten actuators (four legs, three neck, two ears, one tail) to communicate with users through life-like motions. While the tail motor is connected to a mechanism to convert the motor's motion to a continuous sweeping back and forth motion, all other actuators are directly attached to the component they drive.

2) Electronics and Sensors: Therabot is powered by a 10.8 volt, 5.2 amp-hour lithium ion battery pack. Power is regulated to 5 and 3.3 volts for the onboard computer, ear servo motors, and sensors boards, while other smart servo motors receive unregulated power from the battery pack. The current generation of the robot incorporates an ODROID-C0 single-board computer, which provides an ARM® Cortex®-A5 quad core 1.5Ghz processor, 1 Gigabyte of RAM, and digital IO pins.

The robot's physical poses and movements are expressed through manipulating 10 actuators (four (4) leg joints, three (3) head rotation joints, two (2) ear actuators, and one (1) tail actuator). Each ear is actuated using a small hobby grade servo, controlled via a pulse-width modulation signal. The seven head and leg joints are actuated using Dynamixel AX-12A smart servos, controlled via serial communication. The tail is driven by a Dynamixel MX-12W smart servo connected to the same data bus as the joint actuators. In addition to body actuation, the robot includes an audio system for playing sounds and a collar lined with RGB-LEDs to indicate the robot's status to the user.

Therabot senses its environment using an inertial measurement unit (IMU), an array of microphones, and conductive fabric. The IMU provides data about the robots position in and movement through space. An array of three microphones allows the robot to approximate the origin of any sound sources, allowing it to orient towards noises or a person speaking. Strips of conductive fabric placed underneath the robots outer covering use capacitive sensing to make the robot aware of how it is being touched or petted when people interacting with it.

3) Covering and Padding: The initial design of Therabot™ was based on a stuffed animal in a beagle form and then modified to address the electronic and mechanical components that needed to be placed inside of the covering along with the extensive padding. This initial covering design was a challenge because the internal design of the robot had very little shape or structure; therefore, the shape of the dog was achieved primarily from the fabric covering. Not having a defined shape made it very difficult to develop a pattern for making the cloth covering. The fabric selected for the covering was a ”mini minky shaggy” fabric, which is a soft fur-like fabric with a shorter pile length. The initial design was made in parts: (1) main body and tail covering with velcro on the underside of the dog for easy entry, (2) head covering with a neck extension that is attached to the main body fabric with velcro, and (3) leg coverings for each leg that has elastic thread that gathers the leg covering over disks on the main body to hold them in place at the leg connection points.

Under the main body covering are layers of premium polyester fiberfill that is high-loft to make it more resilient when the robot is touched. In the original design, most of the fiberfill was just stuffed into the covering to fill it out, but this caused several issues. In the next version, the fiberfill

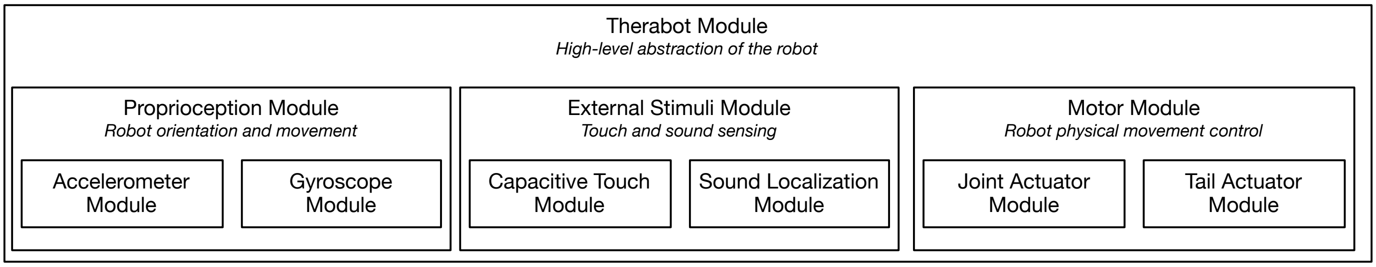

Fig. 5. The robot's core software uses layered abstractions to provide appropriate levels of abstraction for behavior development.

padding was encased with a Lycra four-way stretch fabric to contain it and so that is moves more easily with the Therabot™ as it moves and for a more consistent appearance. The most recent version of padding has a flap on the underside of the robot, that allows easy access to the battery compartment. The tail has a separate set of padding with an inner sleeve of Lycra material, then it has a fiberfill sleeve, and then covered with another Lycra sleeve. The leg padding was made in a similar layered manner as the tail covering. Each foot covering had a padded paw on the underside of the end of each leg covering. The current head padding is made from high-loft fiberfill and is formed to the shape of the head covering and covered in the Lycra material using a folded over design that allows for the front part of the covering to fit in front of the head framework and then another part that would fill out on top of and behind the head framework. This allowed for easy covering of the Therabot™ head and made the covering and padding consistent and more natural in appearance.

B. *Software Architecture*

The first Therabot™ prototypes used a single-board computer running the Ubuntu operating system and equipped with the Robot Operating System (ROS) frameworks. Independent software modules connected through the ROS framework's messaging system were implemented in the Python programming language to support sensing and actuation functionality. Two ROS action servers were created to allow additional programming of the robot. One action server generated higher-level behaviors that involved multiple actuators or sensors (e.g., sitting, standing, rolling over), while the other action server exposed the robot's individual actuators to allow for direct control.

As development of the platform continued, the robot's core software was replaced with a set of modules written in the JavaScript programming language using the Node.js run-time environment. Although the ROS framework has been adopted for many robotics research platforms, at the time it was cumbersome to interface with non-ROS technologies like web interfaces. The Node.js run-time environment allowed JavaScript to be used both on-board the robot and in web-based interfaces. The shifting of the programming paradigm of the core systems from ROS to one that emphasized asynchronous coding styles, allowed a reduction in the computational overhead. Additionally, the Node.js community maintains a large number of open source packages which can be leveraged for tasks like interfacing with USB human interface devices (HID) or communicating over an inter-integrated circuit (I2C) bus.

Our software architecture uses a layered abstraction approach (See Figure 5), with software modules written for: low-level objects (e.g., an accelerometer), logical sub-systems (e.g., an inertial measurement unit), conceptual sub-systems (e.g., proprioception, motor control), and the overall system (i.e., the robot). As a result, custom behaviors can be more easily developed and managed by interfacing with the appropriate level of abstraction. For example, a behavior which moves the robot's legs when it is oriented on its back can be developed by subscribing to orientation change events from the proprioception module and activating a leg movement sequence through the motor module.

Though the Node.js run-time environment typically encourages using a single processing thread along with non-blocking operations, we opted to distribute the continuous processing of sensor and motor data across CPU cores by executing high frequency polling and processing operations in their own processes using inter-process communication (IPC) to allow them to communicate with the core software's main thread. This arrangement is critical for creating natural interactions with the robot's sensors and actuators. For example, the robot contains seven joint actuators, which share a data bus and benefit from receiving position goals as frequently as possible (typically a goal of 30 times per second). Furthermore, this design ensures the robot will remain responsive and performance will degrade gracefully if new higher-level software inadvertently introduces bugs that tax the robot's resources excessively.

V. THERABOT™ BEHAVIORS AND INTELLIGENCE

Therabot's core software supports the development of arbitrary specialized behavior modules, while incorporating basic aliveness and awareness behaviors by default. As the platform develops and domain-specific feature needs are identified, additional specialized behaviors will be developed for the platform. For example, some courses of therapy incorporate daily ”homework” exercises for clients (users), like engaging in a guided breathing exercise. The robot's software can accommodate this by the development and activation of a behavior module that allows the robot to use time of day, user proximity, and other data sources to proactively remind the user to engage with the system for their daily breathing exercises. These types of specialized behaviors can be configured and adjusted by the therapist and/or their client (e.g., such as turning off behaviors that are annoying or adjusting sound levels).

In addition to developing specialized behavior modules for use in domain-specific therapeutic applications, behavior modules are also convenient mechanisms for creating interfaces that allow direct triggering of specific actions (useful for demonstrations of the platform's capabilities) and direct manipulation of actuators and sensors (useful during development and debugging). For example, a specialized behavior module for recording actuator temperatures can be deployed for diagnostic use.

Current Therabot™ prototypes include basic aliveness and awareness behavior modules that are active by default. The basic aliveness behavior incorporates a randomized cycling of postures that indicate the robot is powered and ready for engagement. This behavior, though basic, establishes the robot's presence in the environment and approximates behaviors exhibited by animals. The awareness behavior module ensures that the robot responds to environmental stimuli like touch and sound. For example, when an area of the robot's body is touched, it will orient towards this area. Touch gestures like stroking or petting also elicit motor and auditory responses from the robot. The module manages rapid fire stimulus events (e.g., multiple touches or frequent and loud sounds) and approximates the type of habituation that would occur with an animal in a similar situation.

We have also explored gesture recognition using touch inputs and adapting the robot's behavior based on the user's touch interactions over time. Using a sample of 20 university students performing the gestures of petting, patting, holding, and scratching, using a random forest algorithm, the system was 98.54% accurate when measured with 10-fold cross-validation. When tested with different users, an 89.77% level of accuracy was achieved.

In a separate study, 20 university students provided touch input while the robot explored a state-space of poses. Using the participants' inputs and "enjoyment" ratings, reinforcement learning (Q-learning with Boltzman-distributed exploration) was used to adjust the weights of potential actions and touch sensor inputs. This approach is expected to be useful in tailoring the robot's actions to each user's preferences.

VI. CONCLUSIONS

Therabot™ used an iterative design approach that incorporated input and feedback from potential end users of the robotic platform that provided essential information for product development that is usable, provides a positive user experience, and meets the needs of the end users. The approach used in the development of the Therabot™ robot was to solicit input from the general population regarding a preferred form factor and covering for the platform, followed by information gathering from potential end-users (past trauma survivors and clinicians) for their opinions on desired features. One concern expressed through conversations with clinicians with regards to the use of Therabot™ was the potential for separation anxiety when patients would be required to return the robotic platform upon completion of therapy. To address this concern, it was decided that a stuffed form of the Therabot™ would be made available for the patient to keep as a reminder to continue home therapy practices and to acknowledge their accomplishments in the therapy process.

The Therabot™ system was designed to be a familiar and requested form factor with coloring similar to a beagle. Based on responses from the three surveys administered it was determined that the first features to be included in the prototype would be a size comfortable to fit in a person's lap; a covering that is soft, durable, and multi-textured; touch sensors to detect and respond to a person's touch or squeeze; and torque-controlled compliant joints for natural responses.

VII. FUTURE WORK

The most recent version of the platform relies solely upon on-board sensors as data input sources, limiting perception to microphones, touch sensors, and proprioception (e.g., the inertial measurement unit). Though this limits the robot's ability to respond to visual stimuli, privacy concerns currently outweigh the benefits we suspect would be obtained from the inclusion of cameras. Ongoing research efforts are investigating the integration of data from other devices (e.g., mobile phones, fitness trackers, etc.) and other sensing technologies, which may adequately address privacy concerns (e.g., ultra wideband radar). We are also developing intelligent adaptive behaviors of the robot based on user touch. There is a desire to have the robot respond to each user in a unique way through using machine learning and other artificial intelligence techniques to customize interactions to the preferences of each user.

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