# Developing a Social Robotic Companion for Stress and Anxiety Mitigation in Pediatric Hospitals

By

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BSc. Electrical Engineering and Computer Science, MIT (2014)

Submitted to the Department of Electrical Engineering and Computer Science

in Partial Fulfillment of the Requirements for the Degree of

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at the Massachusetts Institute of Technology

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## ABSTRACT

The potential value of using social robot has started to be explored in the fields of education, eldercare and health management for the past decade. However, there has not been much research in how robots can socially engage in order to reduce negative affects of patients in pediatric context. This thesis introduces the Huggable robot that was made to mitigate stress and anxiety of child patients at a hospital and take a role of social and emotional advocate for them during hospital stay. The mechanism of the hardware and software system is illustrated extensively throughout the thesis, followed by the description of the experimental study design that compares the impact of three different interventions (a plush teddy bear, virtual Huggable on a screen and the robotic Huggable) on child patients' levels of mood, stress and pain. Insights from pilot sessions showed that people were able to bond with the Huggable robot emotionally and socially well and other activities that would help patients build higher self-efficacy for enduring medical procedures are proposed. The recruitment process for potential subjects has begun at the hospital site and the formal experiment will be executed shortly.

Thesis Supervisor: Prof. Cynthia L. Breazeal

Title: Associate Professor of Media Arts and Sciences, Program in Media Arts and Sciences

**Acknowledgements**

First of all, I would like to acknowledge Dr. Cynthia Breazeal, who has provided me tremendous amount of support in working on the Huggable project. Her vision and enthusiasm on making social robots live in the real world with people inspired me to push myself forward and to think beyond the box.

I would like to send many thanks to Kristopher Dos Santos, who designed the hardware component of the Huggable. Without his previous work and continuous effort to improve the robot, the Huggable robot wouldn't have been able to actually come out of the simulation world. I also thank Siggi Orn for helping with upgrading and debugging electrical components of the robot and also for teaching me many things about r1d1 codebase and other programming tricks. I would like to appreciate Adina Roth for designing the teleoperator interface and brainstorming on what would make a better interface to operate the robot from a non-expert's point of view.

I would like to acknowledge many staffs in Boston Children's Hospital in supporting my thesis study. Dr. Peter Weinstock sponsored the project and pulling many people inside and outside of the Simulation Program to make the experiment happen. Katie Fitzpatrick, Nicole Stenquist, and Duncan Smith-Freedman, as part of Simulation Program at BCH, spent countless hours getting trained on how to use the robot and the interface and doing dry runs with me. Brianna O'Connell, Suzanne Graca and Laurel Anderson offered insights on what child patients need as Child Life specialists and actually using the robot to talk to children.

I received much support and help from all members in Personal Robots Group for the past two years. Polly Guggenheim was there for me to talk with whenever I had felt down and cheered me with big hugs and smiles. Natalie Freed brought me into the group as her UROP and had been a great mentor for me to set my heart on social robotics. Adam Setapen established a foundation for developing Android-based robots. I was lucky to share the office with Jacqueline Kory who I had much delight in drinking tea together and talking about all sorts of fantasies we share for future of robotics. Goren and Michal Gordon have graciously volunteered their daughter, Noga, for the pilot run and video filming with Huggable in the Simulation Suite, and shared many pieces of wisdom and advice in my research. Jin Joo Lee advised me on how to work as a graduate student and managing several projects happening at the same time. Nick DePalma shared many insights and wisdom on the topic of Artificial Intelligence over many coffee breaks, which inspired me to think deeper about research. Thanks to Jesse Gray who gave many tips and advice in getting Android phone to work with the robot and "blessing" the Maya rig to be exported into the r1d1 codebase. Angela Chang has been a wonderful officemate before Jackie came to the lab and shared many stories of how it is being a researcher and a mom at the same time. Also many thanks go to all the other members of the Personal Robots Group (David Nunez, David Robert, Kenton Williams, Brad Knox, Sam Spaulding and Palash Nandy) for being supportive throughout my journey and adventure with this project.

Jason Wiser and Fardad Faridi have provided wonderful animations for Huggable to move naturally and expressively. Rachel Dziezynskiom the sound clips for canned animations of Huggable.

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# Chapter 1

# Introduction

## 1.1 Motivation

Hospital is a place where many stressful events for a young child. From their perspective, big adults in white gowns come and go with strange looking tools in their hands and sometimes even poke a big needle his/her body. Sometimes, the grownups give him/her a couple of stickers or treats after they are all done but the stressful memories usually stay and are brought up again at the next visit to the doctor's office.

The level of stress and anxiety is even higher for child patients who either have to stay at the hospital for an elongated period of time for a chronic illness or a complicated surgical procedure. Often times, they have no one to keep them company because the parents need to go to work and other staffs at the hospital are occupied with other patients who need more urgent care. For the most part, the children at the hospital are provided with much less social and emotional support than normal healthy children are, and left alone in situations and environments in which they do not feel comfortable and relaxed.

Frequently, caregivers or medical staffs utilize different toys for either entertainment or distraction purpose during the child's stay at the hospital. They are mostly composed of stuffed animals, movie DVDs, arts & crafts supplies, electronic devices such as iPads, to play game applications on, etc. However, most of these devices cannot provide any social and emotional sense of accompaniment and presence, even though a lot of child patients crave for someone to talk to and be with. As a result, it has been anecdotally noted among medical staffs that the children often press the nurse call button for no urgent medical reason but to have someone they want some company.

In most children's hospitals in the U.S., a group of child life specialists assist the patients and their family in various non-medical ways to provide this lacking social and emotional component of treatment. However, the ratio between the number of child life specialists and the number of child patients and family members who seek their services is high, and as noted above not everyone can get the support they need and want when they need it. If there is another form of presence that can extend and augment the role a child life specialist takes, it would greatly benefit children who are left bored or lonely in their patient units. Furthermore, many previous research works show that stress impairs fast recovery from illness or wounds, and positive social interactions promote faster healing. In other words, supplying this kind of promotion in positive and pleasant social interaction might even enhance the effect of medical treatments.

For patients and families, this is definitely preferred and beneficial for them. For doctors, nurses and other medical staffs, they can attend more patients more efficiently if the patient is more relaxed and cooperative during treatments. For the hospital as an institution, this can be financially beneficial as patients and families have greater experience and satisfaction, and as a result choose to come back for more medical services and recommend the institution to others around them.

## 1.2 Research Questions & Goals

The thesis attempts to answer this research question; can a robot socially and emotionally assist patients in pediatric hospitals to cope with stress and anxiety better than other conventional intervention methods? In order to build a robotic platform that could answer this question, the thesis aims (1) to develop a social robotic platform that is able to engage and entertain pediatric patients with high expressivity and social contingency, (2) to create a teleoperation interface for hospital staffs to control the robot fluidly with the sense of mental closeness themselves through the Huggable, (3) to find appropriate behaviors and nature for the teleoperated robot to enhance emotional bond and improve the overall experience during the hospital stay and (4) to design an experimental study that will prove the superiority of a social robot in comparison to other non-social and/or non-physical interventions.

## 1.3 Thesis Overview

Chapter 2 illustrates prior works on social and non-social robots used in healthcare field, and conventional methods used to reduce pain and anxiety at pediatric hospitals. Also, examples of robots used in Boston Children’s Hospital, which is one of the collaborators for the project, and roles of child life specialists who work with patients and their family are represented. Difficulties caused by running an user study in individual patient unit are explained to give better insights on what it is like to deploy robots in the wild. Chapter 3 provides an overview of the hardware design of the new Huggable robot in comparison to the older model. Software system design for robot controller and teleoperation interface is extensively explained in Chapter 4. In Chapter 5, the experiment procedures designed in collaboration with Boston Children's Hospital and Northeaster University are described. Chapter 6 claims the hypotheses for the proposed experiment and explores the insights gained from several pilot runs at the hospital site. Chapter 7 summarizes the contributions of the thesis and works to be done in the future.

# Chapter 2

# Background and Related Works

## 2.1 Prior Works

### 2.1.1 Healthcare Robotics

For the past several years, robotics has been applied in the field of healthcare in various ways. Surgical robots are now widely used in numerous hospitals for higher precision and minimal invasion during the surgical procedures. Service robots are increasing in number in the hospital as well. HOSPI developed by Panasonic transports samples and drugs in Japanese hospitals, [1] TUG by Aethon delivers medical supplies, blood and meals, [2] and QC Bot by Vecna also performs medication, materials and meal delivery along with the medical telepresence and patient self-service features. [3] Many of these robots are currently used in hospital settings and have integrated into the routines of medicals staffs.

While surgical robots and service robots mostly assist staffs and patients by performing minimal or complicated physical tasks and thus increasing people's productivity, social robots in healthcare domain aims to motivate and encourage them to keep up with the medical routine, to offer physical or psychological therapies, and to maintain a healthier life style.

### 2.1.2 Social Robots in Healthcare Field

Paro, a robotic baby seal developed by AIST, is used for elders with dementia and Alzheimer's disease in nursing homes for therapeutic purposes. The robot was found to increase the social and emotional engagement among the residents in the nursing home and also between patients and their caregivers. [4, 5] It also had the effect of reducing the stress, which was shown through the physiologic test. [4, 6, 7] Jerry the bear helps children with Type 1 diabetes to master their medical routine procedures through playful activities and peer modeling behavior. [8, 9] Multiple European institutions are investing in the research of utilizing social robots for supporting children with clinical and medical needs. Works from ALIZ-E (Adaptive Strategies for Sustainable Long-Term Social Interaction) project shows how social robots can motivate and persuade diabetic children to maintain a healthier lifestyle, and emotionally and socially engage and connect with children to increase self-efficacy and self-confidence. [10-12] In the U.S., Socially Assistive Robotics projected funded by National Science Foundation Expedition in Computing grant pursues to develop social robots that provide therapy and companionship for autistic children [13–18] and teach diverse range children how to make healthy food choices. [19] Autom, developed by Cory Kidd, is a commercial robot that coaches adults to lose weight at home by regulating their diet and exercise on daily basis. [20]

As noted above, there have been numerous approaches and attempts to develop social robots to help patients or healthy people to stay healthy or keep up with healthy habits. These studies attempt to change human people's behavior using persuasive and encouraging interactions. However, not much research has been done on how social robots can socially and emotionally support young patients in high level of stress and anxiety at the hospital. And this thesis addresses how a social robot can be there for a child patient through thick and thin by their bedside.

### 2.1.3 Anxiety and Pain Management in Pediatric Hospitals

Pediatric hospitals have been trying to develop nonpharmacologic intervention methods to reduce the pain in child patients. Most frequently used methods are activities that cause distraction from the painful procedure by engaging activities like blowing bubbles, playing video games, watching cartoon movies or listening to music. [21–26] For managing short-term procedural pain, oral sucrose or cold therapy are often used as well. Many studies have been done on the result of oral sucrose application with preterm and full term infants or younger children. [24, 27, 28] Cold therapy is used to reduce the local pain temporarily by numbing the pain sensory on the part applied. However, most of these interventions were shown to have "moderate effect size on one measure of pain." [26] Alternatively, some researchers tried training children coping skills in order to increase their self-efficacy in dealing with painful medical procedures. Cohen et al. trained children from 3- to 7- year-old to practice deep breathing and positive self-statement reflection methods before a medical procedure, and encouraged the patients to use the learned coping skills during the immunization pain. [29] Unfortunately, these training methodologies did not show a drastic effect on the pain reduction. Currently, child life service team members at Boston Children's Hospital have reported that they occasionally use simple distracting game applications, such as tangram, bubble pop or fireworks, on a smart tablet device during patient's medical procedures.

On the other hand, social and emotional support to children was found to be more effective in decreasing the level of distress and anxiety for pediatric patients compared to simple distraction methods. Chambers et al. showed that girls whose mothers showed pain-reducing manner reported less pain than the control group to lab induced cold pressor pain. [30] Exchanges of social and emotional interaction do not need to happen only between the child patient and his or her caregiver. Animal-assisted therapy has been found to be emotionally supportive and beneficial in diversion for hospitalized children and furthermore, also effective for reducing pain level for patients with age 3-17. [31, 32] However, as advantageous as therapies with pets have proven to be, there are many complications that follow in them. The animals and the handlers need to go through rigorous training in order to ensure the safety of the patient and the staffs participating in the intervention. Also, the therapy cannot apply to either allergic or immunosuppressant patients. In the study done by Cassell et al., the potential efficacy of a storytelling activity with virtual agents on computer screen was explored for young patients to narrate their emotions and feelings during the hospital stay. [33] Recently, more researchers have begun to interest in robots as a platform to apply behavior approaches for anxiety and distress mitigation. The work done by Beran et al. demonstrated that a humanoid robot successfully decreased the level of distress of a child during flu vaccination procedure through a distracting behavior method. [34]

In summary, many different non-pharmacologic intervention methods for pain reduction and anxiety mitigation are being researched in the field of pediatrics, and providing socio-emotional support for patients have demonstrated to result significant impacts on acute or chronic pain. The intervention method of utilizing a social robot in order to develop a rapport with child patients can be considered as an optimal alternative when there are shortage in medical staffs and also can potentially engage with patients in different ways that adult humans or cannot do. In addition, the robot used for the therapy or play activity can be used for assessing the child patient's emotional and affective status, and thus provide more information for the medical staffs to accommodate the patient better during the treatment.

## 2.2 Boston Children's Hospital

The Huggable project was initially started as a collaboration work with Boston Children's Hospital. It is one of the biggest pediatric hospitals in the Boston area and has been exploring broad usage of robots within its environment and research areas. One of the most visible robots used in the hospital is a train robot called TUG, produced by Aethon Inc. It roams around the hospital floors and the cafeteria, delivering meal trays to the children in the patient unit. The robot is equipped with sensors to navigate around the building and avoid collisions. The physical appearance as a colorful train with occasional "choo-- choo--" sound brightens up the atmosphere for the patients visiting or staying at the hospital and their caregivers. Vgo, a widely used telepresence robot, is utilized by the Telehealth Initiative in order to extend the effect of medical consultation, patient care and education. Also, the Robotic Surgery, Research and Training Program investigate the usage of surgical robots that can perform more delicate and precise procedures on the patient with minimal invasion. Due to these various projects and programs employing different types of robots, most staffs and employees at the hospital had positive reaction when seeing the Huggable robot and showed high excitement in its impact on the patient's experience with it.

## 2.3 Child Life Specialists

Child life specialists are pediatric health care professionals, who assist child patients and their families cope with the challenges of hospitalization, illness, and disability. [35] They provide children with age-appropriate preparation for medical procedures, pain management and coping strategies, along with entertaining them with various play and self-expression activities. They also provide information, support, and guidance to parents, siblings, and other family members when under stress. Child life specialists build close relationship with the patient and his/her family and understand each patient's individual personality traits, likes/dislikes, play activity preferences, etc.

During an informal interview, one child life specialist said that many children staying at the hospital for extended period of time tend to press emergency nurse call button repeatedly because they feel lonely and want company of someone who can provide emotional and social support. However, there is a great gap between the supply and demand of the number of child life specialists and other staffs who can assist the patients. Thus, the Huggable project was initiated in order to explore the feasibility of a social robot platform as an extension of the service provided by child life specialists.

For example, when all of the workforce, either child life specialists or on-call nurses, are occupied with accompanying more medically and/or mentally urgent patients, other child patients can be entertained and comforted by the Huggable robot when this One crucial thing to note is that this social robot platform is not to replace the current working force of child life specialists or any other staff at the pediatric hospitals. This social robot is to complement the service provided by these experts as a different format of availability and added functionality as a robotic companion.

## 2.4 Robots in Lab vs. Robots in Hospital

Unlike most human-robot interaction user studies, in which the interaction happens in a controlled environment, the Huggable project was done in a real world setting. Because of the nature of the hospital environment, many components cannot be controlled and additional challenges arise in the process. ALIZ-E projects, which targeted diabetic children in a hospital, faced similar obstacles and found some lessons learned from their previous research. [36] However, the Huggable project faced even bigger issues as the target subjects were had bigger variance and severity in their medical conditions, and the robot-child interaction happened in individual subject's bed space. This section summarizes major challenges that arise in putting a social robot in a hospital, compared to the case in a laboratory space.

### 2.4.1 Legal and Administrative Issues

Due to the enforcement of Health Insurance Portability and Accountability Act of 1996 (HIPPA), the privacy and confidentiality of individual's health information are to be secured and protected. [37] Because of this, the research associate needs to be very careful when performing a video and/or audio recording. Also, there can be incidents of unexpected or unintentional recording of other hospital staffs, family members or another patient sharing the same unit. Recruiting subjects for the experiment is not easy as well. The researchers cannot expect when patients who are eligible for the study will be admitted or do not have any control over their schedule or length of hospitalization. Even after an appropriate subject is recruited, setting days and time to run the experiment requires incorporating schedules of the patient, potential medical operations and timelines of several hospital staffs. Since the target subjects are recruited from MSICU and Oncology floor, a medical urgency can potentially arise in the midst of an experiment session, which requires immediate halt in the study.

### 2.4.2 Hospital Environment

The experiment was run in individual patient units in Medical Surgical Intensive Care Unit and Oncology Service. Based on different services and types of medical conditions patients are in, these two Most MSICU units had two beds in one patient room and some were single bed units. In most cases, the doors to these units are left slightly or half opened, and many medical staffs walk by to do routine check ups and rounds. There are constantly people talking and walking by in the hallway, and alarms go off from time to time. Many of the patients in MSICU are on a mechanical ventilation to assist breathing and sedated, which is not suitable for an interaction with a social robot. Furthermore, the team was told by the nursing staffs that teleoperating the robot in the hallway caused too much disturbance for the patients who are in critical states and must be kept absolutely at rest.

On the other hand, patient bed spaces in Oncology floor are almost all single rooms due to lack of immune system for many patients, and the doors are always closed. In fact, there are two doors installed between the hallway and the patient room to filter the air upon entering/exiting the unit and therefore one of the doors is always shut when the other one is open. This setting was beneficial for the child life specialist to operate the Huggable in the nearby hallway because the sound they were talking through the microphone had much less chance to be heard by the study participant inside the patient unit. A play activity room is located on the same floor for children to watch movies or engage in fun and entertaining activities, which indicated that most patients were mobile and would benefit from a playful interaction with the Huggable robot.

Many challenges arose due to the characteristic of the hospital environment during the preparation of this experiment. Since all the experiment sessions were done in individual patient unit and every unit looked different from one another, the setup for the system had to happen differently accordingly to the physical constraints of the unit location and how the bed space looked inside. There was no controlled experiment room that the subject could come in and thus significant amount of time was used for scouting the patient bed space, setting up the cameras and other equipment appropriately, and packing up the devices after the session was over. Also, the team had to minimize the number of devices located inside the unit for safety issue and had to tape down all the wires running along the wall or on the floor. Originally, the team aimed to use as few wires as possible to make the robot “mobile” and “simple to install.” However, numerous medical devices used in the hospital were creating interference in the wireless signal that was sent from and to among the router, teleoperating laptop and the Android phone for robot controller, and at the end the team had to use an wireless access point that boosts up the signal, and tether the devices to one another as much as possible to minimize the loss of packets sent among the devices. The quality of wireless signal stream was fluctuate slightly depending on the floor, specific unit, the day and time, which made it hard to maintain an exactly consistent behavior for the robot overall.

### 2.4.3 Working with Patients and Family

Most of patients and their family reacted positively to the idea of having a social robot that could potentially entertain and assist children who are hospitalized for an extended period of time. However, some parents expressed concerns of their son or daughter being “thrown a robot” and not provided with human services by child life specialists or nurses when the child is “hard to deal with or annoying.” Thus, it is crucial that research associates recruiting a potential subject convince the family that the service provided to any patient will not degrade, and appeal that any child who needs urgent care ands support will be attended by a human staff with full capacity.

In the same manner, some child life specialists raised another potential complaint that caregivers might have. Most bed spaces at the experiment site are double bedroom units and there are very few single bedroom units. Thus, when one subject interacts with a robot, it is very likely that the other patient and perhaps his or her family will recognize that another child got to interact with a robotic toy. This could possibly cause the neighboring patient and his/her caregivers desiring to be provided the same service as well, and potentially lead to running extra robot interaction session with a patient that does not qualify for the subject criteria.

# Chapter 3

# Hardware Design

## 3.1 Overview

The current version of the Huggable is hardware version 5.0 (counting every hardware iteration of the Huggable Project to date), and a direct iteration of the Huggable Project developed by the Personal Robots Group and Jetta Manufacturing as part of the Master's thesis of Kristopher Dos Santos. The thesis completely updated the old system, started by Dan Stiehl and Cynthia Breazeal back in 2005, with a robust and stable mechanical structure, an updated electronic system, and a wireless computation system incorporating the Android software and r1d1 codebase, which had been developed by the Personal Robots Group. Huggable v.5 sought to further improve on its predecessor, by including improved motion, modular components, and easier access to electrical hardware for troubleshooting.

The report will first describe the mechanical system, and cover the changes made as well as the system's features. It will also describe the electrical system, covering the various components used in the robot.

## 3.2 Mechanical System

Huggable v.5 needed quite the mechanical overhaul from its predecessor. While most of the bear's mechanism designs could be salvaged, most of the interior structure needed to be redesigned to properly organize the internal features and provide smooth and stable movement of all of the DOFs. And it needed to be done quickly. Accounting for this, the bear was designed with the assumption that the first two robots would be fabricated as functional prototypes, with 3D printed ABS shells. This allowed for part features that would not be easily created using injection molding. Designated pathways for wires, as well as modularity of certain parts, were also necessary for the new robot. Ultimately, this new version was designed with the researcher in mind: easy to maintain, easy to troubleshoot and debug.

### 3.2.1 Motor Selection

| DOF | Range (degrees) | Motor | Gear Ratio | Est. Applied Torque (mN*m) | Final Speed (rev/s) |
|---|---|---|---|---|---|
| Elbow Joint | 0, -80 | Faulhaber 1717 | 1:104 | 55.27 | 2.05 |
| Shoulder Rotation | +30, -90 | Faulhaber 1717 | 1:280 | 153.04 | 0.77 |
| Shoulder Lift | +65, -15 | Faulhaber 1717 | 1:280 | 153.04 | 0.77 |
| Head Nod | +15, -25 | Faulhaber 1717 | 1:369 | 475.1 | 0.53 |
| Head Tilt | +15, -15 | Faulhaber 1717 | 1:369 | 352.91 | 0.55 |
| Head Rotation | +60, -60 | Faulhaber 1516 | 1:152 | 84.62 | 0.7 |
| Waist Pivot | +10, -10 | Faulhaber 2232 | 1:249 | 881.21 | 0.43 |
| Ear Wiggle | +40, -40 | Faulhaber 1024 | 1:64 | 30.84 | 3.06 |
| Muzzle Wiggle | 0, -60 | Faulhaber 1024 | 1:64 | 37.27 | 2.9 |

Table 3.1: Selection of motors for each joint and the corresponding specifications

For the selection of motors, high preference was given to Faulhaber motors due to their compact size and powerful output. The calculations for these new motors were more easily performed due to the availability of weighing the previous model of the bear. From there, calculations were performed to select motors that could deliver the necessary speed/torque whilst not breaching a maximum current draw of 500mA. The motors were also chosen at 12V for the optimal operation on the MCBMini motor controller boards.

### 3.2.2 Head

Much of the changes necessary for Huggable v.5 originated from problems with the Huggable that was created in partnership with Jetta (referred in this report as version 4). As listed, here were some of the changes needed:

- Better stabilization of the head
- Redesign head tilt / head nod mechanisms for stability
- Redesign head structure to include new ear mechanism

- Redesign muzzle mechanism with new spring
- Perforate the head shell for air ventilation
- Better accessibility to electronic hardware of troubleshooting
- Redesign shells for easy removal
- Redesign ear mechanism for modularity
- Extend out the muzzle bar to avoid mask and fur collision

Huggable v.5 aimed to address these changes.

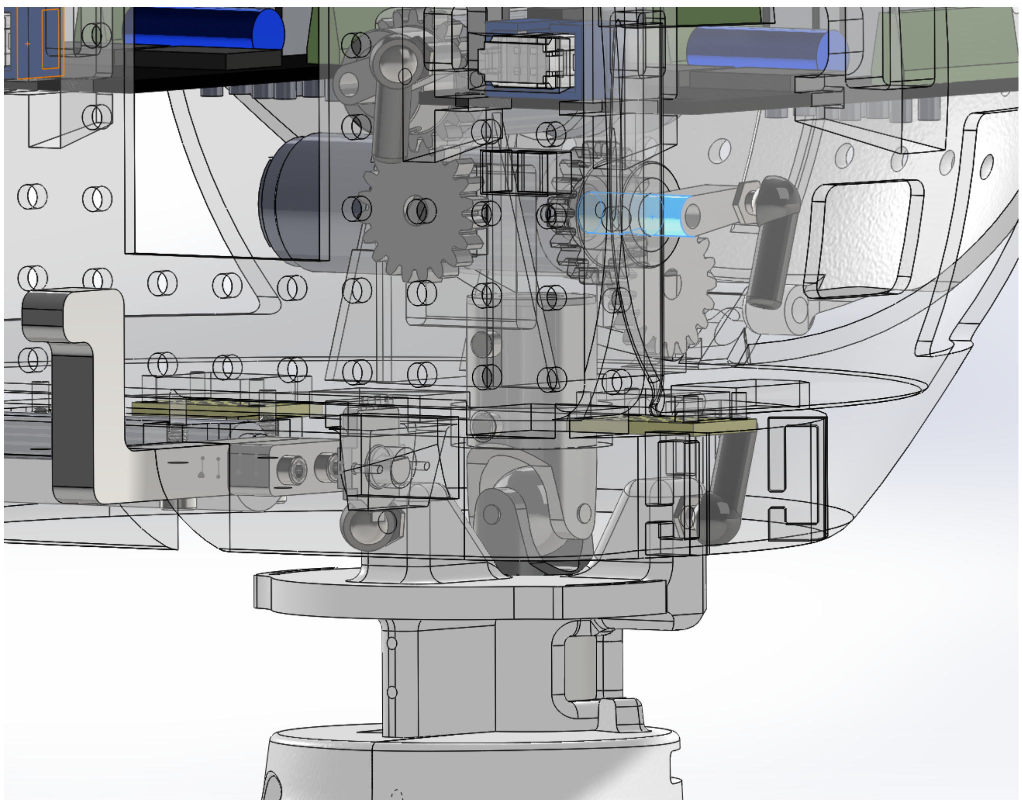


Figure 3-1. Neck platform

To address head stabilization and the head tilt/nod mechanisms, the original design was considered. Version 4 used a U-joint and ball-joint rods to create the tilt and nod gestures of the head. While this was not an incorrect method of achieving this motion, the execution needed improvement. Starting from the bottom, the neck platform (Figure 3-1) was created with a more solid structure to prevent the neck from rocking too much, which was a problem in version

4. Also, the original design's U-joint was exactly constrained by the concentric collar in the neck platform and a locking pin. However, the large amount of error between the two points would cause rocking, so a second locking pin was added to over-constrain and account for error. These changes were also made to the top of the U-joint that connected to the base of the head shell.

The ball-joint rods were modified such that the balls could be implemented as threaded joints, while the rods were comprised of threaded rods and tapped cups. This made it easier for assembly. Also, the lever arms that applied the pushing force onto the rods were created as a solid piece, which is highlighted in Figure 3-1, instead of as a flat plate. The problem that arose in version 4 was that the flat arm kept falling off due to inconsistencies in the press-fit peg that secured it the mating gear. In Huggable v.5, the lever was made to be thicker, with a tapped hole for the ball joint, and a shaft collar that accompanied the motor shaft and the mating gear that transferred motion to the potentiometer. The mating gear already contained a set screw, so the lever arm contain a through-hole that allowed the set screw to pin everything together - mating gear, lever arm, and motor shaft.

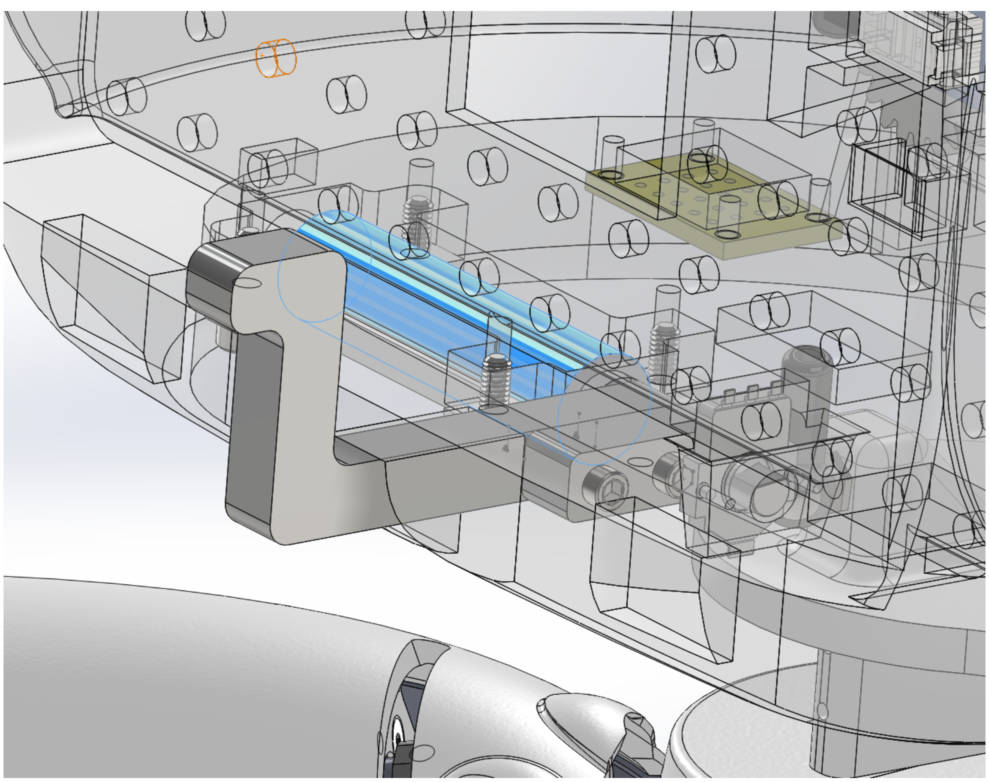


Figure 3-2. Muzzle mechanism

The original muzzle design had a cam system that pressed upon a spring-loaded muzzle bar; this bar would attach to the nose of the fur and move the muzzle of the bear. Rather than deal with springs, the muzzle bar was extended outward for collision avoidance with the mask/face and directly attached to the motor shaft. This made the whole mechanism compact.

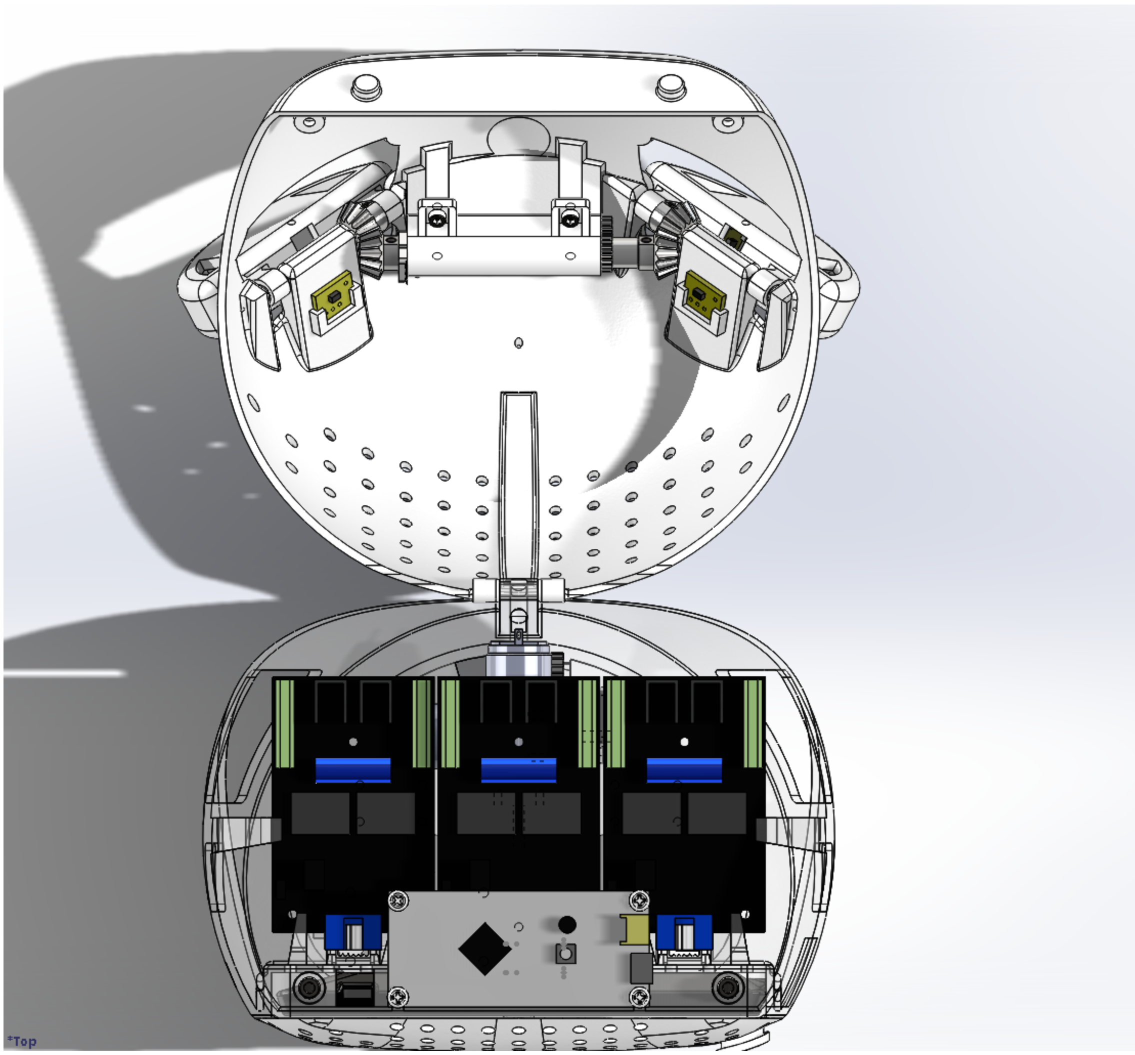



Figure 3-3. Clamshell open/close mechanism of the head

The ears were also a complex issue with version 4. The ears relied on the head being shut at all times, because the two halves of the head would form the support for the axles. However, any warping of the shells caused excessive friction and prevented the ears from moving smoothly. The head is opened very frequently to gain access to the motor boards for debugging or repair purpose. Therefore, the head was designed to open like a clamshell, with a hinge at the base and two screws pinning it down in the front of the head. The ear mechanism was then affixed to the top half of the head, so that opening the head would not hinder ear operation as shown in Figure 3-3. To operate the ears, a motor drove a spur gear that spun a shaft containing two miter gears, designed to operate at 45 degree angles. They meshed with gears that turned shafts connected to the ear pieces. The wires connecting the motor/potentiometer to the corresponding motor board were properly measured to allow slack for opening the head.

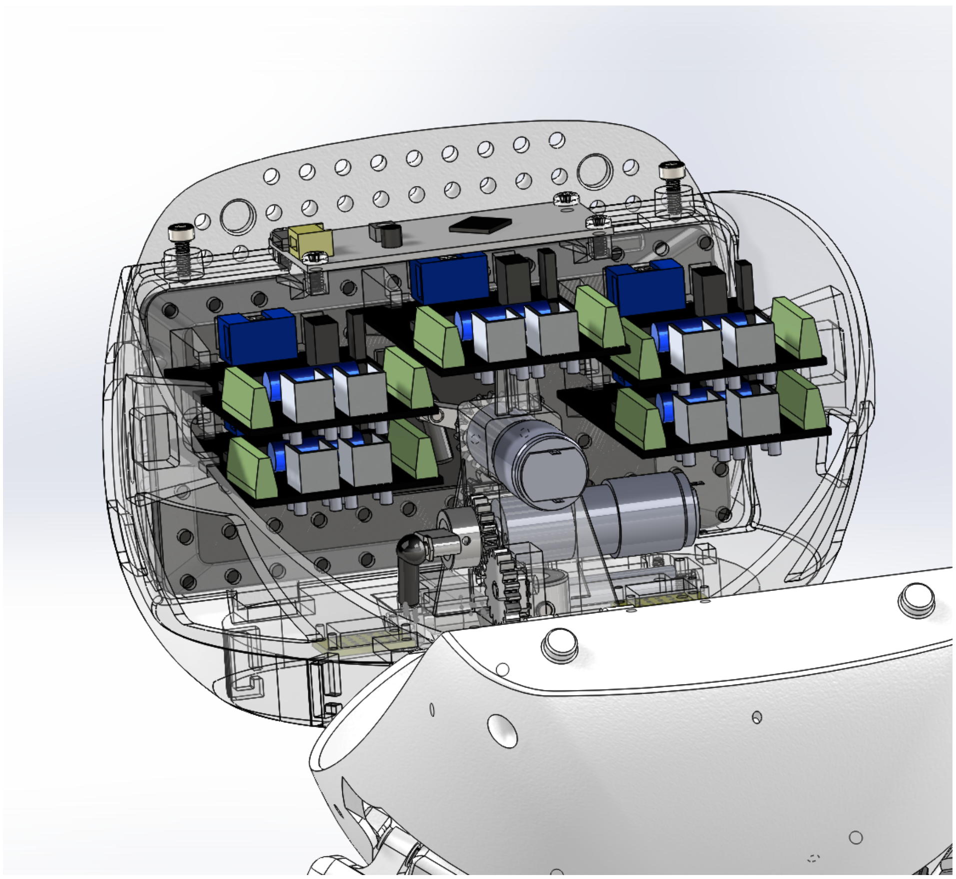


Figure 3-4. Motor boards placement inside the head platform

In version 4, the motor boards were positioned in such a way that many of the sides were inaccessible when mounted. This made troubleshooting a difficult task. This new design was created such that the motor boards "slide" into place, and connect to the corresponding connector, which is press-fit into the head wall. The electronics and wires were all organized in such a way as to make everything as accessible as possible for debugging and troubleshooting. The wires were all grouped together to run down the side and along the bottom of the head, on the left, and then back down, creating a "spinal cord". These would connect the last motor board in the body to the rest of the stack, and the power lines to the power distribution board in the base. The other motor wires were also connected to halfway boards in the base that allowed the arm wires to unplug for modularity (discussed later).

### 3.2.3 Body

There were many changes that were to happen to Huggable v.5 for the body originating from Huggable v.4:

- Better clearance for motor casing fasteners
- Press fit slot for speaker amp board
- Actual slot to press fit onto waist potentiometer shaft
- Remake neck bushing to include actual ball bearing
- Wider channel for wires to pass
- Better bearing for arm rotation
- Better track for waist bend

The original neck rotation had its fair share of issues. As is customary with many low-cost machines, version 4 used an acetal bushing to ensure smooth movement. However, the amount of alignment error that occurred in version 4 caused the neck to move very stiffly. Also, the coupling used to grip the motor shaft for neck rotation slipped frequently. To counteract these, a ball bearing was used instead of a bushing, and a coupling was designed that pinned with the U-joint, the mating gear for the potentiometer, and the motor shaft (Figure 3-5). The motor then was kept in place by a cylindrical channel created by the two mating body shells and a face plate that mated with a long screw that was part of fastening the body shells together.

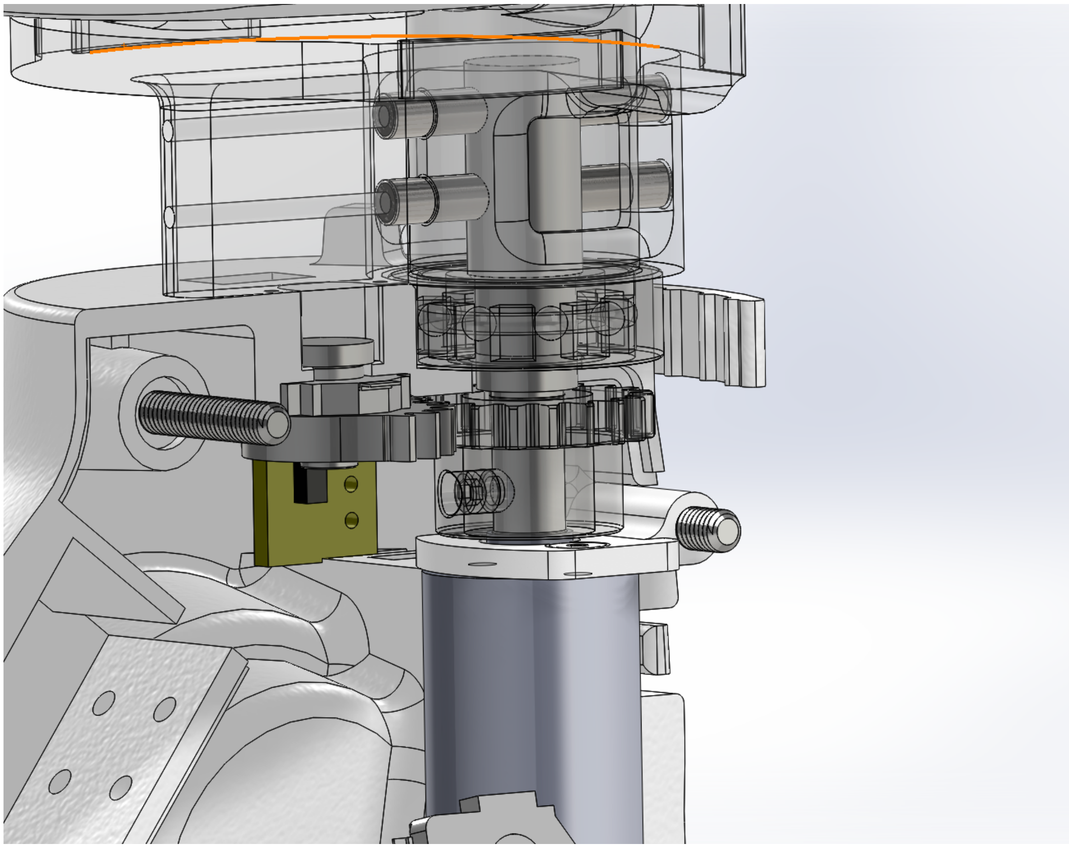


Figure 3-5. The use of ball bearing in the neck

The big change that resulted for Huggable v.5 was how the body shells mated. This change would affect many of the features that existed in the design. Originally, the two shells were front and back, which clamped the arm rotation bushings in place and clipped into a central shaft for waist rotation. However, this caused the arm rotation to be stiff if the fasteners for the shells were fastened too tightly, and recording waist rotation feedback was difficult due to the lack of a stable mechanism for the potentiometer. Also, the desire to take the motor out of the body was desired so as to not contribute to the inertia of the already taxing masses rotating about the waist's axis. The last feature change was to move a motor board closer to the two DOFs located in the body: the neck rotation and the waist rotation, providing that the board could be somewhat accessible. All of these changes were implemented by changing the way the shells are split: down the middle. This allowed for a couple of things to happen. One, the arms could now rotate in a cylindrical "pocket" that ensures alignment with its bevel gear drive system. Two, by creating an internal gear pattern on the edge of one shell and affixing the potentiometer on the other, the waist motor could be moved to the base, and the body could rotate along a spur gear attached to said motor (Figure 3-6). Having a rigid D-shaped shaft on one side ensured that the potentiometer was always set in the same range every time. Of course, this part was designed to also make sure that the motor shaft did not take the full load of the weight of the bear.

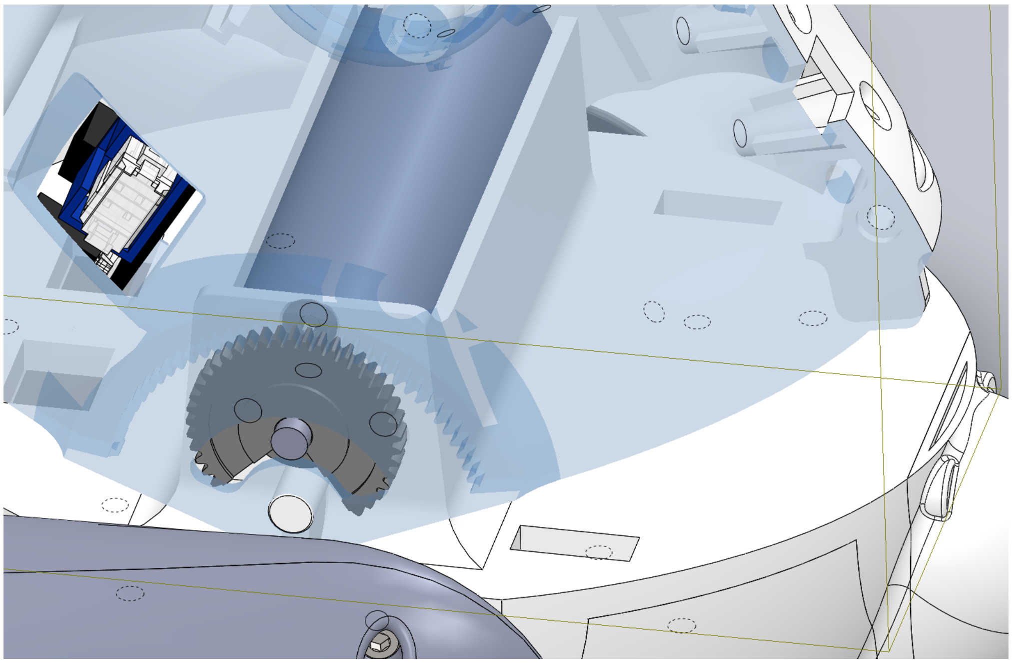


Figure 3-6. Waist motor in the base

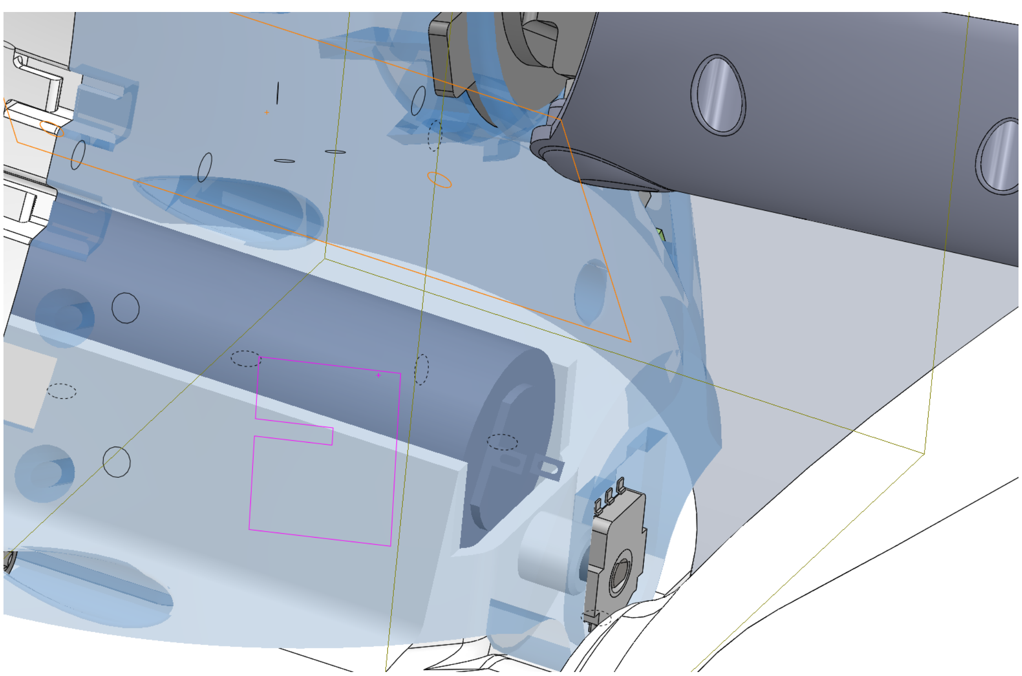


Figure 3-7. Potentiometer location in the waist joint

The arm rotation mechanism was kept in a similar fashion to version 4: motors placed at a slight angle with bevel gears drive the shoulder rotations. Now that that body was split down the middle, however, the original supports were lost. To counteract this, a “socket” was developed into each half of the body. The whole arm would fit into an initial support bearing, and the end of it would fit through a potentiometer and a smaller bearing. The motor was then secured to the shells by means of a separate chassis that screwed into the shells (Figure 3-8)

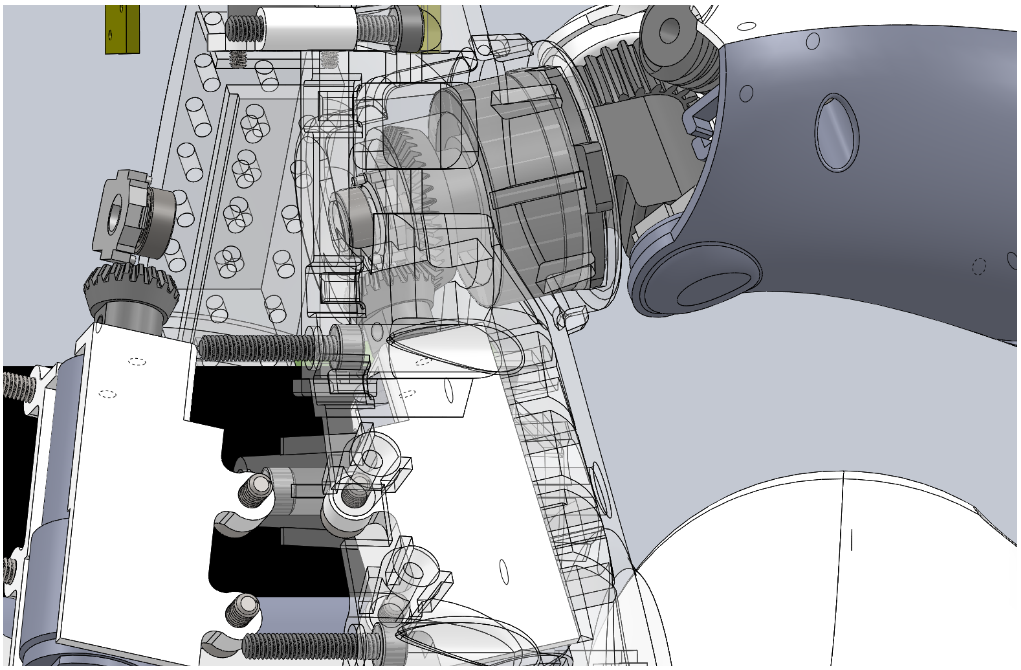


Figure 3-8. Connection between the body platform and the arm component

This meant that the arm could then be made modular, and if needed, removable for troubleshooting. A simple locking shield was implemented to keep the arm in place during operation. The other feature in the body worth noting is the speaker slot, which changed from its predecessor. The slot changed to a rectangular slot to match the new speaker and amplification board in use. With all of these features newly reorganized in the body, there was actually room for the last or in its proper sequence the first motor board to fit in the body. One side was secured using the same press-fit slots used in the head, and the other with an accessible screw that can be removed when disassembling the body. All of the necessary ports and features are accessible from outside of the body, so that one could probe it and flash the firmware as necessary.

### 3.2.4 Arms

The arm design was in need of many improvements in small detail.

(1) Stronger casing for pressure tube
(2) Include heartbeat sensor system
(3) Press fit slot for pressure sensor PCB
(4) Improved bearing block for elbow joint
(5) Designated path for elbow potentiometer wire to travel
(6) Improved shoulder gear train to prevent spur gear backlash
(7) Better potentiometer casing to include room for terminals and wires
(8) Position wires to travel through body and closer to arm rotation axis for less tangle and more concealment (if possible)
(9) More modularity for easy removal and troubleshooting

One of the biggest improvements necessary was adding ball bearings to the joints of the arms for smooth movement. Version 4 had way too much friction in the joints caused by rough plastic contact. Each joint was fitted with a ball bearing on either side, which greatly improved the movement.

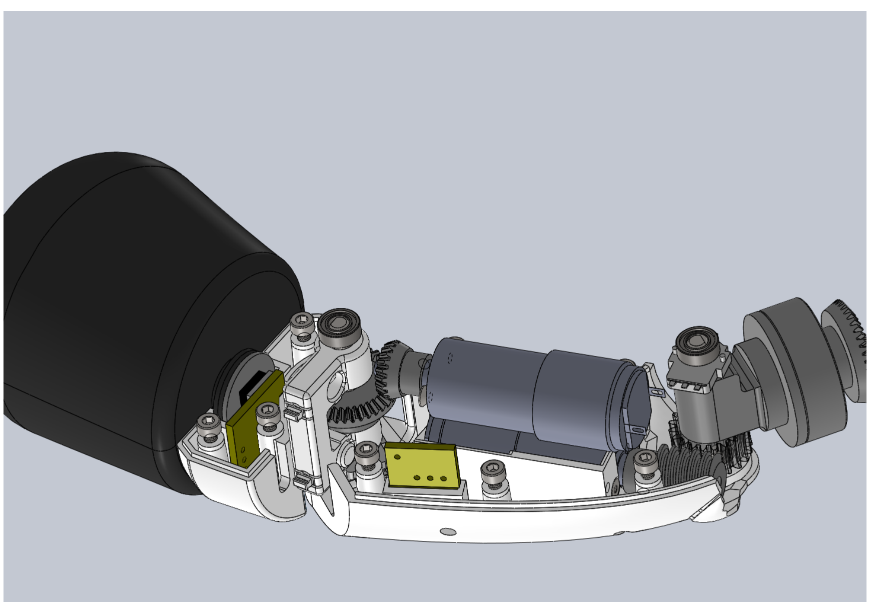


Figure 3-9. Arm component design

The desire for these new arms was that they could be modular and removable from the robot. This way, assembly/disassembly would be simple, and troubleshooting any problems would be easy. Also, the Huggable could be used for different activities with child patients, so a need for variable "paw" tools arose. An interchangeable paw (Figure 3-9) that would mate with a block, which is permanently fixed to the elbow axle, enables the easy replacement of various types of sensors as part of the paw for the Huggable robot. The paw could be interchanged for another sensing module by removing two small pins and disconnecting its sensing device. The figure above shows the pressure sensor module as an example. The elbow is driven using a bevel gear to allow the motor to rest lengthwise along the arm, thus saving space, which is critical in this module. The driven gear is custom cut with a design that houses a special flexure to protect the gears from breaking should over-torquing happen. This flexure, implemented in other gears as well, acts like a slip clutch (Figure 3-10) that allows the shaft to spin instead of forcing a back-drive of the gearboxes and motors. This was first implemented in version 4 and brought back to Huggable v.5 with a few modifications after doing a bit of FEA on the part itself.

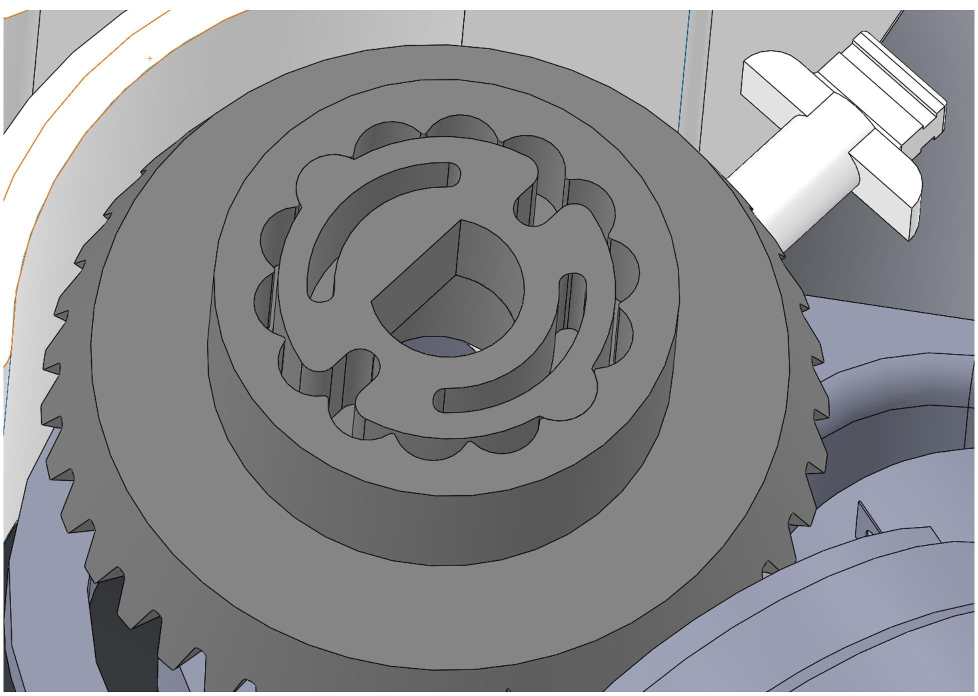


Figure 3-10. Clutch mechanism used to prevent gear damage

The same flexure was used in the worm gear drive for the shoulder lift DOF (Figure 3-11). The worm gear mechanism was kept for Huggable v.5 because, albeit noisy, it provided the most compact gear reduction solution, and compact was a high priority, especially at this DOF. While the wires were not able to fit through the central rotation point of the shoulder as desired, better routing in the arm was designed by means of a defined channel and a pinch point for all of the wires to collect. The wires were then connected under the head at removable points so that the arm could truly be disconnected from the bear for debugging. The wires follow the contour of the sides of the neck to avoid becoming too wild, but have enough excess wires to provide mobility. The fur conceals this excess once Huggable is dressed.

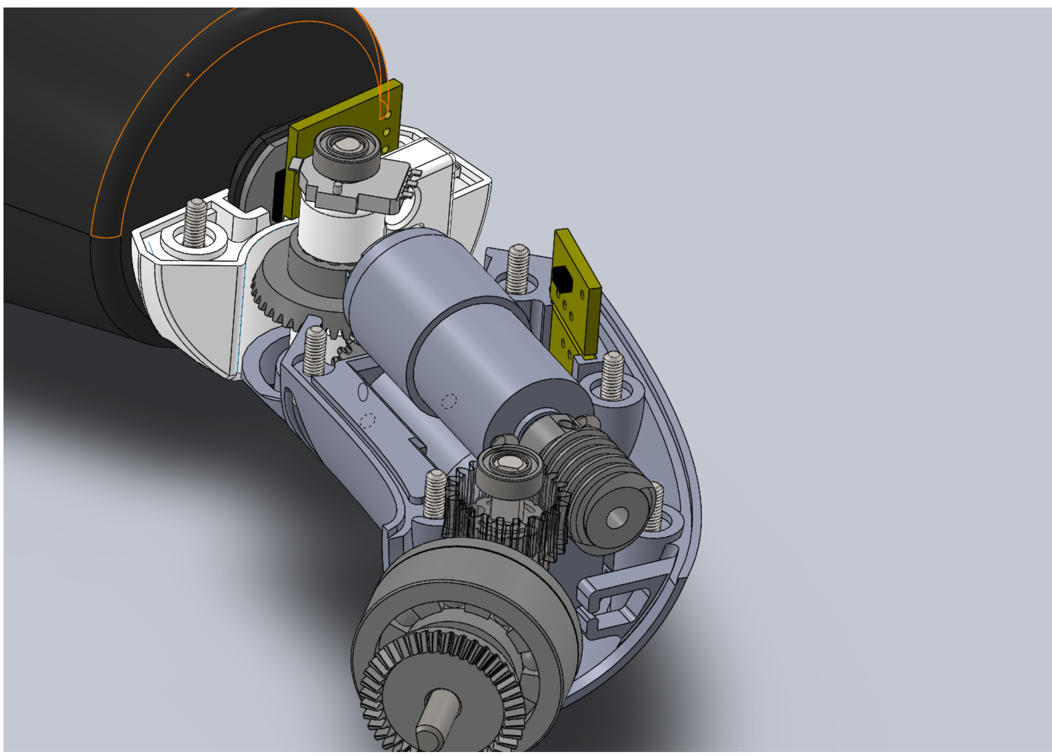


Figure 3-11. Worm gear mechanism in the arm

### 3.2.5 Base and Legs

The base and the legs did not change as much in function, but slightly changed in form. One of the features that were desired was having better access to the electrical components located in the base. In version 4, it was rather cumbersome to inspect the electronics. The change made was to make the base shell as disconnected electrically as possible from the structure.  The on/off switch had excess wires long enough to extend when the bottom shell was removed, proving enough access to the power distribution board. The top shell was then tasked with supporting the features that held the power port and the legs.  The legs needed to be freely rotating, so a ball bearing was placed in either leg.  This was to provide the effect of the legs drooping down when picked up off a flat surface.  Then, cylindrical snap-fits were designed in the top shell to mate with the legs, and provide a means of detachment.  This operates much like an action figure joint; the snap-fit flexes to allow leg to pop on and off of the robot.  The cylinder was also made hollow to allow the battery wires to pass through to the power distribution board.

The batteries were changed from version 4, from custom-made packs to a more standard LiPo pack that had a bigger charge capacity (14.8V @ 2.2 Ah).  This did mean a larger shell for the legs, but the tradeoff was indeed worth the increase in battery life.

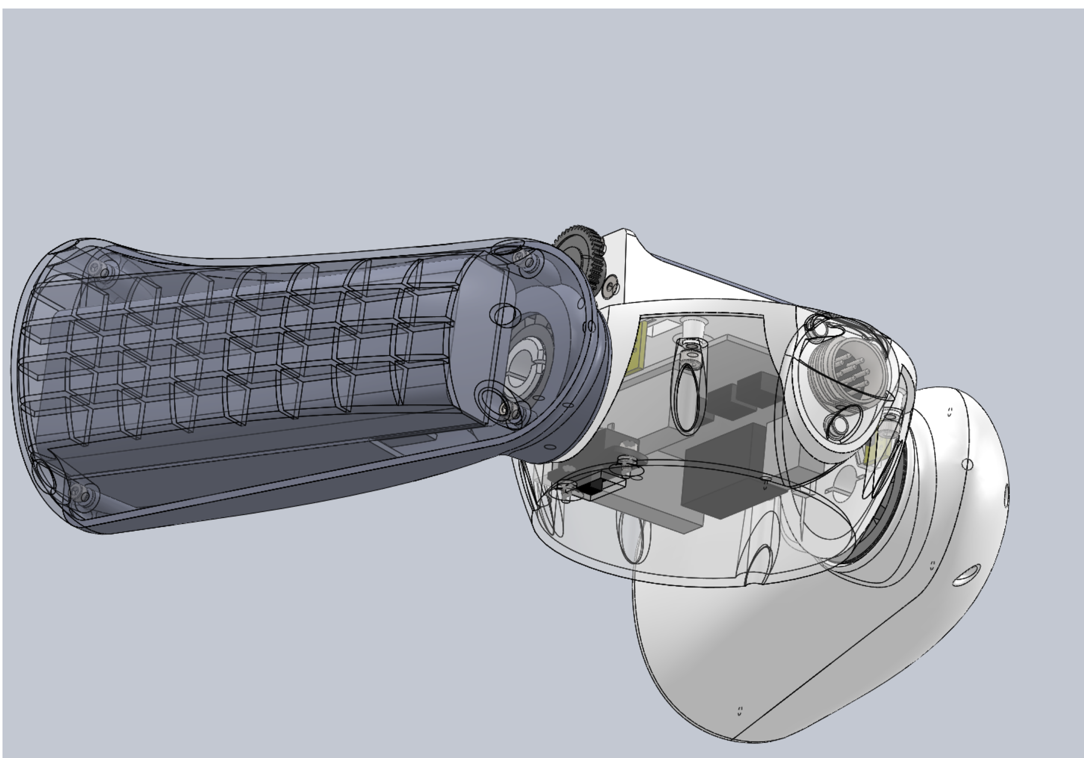


Figure 3-12. Base platform that holds batteries inside

### 3.2.6 Base Stabilizer

Overall, the quality of motions for each joint has been improved greatly. Most of the joints have better speed and acceleration, and moved very smoothly without barely any jerkiness or oscillation. Especially, the torque of the waist joint in Huggable v.5 is much higher, enabling very expressive animations with sudden torso movements. Certain animations, such as *Ewww*, *Woohoo*, *Laugh*, *Alert*, etc, are expressed through Huggable v.5 much better than through Huggable v.4 due to this upgraded motor speed on the waist.

However, the Huggable robot is a top-heavy platform. As noted in Kris Dos Santos' thesis, the external appearance of the robot assimilates that of a human infant, with big head and rather small body.  is a lot stronger compared to the However, the improved speed

Figure 3-13. Base stabilizer from the front and side views

Figure 3-14. Acrylic base stabilizer screwed at
the bottom of the robot with access to the power button

## 3.3 Electrical System

### 3.3.1 SEEDPower Management Board

The Personal Robots Group decided to use a customized power management solution for use in the Huggable. Adam Setapen, the creator of the Dragonbot platform, developed a power board that catered to the needs of the Huggable's electrical system, which was designed to be very similar to the DragonBot system. The board can provide power at 12V, 5V, and 3.3V, support battery charging alongside external power operation, and separate motor and logic power supply for protection to either source. The board can take up to 3 batteries for power input, and can provide 4 different power outputs (the 3 voltage ratings listed above, and a raw voltage supply for motor power). The board supports a DPST (dual pole, single throw) switch for powering the robot on/off, and uses an on-board relay to switch between battery operation and external power operation. Since the board at its current dimensions would not have fit in the base of the bear (and since the Huggable did not have use for 3.3V power) the connectors at the end of the board were trimmed, which provided an even more compact power solution for the Huggable. The robot uses the raw power line to operate the motors, the 5V line to power the speaker board, and the 12V line to support the IOIO board.

### 3.3.2 Batteries

Version 4 utilized a custom battery pack, made up of a series of four 3.7V, 1100 mAh lithium polymer battery cells connected to a protection PCB (for safe charge/discharge). The PCB is a Protection Circuit Module for use with 14.8V Li-Ion batteries at 10A, equipped with an equilibrium charge function (which is very critical for multiple-cell lithium polymer battery packs). To standardize this in Huggable v.5, the dimensions of the battery cavities in the legs were increased to accommodate a larger battery pack for each leg. These new packs supplied twice the amount of battery life (2.2 Ah) at the same voltage. These packs also included a protection PCB to distribute charging amongst the cells. Buying these packs allowed for a reduction in labor cost and production time.

| Type | Component | Count |
|---|---|---|
| Computation Device | HTC Vivid | 1 |
| Motor Controller | MCBMini Motor Controller | 6 |
| Android Interpreter | Sparkfun IOIO | 1 |
| Position Feedback | Panasonic EVW-AE4001B14 Variable Resistor | 12 |
| Touch Sensing | Atmel AT42QT1011 Capacitive IC (unused) | 12 |
| | Custom PCB (unused) | 12 |
| Pressure Sensing | Honeywell SXSMT100 Ceramic Pressure Sensor (unused) | 2 |
| | Analog Devices AD8223 Instrumentation Amp (unused) | 2 |
| | Custom PCB | 2 |
| Power Source | 14.8V @ 2.2Ah BatterySpace LiPo Pack w/ Protection PCB | 2 |
| Power Management | SEEDPower Management Board | 1 |
| Audio Output | Analog Devices SSM2211 Audio Amplifier | 1 |
| | Custom PCB | 1 |
| | 2W 4Ohm Speaker | 1 |

Table 3.2: List of devices used for the electrical components of Huggable

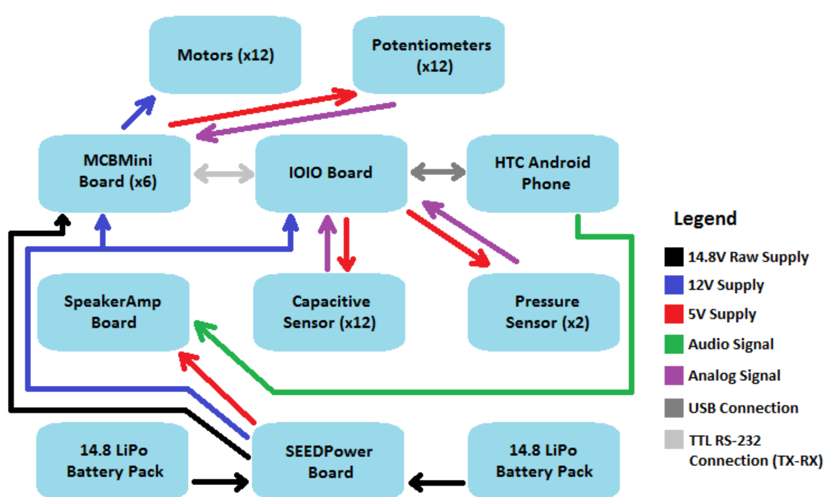



Figure 3-15. Electrical system diagram of the Huggable robot

## 3.4 Fur Design

The problem with fur pieces for Huggable v.4 was that they were restricting the robot's motions, which diminished the performance of expressivity. Even though the fur pieces were separated, there were a lot of hindrance against fluid body movements; cloth was cluttered at the connection point between several moving parts and the material was not stretchy enough. The arm joints could not lifted up to their maximum range with the previous version of the fur on, and many other moderate speed or range movements were dampened due to the friction.

Therefore, a new version of fur for the robot had to be made. The new fur sets for the Huggable robot were designed by Stacey Dyer, a fabric designer. The requirement for the new iteration of fur should (1) impose minimal physical constraint on the moving joints, (2) not clutter between connecting fabric parts, (3) not expose much of the internal mechanical and electronic parts of the robot and (4) be easily washable in typical washer and dryer.

The fur set for the robot was separated in multiple pieces in order to minimize the hindrance imposed on the motors. The fabric material itself was moderately stretchy and the connecting part between joints was stitched with spandex rounding for fixation purpose. Also, the bottom part of the robot was not covered with fabric and maintained flat surface in order to prevent the robot from falling forward or backward.

Figure 3-16. Huggable robot with the fur pieces on

Figure 3-17. Separated ear fur piece that can be fastened with Velcro

Figure 3-18. Arm piece of the robot fur

Figure 3-19. Rubber rounding to fix position

Figure 3-20. The muzzle joint stack is attached to the nose fur

Figure 3-21. Plastic fixator for the eye holes

Figure 3-22. The body suit is fastened at the back of the robot

Since the Huggable robot is used in a hospital setting in which many patients have vulnerable immune systems with high chance of infection, multiple copies of fur was created and each set of fur pieces were washed cold and tumble dried in low setting after each interaction session. For study participants in 6 North Oncology floor, only freshly washed fur set were used on the robot because many of the patients go through bone-marrow transplant procedure and therefore basically no immune system and are highly vulnerable to external contamination. The fabric material is 100% polyester for robustness and was non-allergic. The colors used are officially aqua 2975U for the base color and green 372U for the highlights.

## 3.5 Limitations and Future Work for Hardware

In comparison to the Huggable V4, the Huggable V5 has improved in its hardware capabilities and characteristics to perform overall faster, stronger and much smoother movements. However, there are still a few components that could be upgraded in the future.

First of all, the plastic gears for shoulder rotation are 3D printed and are prone to degradation after some usage. Especially, the teeth on the gear start breaking when the arm is back-driven a few times. Finding sturdier and stronger material for the gears would be able to resolve this issue. Second, the shoulder rotation gear occasionally slips from the motor shaft, causing the motor to spin without actually engaging the gear and moving the arm joint. This is caused due to a small spacing between the gear and the motor shaft, and can be fixed by either editing the design of the arm to fit better or finding a bearing with the right thickness that would fill the space between two parts. Third, hip rotation joint started slipping from the motor shaft after several usages of the robot due to the loosening of a set screw used for the fixation. Temporarily, the set screw had been hot glued into the motor shaft in order to prevent any loosening. Fourth, power cables and potentiometer wires get disconnected or pulled off from the connectors easily. Most wires in the robot are attached to the electric boards, potentiometers or motors through screw terminals and plastic plug in connectors for easy replacement and modularity of parts. However, the wires for the shoulder lift and elbow joint would often come off during the pilot robot interaction session, especially after the robot finishes a big motion with the arms, and resulted in the shut down of the whole robot controller system or a twitching in the disconnected arm part. The resolution for this issue is to use a connector that can be snapped into the other end, enabling stronger connection and yet maintaining the modularity and ease of part replacement.

# Chapter 4

# Software Framework

## 4.1 Overview

The software architecture for the Huggable is based on the DragonBot system framework designed by Adam Setapen with several added features and functionalities. [38] The Huggable controller runs on the Android smartphone and is controlled remotely through the commands sent from either the Teleoperator Interface running on a MacBook or the Nursery Rhyme Teleop on an Android tablet device. The laptop that runs the Teleoperator Interface runs the Real-time Voice Stream module from a Windows 7 virtual machine and sends pitch shifted voice audio data to the Huggable controller. The diagram below shows the data flow among different modules in the Huggable software architecture and the table below lists the devices used for the system. In the following sections, each module will be explained in further details.

Overall, the software architecture for the Huggable aimed to minimize the required devices for ease of setting up the system and to maximize quality of the interaction with minimal latency in network communication despite the significant amount of interferences from neighboring medical devices.

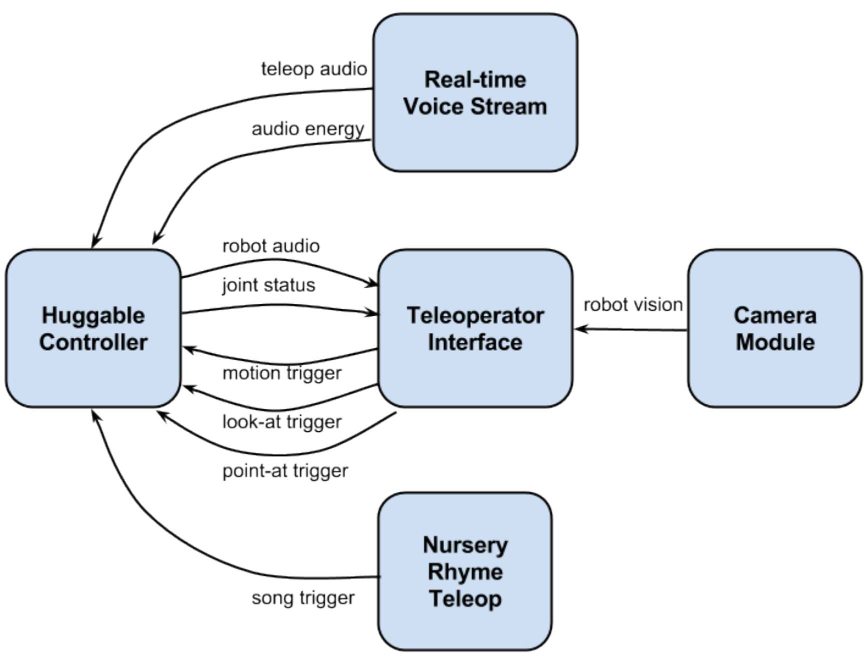



Figure 4-1. Overview scheme of the Huggable robot system

| Device | Module | Operating System |
|---|---|---|
| HTC Vivid | Robotic Huggable Controller | Android 4.0 |
| MacBook 13 inch | Teleoperator Interface | OSX 10.7.5 |
| | Real-time Voice Stream | Windows 7 |
| | Camera Module | OSX 10.7.5 |
| Samsung Galaxy Tab 2 10.1 | Nursery Rhyme Teleop<br>Virtual Huggable Controller | Android 4.2.2 |
| Medialink Router | N/A | N/A |
| Wireless Access Point | N/A | N/A |
| Logitech USB camera | Camera Module | OSX 10.7.5 |
| Microphone | Real-time Voice Stream | Windows 7 (VMWare) |
| Headset | Teleoperator Interface | OSX 10.7.5 |

Table 4.1: List of devices used for the software framework of the Huggable system

# 4.2 Huggable Controller

## 4.2.1 Smart Phone Robot Controller

The Android phone used for the robot controller is HTC Vivid with dimension of 5.07 x 2.64 x 0.44 inches (129 x 67 x 11 mm). Its total weight is 6.24 oz (177 g) and has display size of 4.5 inches with 540 x 960 pixels resolution. The phone has 16 GB of built-in storage space, and is equipped with dual core processing power 1200 MHz and 1024 MB RAM, running on Android OS v2.3.4 (Gingerbread version). There are many other phones equipped with stronger and faster processing power but this choice of smart phone was selected mainly because of its dimension and weight. The device is has built-in microphone, speaker, and front and back cameras that are utilized in the Huggable robot system. The author searched various options for the smart phones to be used in the robot. When the author was selecting an Android smartphone for the robot controller, some of the newly released phones, such as Samsung Galaxy S3, were equipped with quad-core processors and had bigger RAM space. However, most of these phones were produced in bigger size and therefore could not fit in the robot's head. Thus, the best option available was this HTC Vivid model.

The HTC Vivid phone did not contain the strongest computing power available in the market. Yet, the robot controller needed to process great quantity of sensory data and networked information packets to and from the teleoperation interface. With the native HTC phone ROM environment, the robot controller would not exhibit believable behavior performance as a social companion character. The average frame rate was ~15 fps without video streaming, and ~6.5 fps with video streaming via built-in Android front camera in MIT Media Lab. The movements were slowed down a lot and the response animations were not triggered within the time delay that is considered socially meaningful. To make things even worse, the update rate of the robot controller tends to be generally lower at Boston Children's Hospital environment due to many wireless medical devices used in patient units. For previous experience with other Android based robot platform in the Personal Robots Group, the robot requires minimum 14-15 fps in order to perform socially and emotionally contingent behavior for Human-Robot interaction. Thus, the update rate of the robot controller system needed to be boosted up in order to work in network hostile environment at Boston Children's Hospital.

### 4.2.2 Processing Power Enhancement With Custom Android OS

In order to achieve faster processing power for the robot controller, the author chose to "root" the HTC Vivid phone. Android rooting is "process of allowing users of smartphones, tablets, and other devices running the Android mobile operating system to attain privileged control within Android's sub-system." [39] The rooting process allow a normal Android user to perform operations that are typically not feasible within the factory phone environment, e.g. modifying system related applications and settings, running special applications and executions that require administrator permissions, etc. Rooting can also facilitate the complete removal and replacement of the device's operating system. The device manufacturer company, HTC, allows users to unlock the bootloader and root the phone by providing instructions and required materials through their official websites on the *Developers* section. This function allows wiping out native HTC Android ROM and replacing it with any custom-made operating system that has less system restrictions and settings. After reviewing multiple choices of custom ROM created by other developers, *ParanoidAndroid* ROM was chosen as a replacement to the native OS. Required installation process and files were available on *xda-developers* forum, which is an open on-line Android developer community. The new custom ROM installation increased the update rate of the system up to on average 24-26 fps without video streaming functionality from the Android front camera, and to ~17 fps with video streaming feature in MIT Media Lab. Before launching the actual experiment with patients, the whole system was tested in the Simulation Suite located on 7 South floor of Boston Children's Hospital. This location was chosen for the ease of accessibility and also for its poor wifi connection environment. There are many wireless devices for surgical simulation courses, such as microphones, cameras, etc, that are continuously used and the room has lead lined walls, which increases the interference and blockage of wireless signals. Therefore, it was assumed that the system would work successfully in other locations in the hospital if the robot can perform well in the Simulation Suite, and the suite was used as a rigorous testing environment. Below is the summarized comparison between frame rates in different locations with either native HTC operating system or custom *ParanoidAndroid* ROM.

| | **Native HTC OS** | **ParanoidAndroid ROM** |
|---|---|---|
| **MIT Media Lab** | ~6.5 fps (w/ video stream)<br>~15 fps (w/o video stream) | ~17 fps (w/ video stream)<br>~25 fps (w/o video stream) |
| **BCH Sim Suite (7 South)** | N/A (w/ video stream)<br>N/A (w/o video stream) | ~12 fps (w/ video stream)<br>~18.5 fps (w/o video stream) |
| **BCH Oncology Play Room (6 North)** | N/A | ~21 fps (w/o video stream) |

Table 4.2: Improved processing speed after rooting the Android OS

## 4.3 Motor System

The motor system for the Huggable is based on the architecture created by an alum in the Personal Robots Group, Dr. Jesse Gray. [40] The motor system pipeline allows exporting professionally made animation clips from Autodesk Maya format and import them into the r1d1 code base in order to utilize prioritized blending functionality. In the Huggable system, there are multiple motor systems running through each posegraph synchronously: *Idle* motor system, *Blink* motor system, *Motion* motor system, *Muzzle* motor system, *Look-at* motor system, and *Point-at* motor system.

### 4.3.1 Idle

Idle overlay was installed for the life-like behavior for the Huggable robot even when no active gesture is being acted out. The Idle animation moves subtly to give an impression of breathing, slighting lifting and lowering the head and moving the waist back and forth.

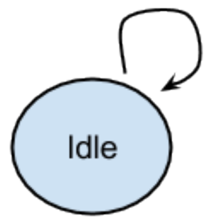



Figure 4-2. Posegraph for Idle motor system

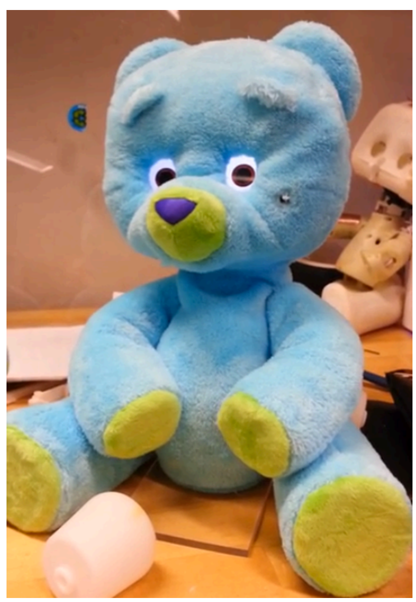


Figure 4-3. Huggable robot in *Idle* state

### 4.3.2 Blink

Blink animation is triggered randomly between 2.5 and 7 seconds when the eye nodes are not occupied by other animations. The blink animation enhances the lifelikeness of the Huggable along with the *Idle* effect.

Figure 4-4. Screen capture of *Blink* animation

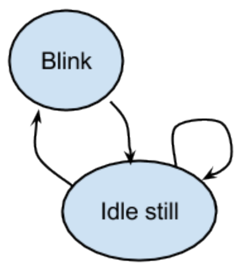



Figure 4-5. Posegraph for *Blink* motor system

### 4.3.3 Motion

Motion motor system incorporates the canned animations that can be triggered on either the table list or the Arousal-Valence graph button. Each animation is connected directly from and to the *Idle_Still* animation in the posegraph. For nursery rhyme animations, each separate gesture animation is connected in the same manner as other canned animations but the sequenced motions are connected accordingly to the order.

Figure 4-6. Still images of general body gesture animations

(*Good job, Hi,* and *Introduction* from left to right)

Figure 4-7. Still images of *Ewww, Alert,* and *Sad* animations from left to right

Figure 4-8. Still images of animations *Happy, Tense* and *Upset* from left to right

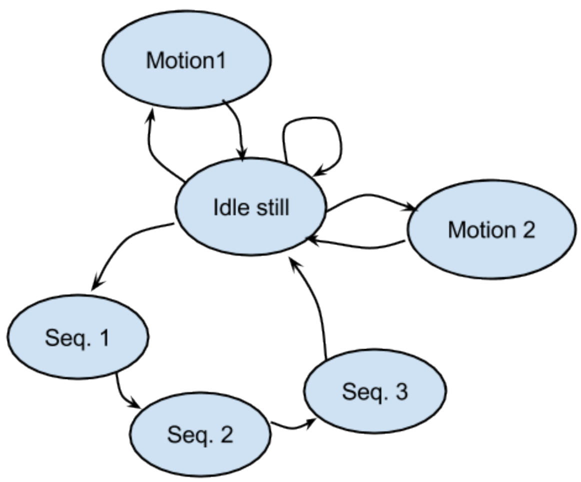



Figure 4-9. Simplified posegraph of *Motion* motor system

### 4.3.4 Muzzle

The snout of the Huggable moves up and down as the robot or the virtual character talks. In idle state when there the Huggable is quiet, the muzzle is located upward. When talking in loud voice, the snout goes down. The muzzle moves according to the energy of the teleoperator's voice streamed out through the Huggable. This synchrony between the audio and the physical movement of the muzzle joint strengthens the illusion effect that the Huggable is talking for itself.

Figure 4-10. Two points of Muzzle animations for blending

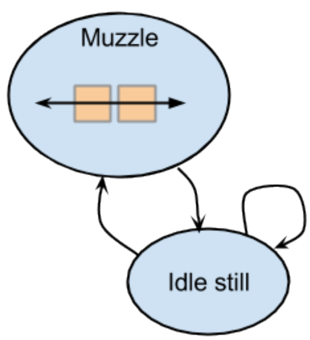



Figure 4-11. Posegraph for *Muzzle* motor system

### 4.3.5 Additive Look-at

Additive Look-at system that blends animations based on the 2-dimensional Cartesian coordinate system was previously implemented in the DragonBot motor system. [38, 41] Nine look-at animations that represent points in four quadrants of the two dimensional space are given for blending. When reference point for look-at target is given as a Cartesian point. The space is normalized into a square with two points on (-1, -1) and (1, 1). The nine point of look-at animations are illustrated as below.

Figure 4-12. Nine points of look-at animations for blending

When a target position is retrieved from the teleoperator interface, 4 look-at animations are blended relatively based on the x and y values of the coordinate and the quadrant it belongs in the space. The look-at can be extended to physical movements of the head. The *neckRotate* joint and *headUpDown* joint are associated with x- and y-axes of the look-at behavior and move proportionally to the point. Once the look-at behavior is triggered, the eyes move first and the head motion follows. After the head movement is finished, the eyes are centered. Also, as the name "additive" notes, the look-at position of the body and the eyes stay stationary after being triggered, and is added to the other canned animations that is played on the Huggable robot in order to create an effect of making gestures and expressions while looking at the same location.

Figure 4-13. Look-at behavior (lower-left on the left and upper-right on the right)

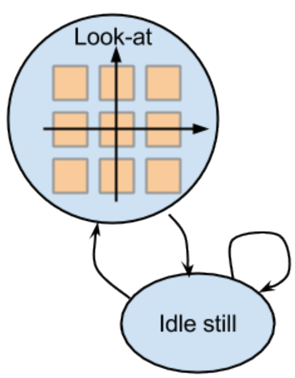



Figure 4-14. Posegraph for *Look-at* motor system

### 4.3.6 Procedural Point-at

The point-at behavior of the Huggable is applied in the same manner that the look-at system had been implemented. [40] The difference was that the quadrants for the look-at behavior system were divided into two parts along the y-axis for two separate point-at systems, *Left Point-at* and *Right Point-at*. Coordinates with negative x coordinate value initiate point-at behavior with left arm, and coordinates with positive x value initiate point-at behavior with right arm. Each point-at system takes normalized position value within the given coordinate space. When point-at behavior is triggered, the appropriate target position for the look-at behavior is applied to the motor system. As a result, the Huggable looks and points at the target location at the same time, increasing the intensity of focus and expressivity of attention.

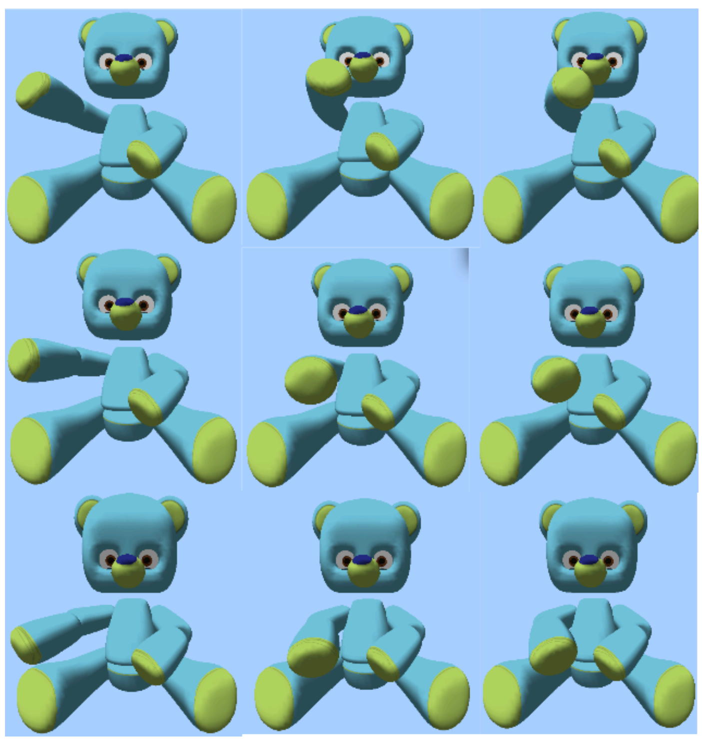


Figure 4-15. Nine points of right point-at animations for blending

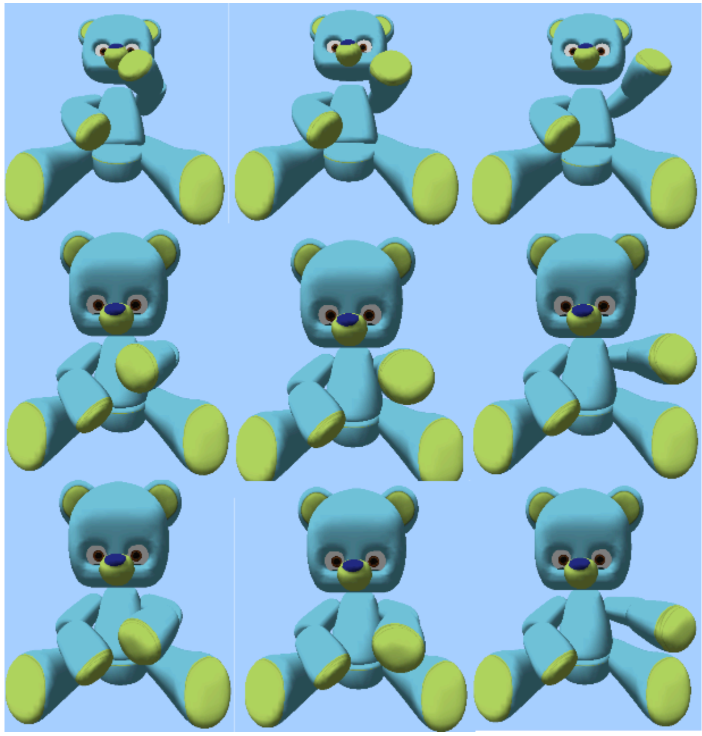


Figure 4-16. Nine points of left point-at animations for blending

Figure 4-17. Point-at behavior with right and left arms

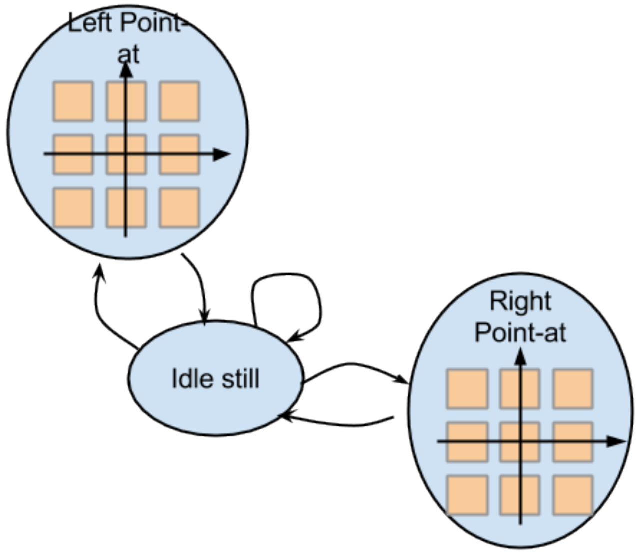



Figure 4-18. Posegraph for *Point-at* motor system

## 4.4 Virtual Huggable

One of the conditions in this experiment was the virtual Huggable on an Android tablet device. The virtual Huggable utilized the same internal motor system, robot controller and animations, and was shown on a Samsung Galaxy Tab 2 10 inch device. The textures for the skin of the Huggable were similar to those of the Huggable robot, bright sky blue and pointers of bright yellow green on ears, paws and the muzzle. Figure 4-19 shows the screen capture of the virtual Huggable shown on the tablet in idle state. The motions of the virtual Huggable had approximately the same quality and speed as those of robotic Huggable movements.

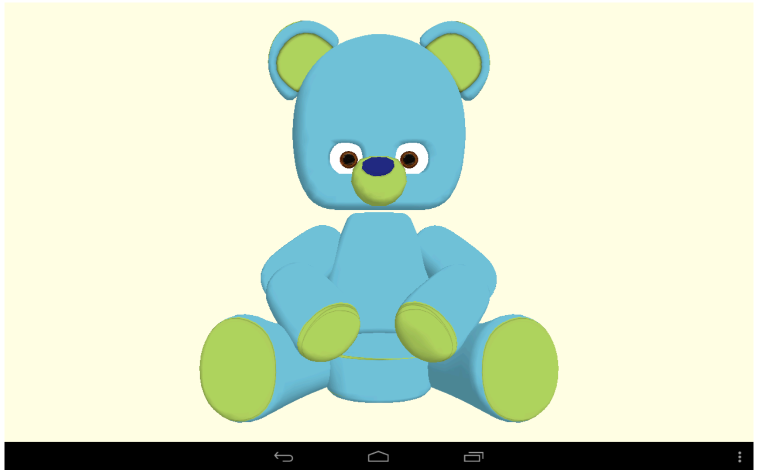


Figure 4-19. Virtual Huggable in idle state on a tablet device

## 4.5 Teleoperator Interface

The previous version of teleoperator interface for the Huggable robot was used on an Android tablet (Samsung Galaxy Tab 10.1). [42] In the second iteration, the interface was used on a 15-inch MacBook Pro for bigger screen and faster processing power. Adina Roth, a visiting student with product design specialty, redesigned the layout and graphical component of the Huggable teleoperation interface. In comparison to the previous version, the new teleoperator interface is added with two options of camera view (stale panoramic camera view and global camera view), categorization of canned animations (*Action-based* list and *Emotion-based* arousal-valence graph), mute/unmute function for pre-recorded audio clips for canned animations, point-at by click feature, and open/close choice for gestures.

| | **Previous version** | **Current version** |
|---|---|---|
| **Camera view** | Robot's field of view through Android camera | Two choices available:<br>(1) Stale panoramic view through Android camera<br>(2) Global view from external camera |
| **Canned animations** | 5 canned animations available (*Surprised*, *Intrigued*, *Happy*, *Sad* and *Confused*) | - Open / close version for majority of animations for expressing two personalities<br>- General body gestures |
| **Look-at** | Touch the target on the camera view | Right-click with the mouse or one-finger touch with the trackpad on the target on the camera view |
| **Point-at** | None | Left-click with the mouse or two-finger touch with trackpad on the target on the camera view |
| **Mute/Unmute audio clip** | None | Can use all animations with or without pre-recorded audio clips |

Table 4.3: Compared expressivity in Huggable V5 via teleop interface

In general, light pastel tone sky blue, green and yellow colors were used for various components in order to induce bright atmosphere and match the theme color of the Huggable, which is bright sky blue and light yellow green. The buttons on the interface are light yellow and the texts are written in light green. The buttons are highlighted with stronger yellow when clicked and would disappear

Given that all three child life specialists using the interface are right-handed, the list of action buttons and emotional state diagram were placed on the right side of the interface for ease of use.

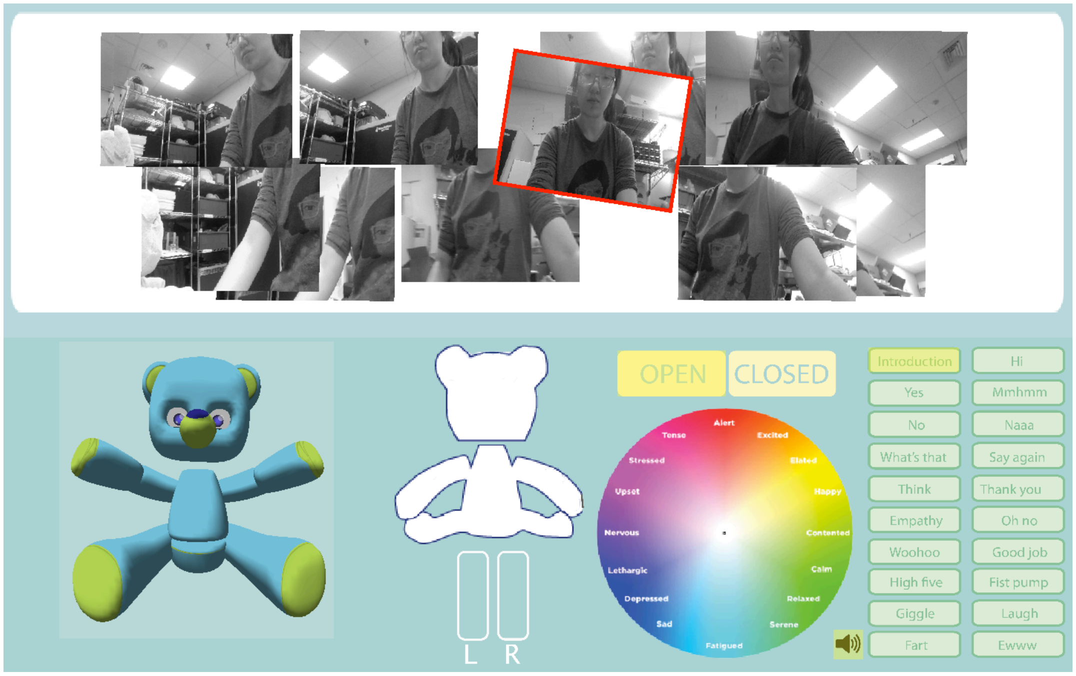



Figure 4-20. Teleoperation interface with stale panora view

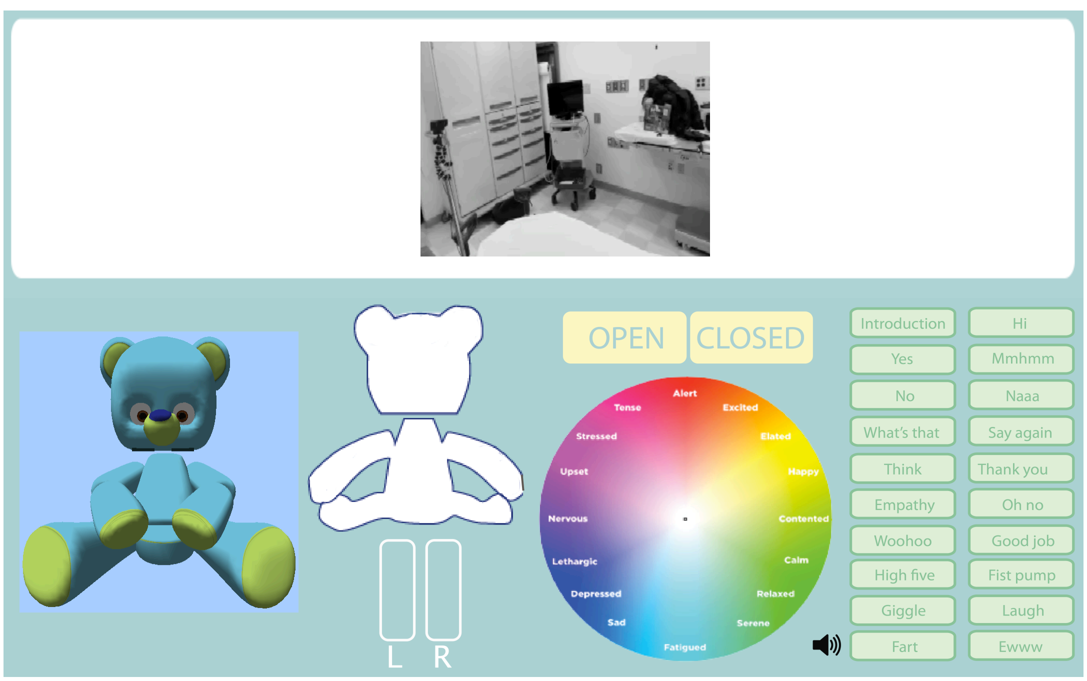



Figure 4-21. Teleoperation interface with global view

### 4.5.1 Stale Panorama View

The camera on the robot's head, either an internal camera on the Android phone or an external webcam hidden in the hat accessory, gives a direct visual feedback of toward which the robot's head is directed. This helps ensuring that the robot is attending to an appropriate human face or an object during the interaction. However, the field of view from the camera is rather narrow and cannot grasp the overall scene of the environment. Due to mechanical constraints and lag in network, the robot cannot move its head and neck fast enough to search objects and faces to match the speed normal humans do.

In order to overcome these limitations, the teleoperator interface utilizes the stale panoramic view. The stale panoramic view is initialized when dragging on the camera view screen in the interface, and the robot starts scanning the surrounding from lower left to lower right, upper right and upper left. During the scanning phase, the robot's head stops at eight points to capture the image from the camera. The interface stores the still images coupled with the neck and head joint position at the stopping time and lays them out appropriately on the camera view panel. The live video feedback is drawn over the stale panorama view according to the current head and neck position of the robot. This approach of stale panorama view was used in the web interface for the older version of Huggable project as well. [40, 41]

With the stale panoramic view, the operator can control the robot's look-at and point-at behavior. The left-click on the camera view controls where the robot looks at, and the right-click controls the point-at behavior of the robot. The target position of the look-at behavior is marked with the red circle on the camera screen and the point-at behavior is marked with the green circle. The real-time camera feed is marked with the red rectangle outline and the position of the video stream moves accordingly to the status of *headTilt* (theta rotation), *headNod* (y-axis) and *neckRotate* (x-axis) joints.

### 4.5.2 Joint Status Visualizer

The teleoperator of the Huggable robot can only view what the robot sees through the camera installed on the head and cannot know the physical status of the robot regarding its movements and position. However, it is important for the robot operator to know how the robot's motions integrate with the overall interaction flow and make sure the physical components are well working. Therefore, the teleoperator interface visualizes the joint position of the robot's 12

DOFs in the lower right corner. Each joint uses a potentiometer for the position control with the motor.

### 4.5.3 Canned Gestures

Twenty canned animations are provided for the teleoperator to trigger on the Huggable robot. These animations are coupled with short sound clips that can be used generally for greetings, agreement/disagreement, backchannels, or etc.

| Animation | Audio Phrase | Gesture |
|---|---|---|
| *Introduction* | "Hi, I'm Huggable. What's your name?" | Hand wave for greeting, point to itself and point ouwtard |
| *Hi* | "Hi!" | Hand wave motion |
| *Yes* | "Yes!" in excited manner | Head nod |
| *Mmhmm* | "Mmhmm" | Head nod with slight tilt |
| *No* | "No" | Head shake |
| *Naaa* | "Naaa" | Head shake and waving arms inward and outward in playful manner |
| *What's that* | "What's that?" | Pointing forward with one arm |
| *Say again* | "Can you say that again?" | Head tilt |
| *Think* | "Hmmm…" | Slow head tilt |
| *Thank you* | "Thank you!" | Both arms (open version) or one arm (closed version) moving outward |
| *Empathy* | "I feel like that, too" | Lightly bending forward and putting one arm forward |
| *Oh no* | "Oh no!" | Big head shake with |
| *Woohoo* | "Woohoo!" | Raising two arms upward and shaking twice |
| *Good job* | "Good job!" | Clapping motion |
| *High five* | "High five!" | Raising left paw and holding for 0.5 sec |
| *Fist pump* | "Woo—hoo—!" | Shake right paw high for a couple times |
| *Giggle* | "Hehehehehe" | Covers the muzzle with two paws |
| *Laugh* | "Ahahahaha!" | Raising both arms and stretch them forward |
| *Fart* | *<Farting sound effect>* | Raising both arms and squeeze them to the side as they come down |
| *Ewww* | "Ewww--" | Waist and head bending backward while covering using arms to cover the face |

Table 4.4: List of canned animations available in the teleoperation interface

### 4.5.4 Emotional Expression

In the field of psychology or cognitive science, emotions are represented in various ways. [42, 43] One method that is popularly used is a dimensional model, expressing one's emotional state in a two or three dimensional vector space. In this project, the 2-dimensional representation with arousal and valence for axes was implemented as an user interface scheme for triggering animations conveying emotional cues on the Huggable. In a typical emotional arousal-valence graph, the vertical axis represents the level of arousal and the horizontal represented indicates the level of valence. (Figure 4-22) For the teleoperator interface, the graph was drawn as a circle with its center to be the origin of the emotional arousal-valence graph, and a set of emotional keywords was marked on the circular graph appropriately to their emotional property. Also, the graph had a gradient color scheme that associated with the affective state. This was intended for the remote operator to be able to find the most appropriate emotional animation without having to read the words on the interface. Positive arousal emotions were associated with bright and warm colors and negative arousal emotions with cold colors. Depressed and Sad were marked with bluish colors.

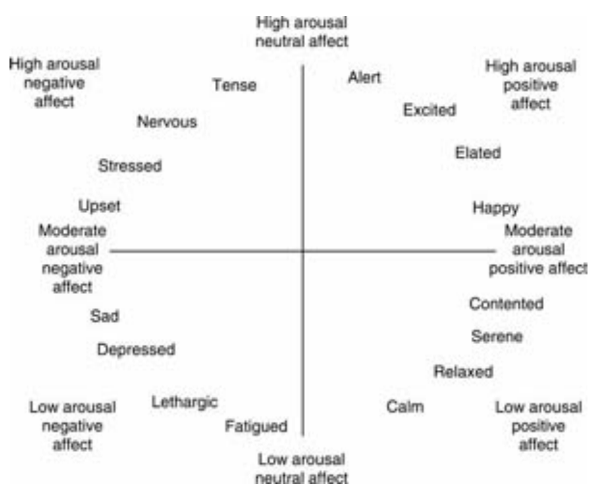



Figure 4-22. Typical arousal valence graph

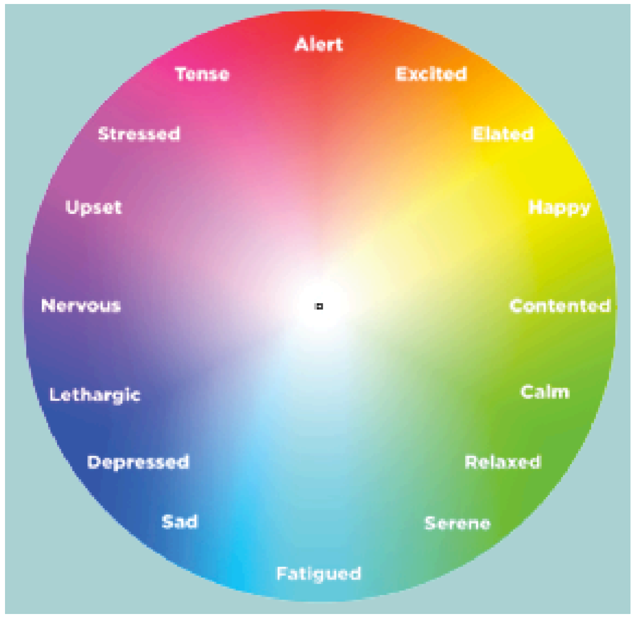



Figure 4-23. Arousal-Valence graph for emotional animation trigger

### 4.5.5 Nursery Rhyme

For some of the younger study participants who cannot hold elongated conversation due to lack of verbal skills or other reasons, the robotic/virtual Huggable incorporated the function of singing three nursery rhymes with the study participant. The child life specialist operating the Huggable can choose one or more songs from three choices: *Wheels on the bus*, *Itsy Bitsy Spider* and *I'm a little teapot*. For *Wheels on the bus* and *Itsy Bitsy Spider*, the Huggable can either perform the whole sequence of body motions for each song, or act out segmented parts of the motion one at a time. Figure 4-24 shows the simplified version of posegraph that allows separated and integrated body motion animations for the songs. The remote control for nursery rhymes was done on a separate tablet device with buttons to touch for triggering the body motions. (Figure 4-25)

| Selection | Parts of the Song |
|---|---|
| *Round x 3* | "(the wheels on the bus go) round and round, round and round, round and round" |
| *Round* | "(the wheels on the bus go) round and round (all through the town)" |
| *Baby x 3* | "(the baby on the bus goes) wah-wah-wah, wah-wah-wah, wah-wah-wah" |
| *Baby* | "(the baby on the bus goes) wah-wah-wah (all through the town)" |
| *Driver x 3* | "(the driver on the bus says) move on back, move on back, move on back" |
| *Driver* | "(the driver on the bus says) move on back (all through the town)" |
| *Horns x 3* | "(the horns on the bus go) beep-beep-beep, beep-beep-beep, beep-beep-beep" |
| *Horns* | "(the horns on the bus go) beep-beep-beep (all through the town)" |
| *Wipers x 3* | "(the wipers on the bus go) swish-swish-swish, swish-swish-swish, swish-swish-swish" |
| *Wipers* | "(the wipers on the bus go) swish-swish-swish (all through the town)" |
| *People x 3* | "(the people on the bus go) up-and-down, up-and-down, up-and-down" |
| *People* | "(the people on the bus go) up-and-down (all through the town)" |
| *Whole song* | The whole song of *Itsy Bitsy Spider* |
| *Up the spout* | "The itsy bitsy spider went up the spout" & "And the itsy bitsy spider went up the spout again" |
| *Rain and wash* | "Down came the rain and washed the spider out" |
| *Out came the sun* | "Out came the sun and dried up all the rain" |
| *I'm a little teapot* | "Here is my handle and here is my spout. When I get a little steamed up, hear me shout. Tip me over and pour me out." |

Table 4.5: List of nursery rhyme gestures

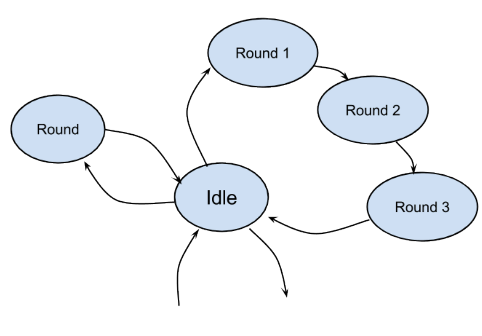



Figure 4-24. Posegraph for *Wheels on the Bus*

The example shows how one separate gesture can be played out or a sequence of multiple motions can be played by one trigger.

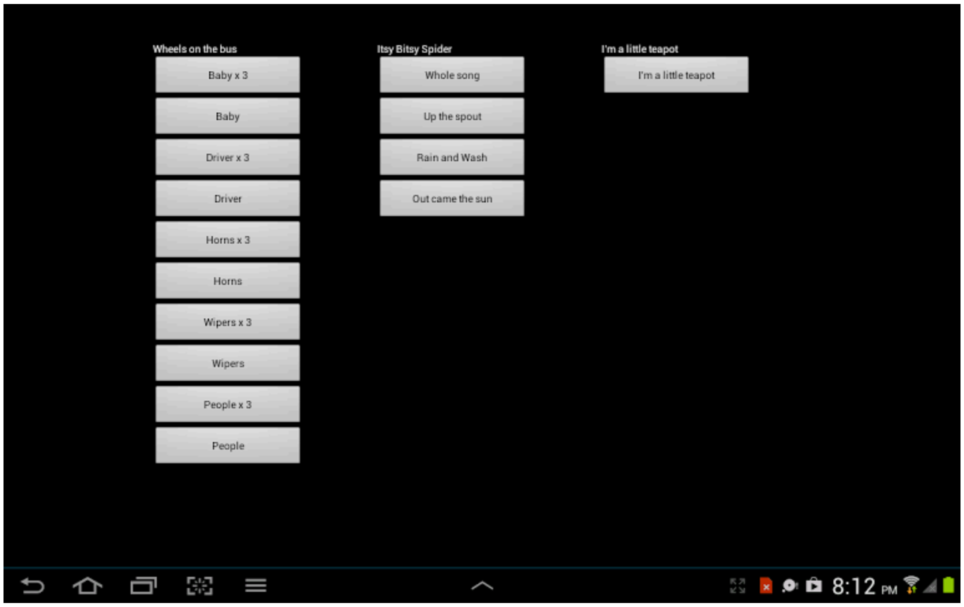


Figure 4-25. Snapshot of the Nursury Rhyme Teleop Interface

### 4.5.6 Humor

*Fart* animation is added in the list of canned animations in case there is a need for an icebreaker. Most children, especially boys, react well to humor related to public passing of gas. Thus, when the participant is hesitant about engaging in an interaction with the Huggable due to its unfamiliarity, an "accidental" farting event can potentially get the study participant to laugh and/or giggle at this new robotic agent, prompting more open and proactive attitude toward the intervention. In addition, it has been found that humor, as one form of distractor, is effective in increasing the tolerance for pain and reducing the self-reported level of pain. [47, 48] Thus, when the child is going through a painful and stressful medical treatment, the Huggable can distract him/her from concentrating on on-going procedure and perceive much less pain that it is in fact afflicted in reality.

### 4.5.7 Sound on/off

The interaction script composed for this study incorporates conversation based activities. Even though the canned animations were created for specific utterances and the appropriate gestures that would enhance expressivity for the phrase, they could be used in more generalized situation to exhibit the engagement/disengagement, likes/dislikes, etc. In addition, the pitch-shifted audio clips coupled with the movements sounded distinctive from the voice of some of the child life specialists who teleoperated the Huggable. The discontinuity of voice quality and texture could potentially break the illusion the robot's believability as a live agent, and therefore the team decided not to use the pre-recorded audio clips for the most part, except for the *Fart* animation, which clearly requires a sound effect. The speaker button on the teleoperator interface enabled or disabled the audio clips to be played out with the canned animations by clicking on it. ("on" in Figure 4-20, "off" in Figure 4-21)

### 4.5.8 Open/Closed Personality

Every canned animation has two versions: *Open* and *Closed*. In general, *Open* animations are a little louder, have bigger motion and express higher level of excitement and energy. *Closed* animations are seen as actions from rather shy character and calm personality. These two personalities were applied to the robot's behavior as a result of advice from the Child Life Specialist team. Several Child Life specialists noted that many of the child patients are very anxious and distressed due to their health condition and the foreign environment in the hospital.

A typical day for a child patient in ICU (Intensive Care Unit) involves watching many grownups, either medical staffs in gown or regular maintenance workers cleaning the unit, come and go without much social interaction with patients in the unit, and being continuously being interrupted without much advanced notice with various medical tests and procedures. The level of anxiety is especially higher for children who are new to this kind of routine, and they tend to be reserved and less willing for full engagement with a stranger. And when meeting this type of patient, Child Life Specialists start out the intervention with calmer tone, softer voice and less exaggerated gestures, preventing the patient from being overwhelmed.

Similar approach is used for the robot's behavior in order to imitate the subject's personality in the form of categorizing actions into *Open* and *Closed* types. Previously, it has been found that a robot with a matching personality to that of the user is perceived more favorable to the patients and is more effective on benefiting humans with its task. [49, 50, 51]

## 4.6 Voice Streaming and Muzzle movement

The Huggable robot streams pitched shifted voice, using the same tool that was used in DragonBot project. [38] The *Speech Box* takes a window of raw audio data from the microphone connected to Windows virtual machine and performs Fast Fourier Transform (FFT) in order to shift the pitch of the original voice of the teleoperator.

There are two reasons for not using the original voice of the teleoperator for the voice of the robot. First, the robot should have a consistent character and personality of its own. Adult female voice coming out of a small teddy bear robot breaks the synchrony and consistency of the peer companion character for the Huggable robot. The subject interacting with the robot should not doubt about the autonomy of the robot and view it as a social agent and a peer-level companion. Streaming untransformed voice of a Child Life Specialist can potentially loose this illusion when the subject recognizes the familiar voice and realizes that someone he or she is talking behind the scene. Second, the voice of the robot should align with the robot's character. The Huggable robot has a physical form of a teddy bear covered with bright sky blue color fur and bright green highlights on ears. Its body proportion is that of an infant with big head in comparison to the body size. Therefore, in order to maintain the young robotic peer character, the robot's voice should be high-pitched (for the youth factor) and a little machine-like (for robotic factor).

While the pitch shifted voice of the teleoperator is played out through the Android phone in the robot's head, Huggable's muzzle moves up and down according to the pressure level of the voice. The synchrony between the mouth and the voice is crucial in delivering utterances for social robots. [52] In idle state, the muzzle stays at its maximum location. When the operator is talking, the muzzle simultaneously moves up and down proportional to the loudness of the voice streaming through the Android phone. The *Speech Box* samples a chunk of raw audio data and averages the sound pressure levels over the whole frame. The sound pressure level for each frame is calculated as below:

$$L_{\mathrm{p}} = 10\ \log_{10}\left(\frac{p^2}{{p_{\mathrm{ref}}}^2}\right) = 20\ \log_{10}\left(\frac{p}{p_{\mathrm{ref}}}\right)\ \mathrm{dB}$$

$L_p$ represents the pressure level, $p$ is the audio signal data at the target frame and $p_{ref}$ is baseline signal. $p_{ref}$ works as a minimum value for the muzzle to start actuating because when $p = p_{ref}$, inside of the log term becomes 1, making the resulting pressure value to be zero. Because the microphone collects noise from the surrounding, it is important for the system to ensure the robot's muzzle to move only when the operator is talking. Audio data frame is expressed in 2-byte (16-bit) Little Endian form. The value for $p_{ref}$ is set to 31.62 after several empirical trials in Boston Children's Hospital. Roughly, the averaged sound pressure level information was sent for every 8192 frame window and the sample rate of the microphone used in the system was 22050 frames per second. In other words, the system sent over new pressure level every ~0.372 second (2.691 Hz). When delivered to the *Robot Controller* over wireless communication, the pressure level is transformed into the target position for the muzzle joint and the motor gets actuated accordingly. As a result, the muzzle position changes dynamically when the robot operator is talking in an energetic manner, and moves less when the operator talks calmly. When the operator is not talking anymore, the muzzle returns back to the idle position and stays still, portraying the listening behavior for the robot. As a result, the pitched shifted voice of the teleoperator accompanied with the appropriate muzzle position enhances the expressivity as a peer companion character for the human subject interacting with the robot.

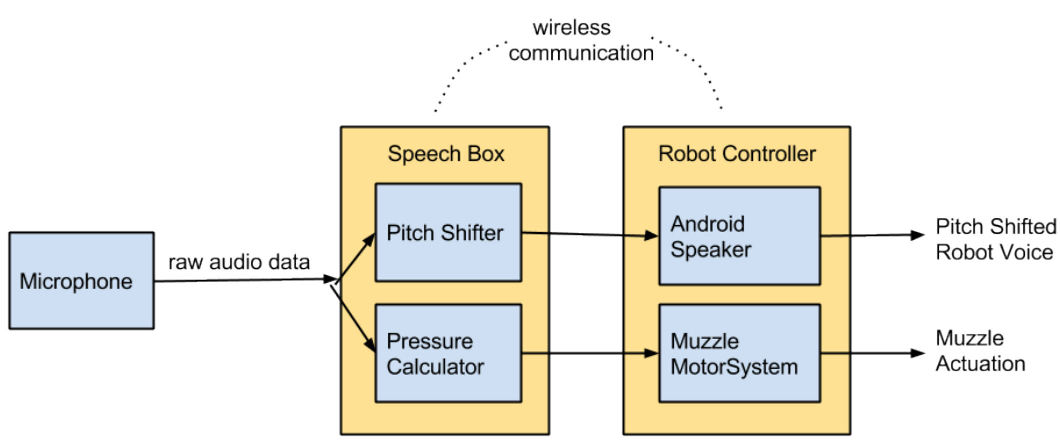



Figure 4-26. System diagram for the Voice Streaming

# Chapter 5

# Experimental Design

## 5.1 Overview

The following study was designed in collaboration with Simulation Program and Child Life Services at Boston Children's Hospital and Dr. Matthew Goodwin's team at Northeastern University, and has been IRB approved by Boston Children's Hospital. The purpose of the experiment in this thesis is to study the effect of a positive social interaction between a child patient and a robotic companion in mitigating stress and anxiety, compared to other standard interventions used in the pediatric context. Three conditions are proposed as a form of intervention in this study in order to address and assess the impact of a social robotic companion in mitigating stress and anxiety for child patients at a pediatric hospital: a plush stuffed teddy bear, the virtual Huggable agent on a tablet device, and the robotic Huggable. The subjects were recruited from Medical Surgical Intensive Care Units (MSICU) and Oncology units, and were in age between 3-10. 30 subjects were recruited for each condition and thus in total 90 patients are participating for the experiment.

The experiment has two phases. Phase 1 aims to identify the baseline of the study participant's affective state through recording video and skin conductance level via a pair of Q sensors for 24 hour period. The recorded video is synchronized with the Q sensor data, and a research associate and the child life specialists annotate the regions of peaks in the electrodermal activity. The data collected are not applied to the behavior of the Huggable robot in this experiment but will be used in the following study for training a computational model for the Huggable robot identifying affective states of the patients' and making the robot more autonomous. In Phase 2, the children are introduced with one of the three intervention methods mentioned previously and freely interact with the given intervention for 30-45 minutes. There are pre- and post-surveys that measure the levels of pain and stress for the child patient and the sessions ends with an open ended interview for feedback on future development of the robot and the experiment. Also, every patient who participated in the experiment was given a plush teddy bear afterward regardless of the study condition they were in.

## 5.2 Training Phase

In order to perform fluid interaction with appropriate reactions in timely manner, the child life specialists had weekly training sessions on controlling the robotic/virtual Huggable for two months prior to the official start date of the experiment. Two simulation specialists at Anesthesia department were trained by the author to set up the whole robot/virtual agent system along with the teleoperator interface software in order to provide technical support in emergency situation during the interaction sessions.

The training session was held once a week and typically lasted 1.5-2 hours on average. One child life specialist controlled the Huggable, whether robotic or virtual, within a mock-up interaction scenario. Two other remaining child life specialists pretended to be child patients in the unit and acted out possible response to the Huggable. A lot of focus was on the teleoperating child life specialist getting comfortable and fluent in talking through the Huggable and triggering appropriate animations at a socially and emotionally contingent time, and accurately using look-at and point-at gestures for the I spy game. After the practice session, the research associates and the child life specialists discussed possible component of the system or the interaction that could be improved. Research ideas for the Huggable in future experiments were brainstormed as well, including specific game activities, behavior patterns, other tools to incorporate, etc. When the child life specialists gained some expertise on controlling the Huggable, the team planned to run four pilot sessions with patients at the hospital who either qualified for the experiment or not in order to confirm the validity and appropriateness of the experiment protocol, and successfully ran two of the four before the submission of this thesis. For pilot testing that included video recording and Q sensor data collection, the team got consent forms from the patients' parents in advance even though those specific data were excluded from the analysis.

## 5.3 Participants

Patients with age between 3-10 in either MSICU or Oncology floor will be recruited based on the recommendations from the child life specialists. In total 90 subjects, thirty patients in each condition, will recruited for this thesis experiment. The study participants are English speaking children and it will be confirmed that the experiment would not be interfere with any medical device or wire used for the patient's medical condition. The child life members will consider the patient's personality, mood at the time, willingness to engage in an interactive play, and medical and other related conditions before recommending him/her to the research associates. Below is the flow chart of the patient recruitment process.

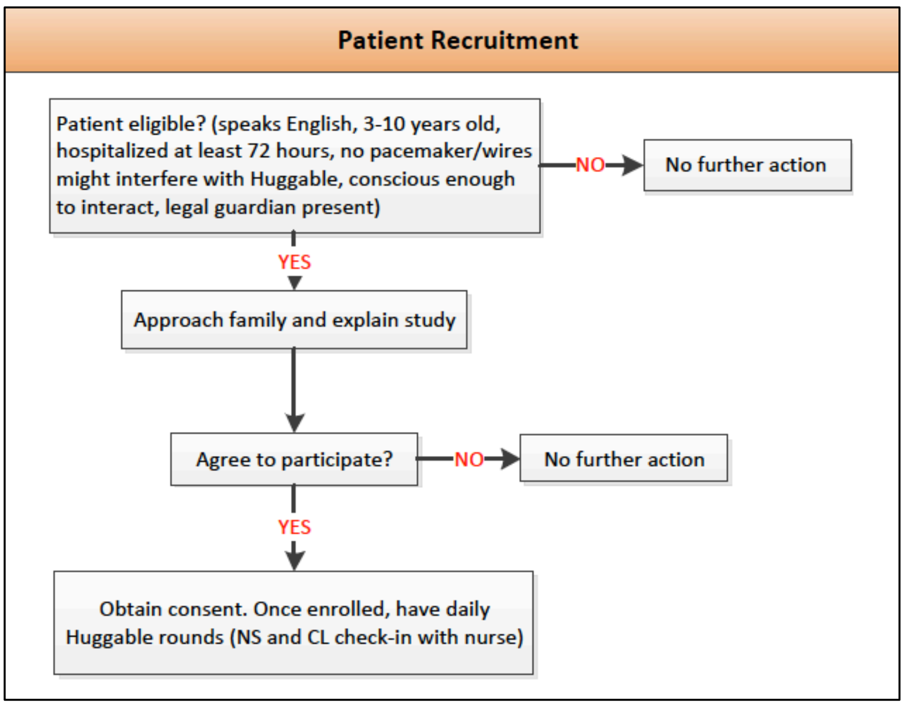



Figure 5-1. Patient recruitment flow chart

## 5.4 Phase 1: 24 Hour Observation

For Phase 1, the recruited patients will be observed for 24-hour period in their designated patient unit while engaging in normal activities with the Q-sensors on each wrist. The participants will be filmed with two USB cameras connected to a laptop without audio recording, along with two Q-sensors recording data log synchronously on a sampling rate of 32 Hz. When bathing, the participants will be instructed to remove the sensors to avoid getting the devices broken from water exposure. In order to prevent other people from being filmed during the experiment, a sign noting the video recording will be put on the door of the patient unit. The cameras will be angled to direct the patient's bed tightly so that only the patient and his/her interaction with the toy s/he is given to play with were captured. When a non-consented person is accidently recorded during either Phase 1 or Phase 2, the research coordinator will ask to sign a consent document for academic usage of the data. If the individual refused, the related portion of the video will be deleted.

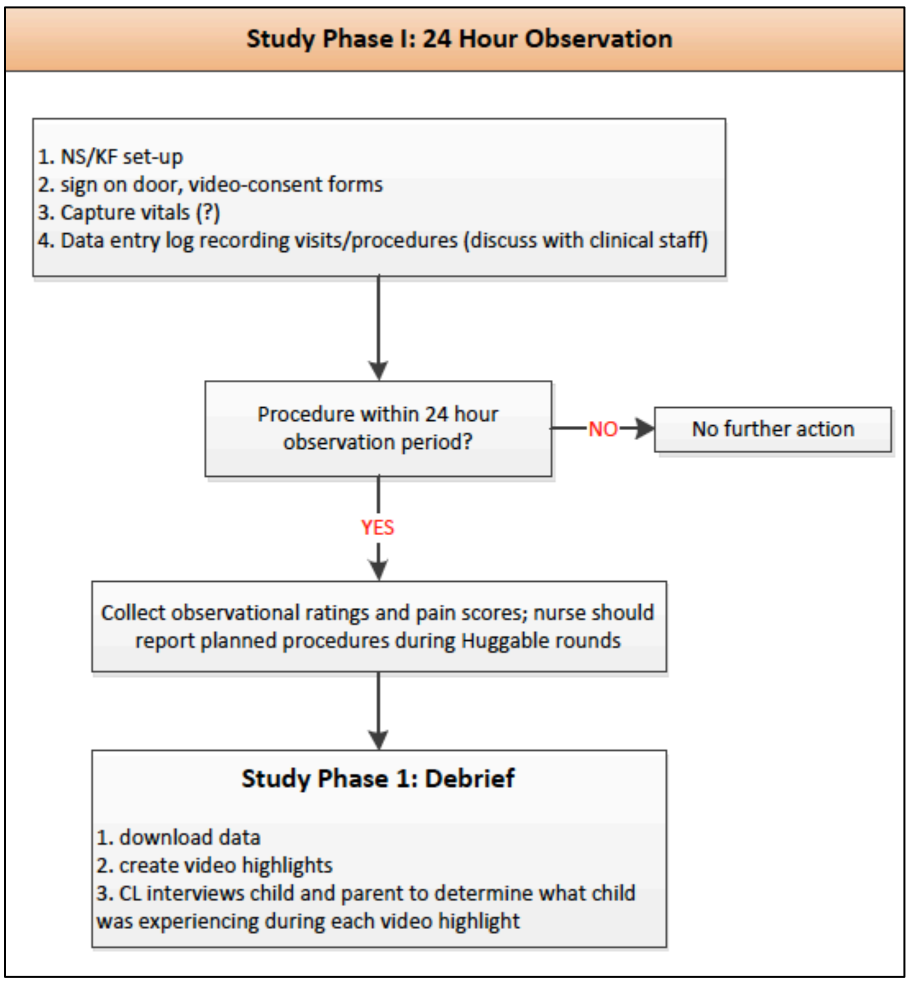



Figure 5-2. Study Phase I flow chart

## 5.5 Phase 2: Intervention Interaction

During the 1-hour intervention period, a member of Child Life specialists who is already familiar with the study participant went into the unit and introduced one of the three interventions (plush teddy bear, virtual Huggable or robotic Huggable) to the child. The child will be given an orientation on proper usage of each appropriate intervention, and will be explained that the intervention could be removed if he/she wished. If parents or other family members are also present in the unit, the research coordinator will ask them to supervise the child's play to help enforce appropriate use of the object.

For the plush teddy bear condition, children will be asked to can play with the toy as they choose. For the virtual and robotic Huggable conditions, one remote child-life staff member will be located outside of the patient unit, either in the hallway or in nearby empty room, and teleoperated the Huggable according to the interaction script, which includes storytelling, singing songs, and playing games. Another member of child life services will stay by the study participant to accommodate a safe and appropriate usage of the intervention given to the child.

The virtual Huggable appeared on the Samsung Galaxy Tab 2.0 10 inch and was set up vertically on the bedside table for the patient to be able to interact with. The robotic Huggable was also put on the bedside table. The children were instructed that they could gently touch the robot if they'd like but not to move it from its sitting position for safety reason.

| **Condition** | **Intervention Type** | **Physical** | **Social** | **Emotional** |
|---|---|---|---|---|
| I | Plush teddy bear | O | | O |
| II | Virtual Huggable on Android Tablet | | O | O |
| III | Huggable robot | O | O | O |

Table 5.1: Three experimental conditions in comparison

An interaction script (Figure 5-4) was created by the child life service team as a rough guideline. First, the Huggable introduces itself to the child by asking questions about the child's name and age, and the child's opinion on the robot's age. Once the child becomes more familiar with the Huggable and how to converse with it, the robotic/virtual Huggable holds a small talk with the patient about favorite colors, animals and activities, things the child likes or dislikes about being in the hospital, etc. Then, the Huggable and child delves into more interactive activities appropriate for the child's age and developmental status. For younger children, the Huggable engages the participant with age appropriate song singing activities or a simple I Spy game. The digression from the given interaction trajectories is allowed when the child wants to be engaged in an activity that was out of scope from the pre-determined script and the child life specialist deems appropriate.

At the end of the 1-hour period, the child life specialist retrieves the intervention the child plays with. The pre-test, intervention interaction and post-test are all video and audio recorded from two angles, and the Q sensor data logs are recorded. If available, other biometric data, such as heart rate, respiratory rate and blood pressure, from monitoring devices are gathered as well from the Boston Children's Hospital server.

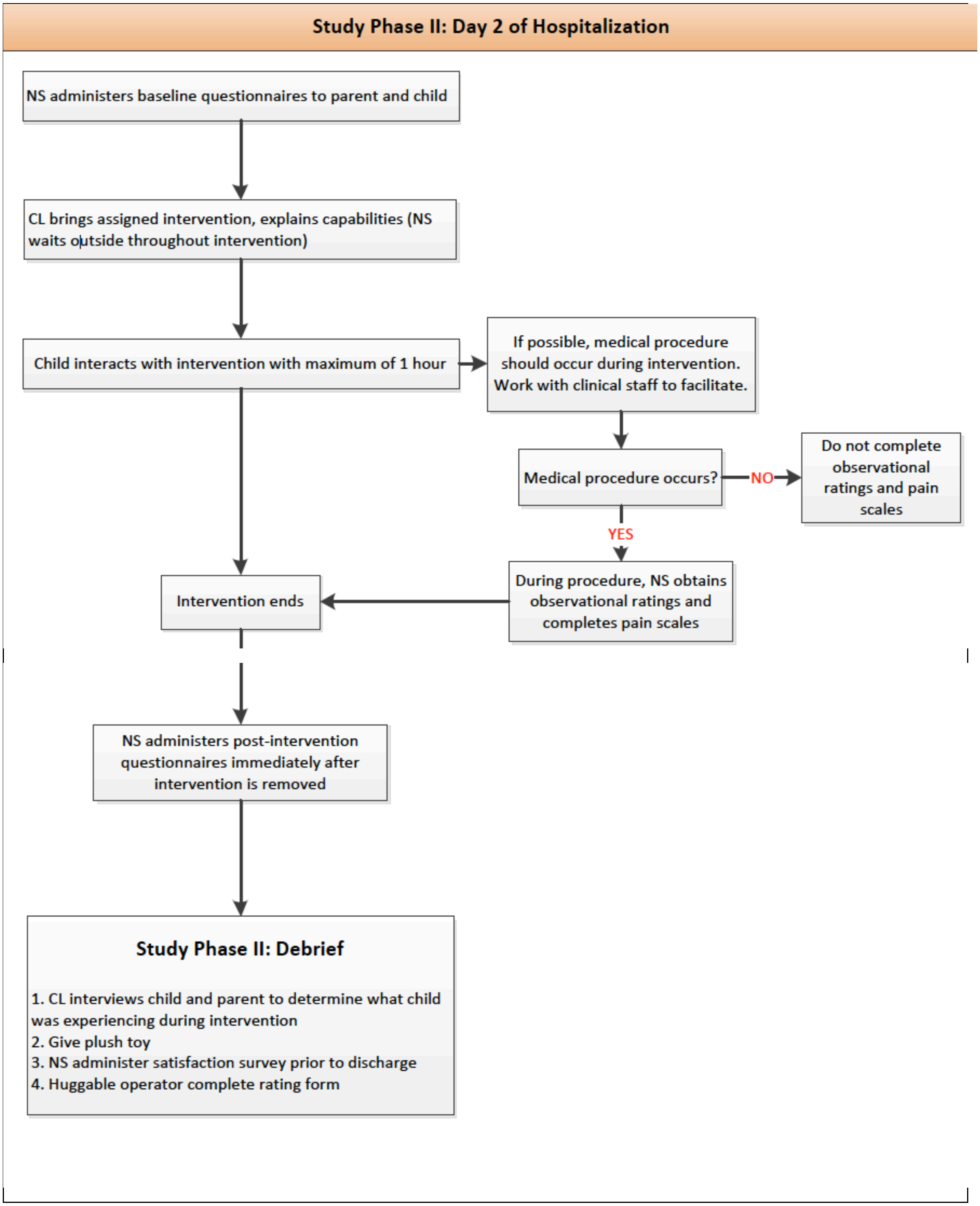



Figure 5-3. Study Phase II flow chart

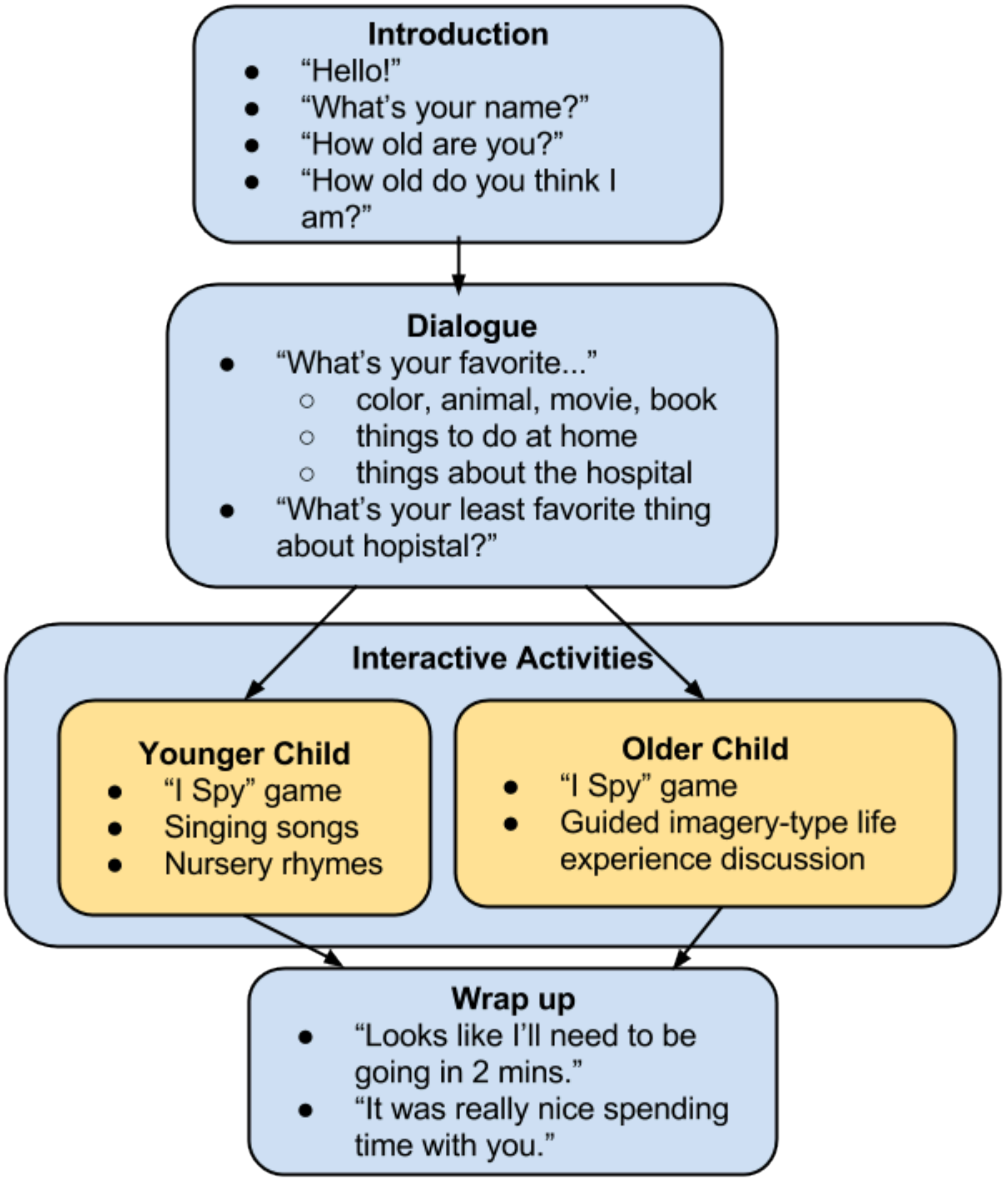



Figure 5-4. Flow chart of interaction script

## 5.6 Video Footage Annotation

The video recordings and synchronized Q sensor data from Phase 1 and Phase 2 will be analyzed in order to determine the level of stress and anxiety of the patient and the cause for them. The recording and annotation procedures follow as described in the works of Hedman et al. and Madsen et al. (i.e. video EEG monitoring). [44, 45]

In the 24-hour observation footage and interaction video, peaks in the Q-sensor data will be used to filter out the highly aroused moment for the child patient and the segments of the video footage during the peak moments will be highlighted for annotation. The tablet logs of medical visits will be supplied for additional information in analyzing the cause the high arousal level. After the highlighting process is finished, the video sections will be reviewed and annotated by a member of child life specialists for the child's emotional and affective state. If necessary, suitable highlights will be reviewed with the patient/parent by a Child Life study team member on a laptop computer for clarification on uncertainties.

The interactions between the child and the intervention in one of the three experimental conditions will be video recorded as well. For the interaction footage, a research associate annotated general behaviors of the study participants using NOLDUS software framework. Both verbal and non-verbal behaviors of the child, his/her parent(s), and the Huggable expressing emotional and affective meaning will be coded in the system, such as the child's facial expression, gestures and gaze upon introduction of the intervention and during the interaction, the virtual/robotic Huggable's non-verbal cues for social and emotional support and communication, family member's behavior during the visit, etc. In addition, the research associate and child life specialists will log general comments about the session for future improvements. The collected video recordings will be securely stored at Boston Children's Hospital.

## 5.7 Evaluation Methods

### 5.7.1 Pain, Distress and Anxiety Measure for Children and Parents

A set of surveys measuring levels of pain, mood and anxiety will be applied pre- and post-interaction session for study participants and their parents in order to quantify the effects of three intervention methods. The administered tests slightly differ depending on the age of the subject, and when a previously scheduled or unexpected medical procedure happens during the interaction phase, the research associate will code the child's behavior of distress and anxiety during the operation.

Children with age 3-5 and their parents will complete the Facial Affective Scale (FAS) [55] to measure the child's and parents' affective state before and after the 1-hour intervention session, and also Faces Pain Rating Scale-Revised [56] will be used for children in this age group to rate the intensity of pain before and after the intervention. Children who are 6-10 years old completed will be asked to self-report on their affective and anxiety level pre- and post-interaction phase. Positive and Negative Affect Scales for Children will be used for measuring the child's emotional state and STAIC [57] will measure the level of anxiety and stress. Also, the children will be asked to rate the current intensity of pain on a Numeric Rating Scale [58] on the scale of 0 to 10. The research associate will read all of the questions aloud to children who preferred or required it. Also, if any medical procedure occurs during the intervention for a routine check up or some other medical needs, the research associate completed the Observational Scale of Behavioral Distress [59] for the first procedure that happens within the interaction phase.

Parents of the study participants will be asked to fill out the pre- and post-questionnaires as well in order to evaluate whether not only the patients but also the parents can be supported emotionally and/or socially through these different types of interventions. If available, the parents will be asked to report the levels of their own anxiety using the State Trait Anxiety Inventory [60] before and after the intervention phase.

Same sets of questionnaires related to reporting levels of affective state, anxiety and pain, will be asked for children and their parents for pre- and post- interaction phase in order to compare the effect of each intervention method on the mental states of the child and his/her parents. In addition, the parent and child were asked to complete the Pediatric Hematology/Oncology Parent Satisfaction Survey [61] and a standard BCH satisfaction survey before finishing the study participation. All of the questionnaires had been validated with its quality in the related field and are currently widely used in numerous hospitals and research centers for quantitatively measuring the level of emotional states.

Lastly, a research associate will asked much more open-ended questions as part of post-session interview after the formal survey questions, receiving feedback on child's judgment on overall engagement and perception on the intervention method for each condition. Some questions would include getting more informal information on typical methods or habits patients use to cope with anxiety and stress. Also, the research associate will ask for suggestions on potential activities or games Huggable can play with children in the hospital and any possible improvements in the robot.

### 5.7.2 Usability Measure for Huggable Teleoperators

The Child Life specialist who teleoperate the virtual/robotic Huggable will be asked to fill out a SUMI usability survey [62], Networked Minds Social Presence Scale [63] and NASA-TLX [64]. These surveys assess the cognitive load of remotely controlling the Huggable, the usability of the teleoperator interface and the level of social presence during the remote operation of the Huggable. [63] These tests will be administered after the first and the last experiment sessions with the virtual and robotic Huggable.

### 5.7.3 Survey Summary

Below is the table showing the list of pre- and post-tests done for the study and summaries of each evaluation tool.

| | **Pre-questionnaires** | **Post-questionnaires** |
|---|---|---|
| **Parents** | Facial Affective Scale<br>STAI | Facial Affective Scale<br>STAI<br>Par.SS |
| **Child** | | |
| Ages 3-5 | Facial Affective Scale<br>Faces Pain Scale-Revised* | Facial Affective Scale<br>Faces Pain Scale-Revised*<br>BCH Satisfaction Survey<br>Drawing with paper and crayon<br>Interview |
| Ages 6 | Positive and Negative Affect Scales for Children<br>Numeric Rating Scale for pain* | Positive and Negative Affect Scales for Children<br>Numeric Rating Scale for pain*<br>BCH Satisfaction survey<br>Drawing with paper and crayon<br>Interview |
| Ages 7-10 | Positive and Negative Affect Scales for Children<br>Numeric Rating Scale for pain* | Positive and Negative Affect Scales for Children<br>Numeric Rating Scale for pain*<br>STAIC – State (C-1) only (20 questions) |

| | | |
|---|---|---|
| | State-Trait Anxiety Inventory for Children (STAIC) | BCH Satisfaction survey<br>Drawing with paper and crayon<br>Interview |
| **Child Life Specialists** | | Networked Minds Social Presence Scale<br>SUMI Usability Scale |

Table 5.2: Summary of pre- and post-questionnaires. The asterisk marked surveys are applied only when a medical procedure happens during the Phase 2 session.

**(1) Face Affective Scale**

The Facial Affective Scale consists of nine faces that vary in the level of overt distress expressed. [55] The child is asked to choose a face that looks like how he/she feels, making sure that he/she is supposed to select the image that does not visually look like her at the moment but what the child really feels internally. The chosen face is transformed into a numerical value of scale 0-1.

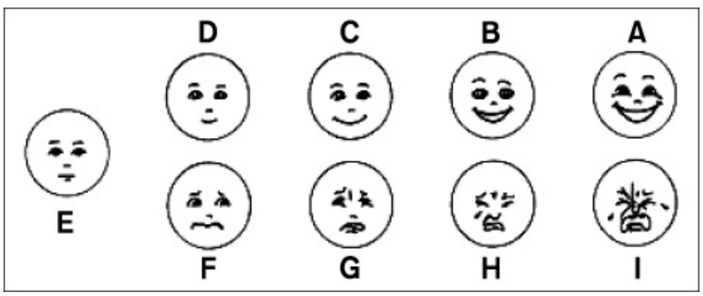



Figure 5-5. Nine faces for Facial Affective Scales

**(2) Positive and Negative Affective Affect Scales for Children**

Positive and Negative Affect Scales for Children [65] is a 30-item self-report measure of affect for children. Children are asked to rate on a scale of 1-5 to indicate how much they feel on the given emotion words, with a score of 1 meaning "very slightly or not at all" and a score of 5 meaning "extremely." These measurements were found to be appropriate for school-age children [65], and were used for patients of age 6-10 in this study. As has been done in previous studies, the children were asked to rate how they felt at the moment when completing the measure at each time point.

| Feeling or emotion | Very slightly or not at all | A little | Moderately | Quite a bit | Extremely |
|---|---|---|---|---|---|
| Interested | 1 | 2 | 3 | 4 | 5 |
| Sad | 1 | 2 | 3 | 4 | 5 |
| Frightened | 1 | 2 | 3 | 4 | 5 |
| Alert | 1 | 2 | 3 | 4 | 5 |
| Excited | 1 | 2 | 3 | 4 | 5 |
| Ashamed | 1 | 2 | 3 | 4 | 5 |
| Upset | 1 | 2 | 3 | 4 | 5 |
| Happy | 1 | 2 | 3 | 4 | 5 |
| Strong | 1 | 2 | 3 | 4 | 5 |
| Nervous | 1 | 2 | 3 | 4 | 5 |
| Guilty | 1 | 2 | 3 | 4 | 5 |
| Energetic | 1 | 2 | 3 | 4 | 5 |
| Scared | 1 | 2 | 3 | 4 | 5 |
| Calm | 1 | 2 | 3 | 4 | 5 |
| Miserable | 1 | 2 | 3 | 4 | 5 |
| Jittery | 1 | 2 | 3 | 4 | 5 |
| Cheerful | 1 | 2 | 3 | 4 | 5 |
| Active | 1 | 2 | 3 | 4 | 5 |
| Proud | 1 | 2 | 3 | 4 | 5 |
| Afraid | 1 | 2 | 3 | 4 | 5 |
| Joyful | 1 | 2 | 3 | 4 | 5 |
| Lonely | 1 | 2 | 3 | 4 | 5 |
| Mad | 1 | 2 | 3 | 4 | 5 |
| Fearless | 1 | 2 | 3 | 4 | 5 |
| Disgusted | 1 | 2 | 3 | 4 | 5 |
| Delighted | 1 | 2 | 3 | 4 | 5 |
| Blue | 1 | 2 | 3 | 4 | 5 |
| Daring | 1 | 2 | 3 | 4 | 5 |
| Gloomy | 1 | 2 | 3 | 4 | 5 |
| Lively | 1 | 2 | 3 | 4 | 5 |

Figure 5-6. Positive and Negative Affect Scales for Children Survey

**(3) State-Trait Anxiety Inventory (STAI) & State-Trait Inventory for Children (STAIC)**

The State-Trait Anxiety Inventory (STAI) consists of 40 self-report based questions on a 4-point Likert scale, and is the most widely used self-report measure of anxiety for adolescents and adults. [60] In this study, STAI was applied to the patient's parents before and after the intervention. Originally, the STAIC was developed in order to study anxiety in elementary school children. Thus, it applied to study participants with age 7-10. Both STAI and STAC categorize the proneness to anxious behavior to either innate personality (trait anxiety, or T-anxiety) or temporal emotional state (state anxiety, or S-anxiety). For the purposes of the present study, only the state anxiety scales were administered because the present experience of anxiety for the child patient and his/her parents before and after the intervention was the interesting component of the experiment, rather than general proneness to anxiety due to individual's intrinsic tendency.

The STAIC is designed for upper elementary and school aged children and consists of two twenty-item scales. The measure was originally validated on children ages 8 and up but has been used in past published studies with children aged 6 and 7. [49, 50, 51, 52] In this study, the research assistant orally administered the questionnaire to children with age between 6 and 7.

**(4) Observational Scale of Behavioral Distress (OSBD)**

Observational Scale of Behavioral Distress [59] is a well-established tool for gauging behavioral distress responses to medical procedures. A study research assistant trained by the study psychologist rated the presence/absence of 8 behavioral and verbal indicators of child distress immediately before, during, and immediately after the medical procedure. The OSBD was obtained for all enrolled experiment participants who underwent a medical procedure after initiating the Huggable intervention. If more than one procedure happened on this patient, the OSBD was completed only during the first procedure.

**(5) Software Usability Measurement Inventory (SUMI)**

The Software Usability Measurement Inventory (SUMI) measures software quality from the end user's point of view. It consists of 50 statements to which the users reply that they either “Agree,” “Don't Know,” or “Disagree.” The test was applied to the child life specialists who teleoperate the Huggable robot or the virtual Huggable agent on the tablet condition in order to assess the usage quality of the teleoperator interface, and to detect any potential usability flaws that need to be improved in the next version. The inventory itself is backed by an extensive reference database embedded in an effective analysis and report generation tool.

**(6) Networked Minds Social Presence Scale**

Networked Minds Social Presence Scale, developed by Biocca, Harms and Gregg to measure social presence, measures the quality of social presence, “the sense of being there.” [70] It is composed of twenty survey questions, each is answered through 1-7 Likert scale from 1 indicating “strongly disagree” to 7 indicating “strongly agree.” The survey questions evaluate the self-report level of co-presence, psychological involvement and behavioral engagement of the teleoperator in the robot or virtual agent interaction. The answers from the survey can indicate the quality of telepresence, the phenomenal sense of “being there” in the virtual environment, and social presence, the sense of “being together with another.”

**(7) Pediatric Hematology/Oncology Parent Satisfaction Survey (Par.SS)**

The Pediatric Hematology/Oncology Parent Satisfaction Survey (Par.SS) was developed at Division of Hematology/Oncology at Children's Hospital and Health Center, San Diego, and contains 25 questions encompassing six areas of domain on 5 point Likert scale, with 1 indicating very dissatisfied to 5 indicating very satisfied. The six domains are general satisfaction with treatment given to the patient and with helpfulness of staffs, provision of staff information about diagnosis, treatment, and side effects to patients and families, sensitivity and responsiveness to family concerns, efforts made by staff to take the time to explain, listen, and prepare children and families for tests and procedures, staff's ability to meet the child's needs in a timely and thoughtful manner and the staff's effort to take the time to address the emotional needs of the child and parent.

# Chapter 6

# Hypotheses and Anecdotes from Practice Sessions

## 6.1 Hypotheses

The robotic Huggable with physical presence and socio-emotional qualities is expected to have bigger impact on reducing stress, anxiety and self-perceived pain for study participants than the influences of virtual Huggable or plush teddy bear intervention methods. From the post-interview, it is expected that children in the robot condition will show higher willingness to engage with the intervention and sense of likeness than the other two conditions. For teleoperators, it is hypothesized that child life specialists would initially feel detached from the events happening in the patient bed space but in time will feel more comfortable and mentally and socially connected with the study participant as the virtual or robotic Huggable. Similarly, the Q-sensor data are anticipated to show lower peaks related negative valence emotion and more frequent and higher peaks with positive valence emotion for the robotic Huggable condition than the other two. Furthermore, the interaction time on average might be longer if the child is assigned with a robot than a virtual agent or a plush teddy bear.

## 6.2 Insights from Training Sessions and Pilot Studies

For the past several months, more than fifteen practice sessions were held at Boston Children's Hospital, of which two included actual patients and one with a health child. Even during the sessions that did not involve any study participants, many people who are unaffiliated with the project were invited to interact with the Huggable and were asked to comment about the believability and the impression of the robot. As mentioned earlier, the last two pilot tests were done on patients with the robotic Huggable condition. One patient was recruited from MSICU floor and the other was a patient from the Oncology floor. The patients involved in the pilot study were ages of twelve and fifteen, which are older than the target subjects illustrated in the experimental design. The choice of running first two pilot sessions on older children was intentional because the team wanted to get more informative verbal feedback on the interaction from the patients.

Most hospital employees, who got to meet the Huggable robot, were greatly entertained by the Fart animation. Many burst out laughter and reported that they felt a bit awkward talking to a teddy bear robot as an adult but the farting behavior broke the ice and got them open up afterward. Also, activities that requires physically touching and cooperating with the robot seemed to be enhancing the emotional connection with the robot. Adults who volunteered to participate in the practice session seemed to be greatly entertained when doing high fives or fist bumps with the robot, and when they failed to get the right timing, requested the robot to try again until they succeeded as if they would do with other people in real life. The pilot session with a healthy child also supported the importance of physical contact initiated by the human and a socially contingent behavior of the robot right after it. The child tickled the robot's belly during the interaction and laughed when the Huggable said "that tickles!" and giggled.

The first trial run only included Phase 2 session with the Huggable robot without installing Q-sensors on the patient. The patient knew that the robot was remotely controlled and the interaction lasted for about thirty minutes. After the experience, the patient reported that she could easily imagine a six year-old enjoying playing with the robot, and thought Huggable was very cute. Likewise, the second patient named a specific patient who would benefit from playing with the Huggable robot.

## 6.3 Pilot Interaction Analysis

An analysis on interaction footage with a healthy 4 year-old child shows the potential of the Huggable robot system. The subject for the pilot interaction was a daughter of the author's colleague at MIT Media Lab, and the parents consented video filming the interaction session for research purposes. The child is a native Hebrew speaker who grew up in Israel and moved to the United States three months before to the interaction took place. After the move to the U.S., she was enrolled in a full time English speaking preschool and had little exposure to English as a spoken language previously. She could answer to short yes/no questions and express herself with simple 2-3 word sentences from time to time with the assistance of her mother. During the interaction, her mother often translated what the robot had said into Hebrew, and mediated the interaction by either prompting her to talk about her experience in more details or modeling what she wanted to say in English. The child had two major memories about hospital experiences prior to the interaction with the Huggable robot. The first one was an ear operation she had in Israel four months prior and the other was a blood draw that took at a local pediatric office in Cambridge area two weeks prior. The robot was teleoperated by the author of the thesis, not a child life specialist, and the interaction was held in the simulation suite room on the MSICU floor at Boston Children's Hospital for about fourteen minutes.

The mother of the child reported before the interaction that the child was still fearful of going to the hospital from the blood draw procedure that happened, and it was apparent through the child's behavior. It took almost four minutes for the mother and the research associate to have the child just sit on a patient bed. The research associate had to show her that there was nothing special or harmful on the bed by sitting on it herself, (Figure 6-1) and in the end the mother had to sit right next to her on the bed to maintain the interaction. Below is the transcription of the mother's utterances when she was trying to get her daughter to sit on the patient bed to start the robot interaction.

> *(in Hebrew) Do you mind sitting on the bed? It's just Sooyeon set up the camera so that they will see you here. ... Do you want me to show you? (sitting on the bed) I'm just showing you. Do you see the camera here? Do you see? (to the research associate in English) Can you sit on the bed so she'll see you on the bed? (in Hebrew) Do you see? We're just seeing her on the camera. I will also be with you. You'll sit on the bed with me. Do you want to sit on the chair? .... If you really want to, you can sit on the chair. But I think it'd be fun for you to sit on the bed. You can stay with your shoes. We're not lying on the bed. We're sitting on it. We're not doing anything. There's no doctor that's coming here. .... Maybe we can tell him [Huggable] that we once were on bed where we did the operation. We'll just tell him, alright? You can sit with me and on me all the time. Ok? ... (sitting down on the bed with the child) on me, on me, on me.*

It was evident that the child was very concerned about sitting on the patient bed and the unfamiliar hospital environment due to her past memories of hospital visits. She was told beforehand that she was only coming into the hospital to talk to a friendly teddy bear robot and no doctor was going to visit her. However, she was still very concerned and anxious, and had trouble following directions from her mother and the research associate initially.

Figure 6-1. A research associate showing the child
that the bed is safe by sitting on it herself.

Once the interaction finally began, the child slowly started to get more relaxed. During the first half of the session, the child refused to talk directly to the Huggable robot and asked her mother to talk to it instead, or acted passively in the interaction, only answering to yes or no questions. However, over time the child started becoming more engaged in the interaction, talking in louder voice, leaning toward the robot and conversing in longer sentences to express her thoughts. More details on the analysis of verbal and nonverbal behaviors of the child and the caregiver are provided in the sections below, and full transcription of the interaction is attached at the end of the thesis. (Appendix A)

### 6.3.1 The Child's Language

Despite the limitation in the child's verbal skill in English, it was shown that the child grew more willing to communicate with the robot over time as she became more comfortable and relaxed. When first introduced, the child refused to converse directly with the Huggable at all, but instead referred to her mother to deliver the message to the robot for her.

**H:** I see. What did you do at the hospital?
**M:** *(in Hebrew)* What did you do at the hospital? Tell him ear operation.
**C:** *(in Hebrew)* You [tell him].
**M:** *(in Hebrew)* do you want to tell him?
**C:** *(in Hebrew)* No. You.
**M:** *(in Hebrew)* try to tell him. He wants to talk to you.
**C:** *(in Hebew)* No. You.

However, the number and the frequency of child's utterances to the robot increased noticeably throughout the session. During the first half of the session, the child made eight utterances in total; two utterances were two words long and the rest of them were in one word answer as either in "yes" or "no" form. The prompts given by the Huggable were mostly about rather negative memories about the hospital. It asked questions such as whether the child had ever been to a hospital in the past and what she did during the visit. When told by the caregiver about the ear operation, the robot asks the child how she felt during the medical procedure.

In the second half of the session, the robot engaged in topics of more positive experiences and complimenting statements. Most of the conversation was about rewards given after medical procedures and how brave the child to go through such operations. During this section of the interaction, the child made thirteen utterances in total, of which six of them were one word long, one of them two-word sentence, and six three-word sentences.

| Length of utterance | First Half Session | Second Half Session |
|---|---|---|
| **1-word** | 6 | 6 |
| **2-word** | 2 | 1 |
| **3-word** | 0 | 6 |
| **Total** | 8 | 13 |
| **Average** | 1.25 (±0.46) | 2 (±1.0) |

Table 6.1: Comparison on the numbers and frequencies of child's utterances between the first and the second half of the interaction

## 6.3.2 The Caregiver's Language

As noted in section 6.2.1, the mother took a role of a messenger express what the child wanted to communicate to the robot in the earlier part of the interaction. She would often translate what the robot said into Hebrew and prompting her child by giving examples or details of what to say in response to the Huggable.

**M:** *(in Hebrew)* What did you do at the hospital? Tell him ear operation.

…

**M:** *(in Hebrew)* He got one sticker. Tell him you got **THREE** stickers.

In this process, it was shown that the mother often used the pronoun "we" as a subject of a sentence to describe what the child had experienced in the past. For example, the mother said "we had an ear operation" and "we had a blood test," even though only the child received those mentioned two procedures at different hospitals. When these utterances were made, the child was refusing to talk directly to the robot, and the mother seemed to be sharing her voice with the child's when conversing to the Huggable. While talking in Hebrew to each other, the mother still addressed the child as a separate entity and used "you" when giving a direction or asking a question, instead of "we". It seemed as if the sharing identity was happening only when the utterance was addressed to the robot.

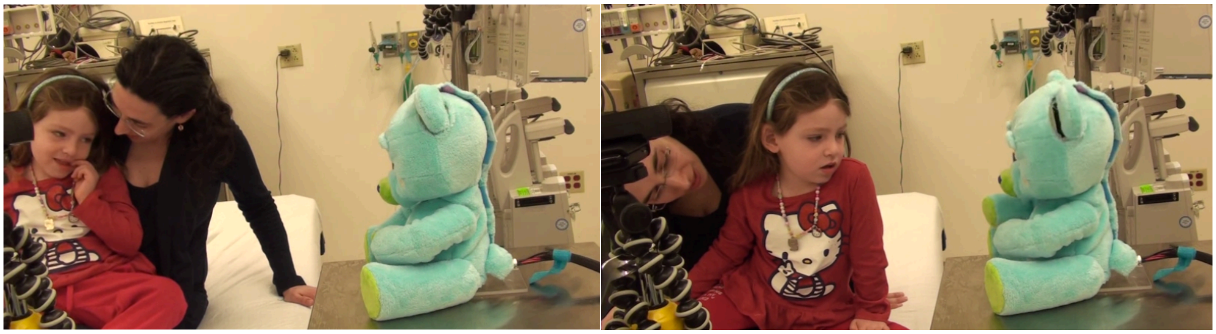
**M:** *(in Hebrew)* try to tell him. He wants to talk to you.
**C:** *(in Hebew)* No. You.
**M:** Ok. She says mommy will tell it. So **<u>we</u>** had an ear operation. Can you show him where?
…
**M:** *(in Hebrew)* did you ever do a blood test? *(in English)* Did we have a blood test?
**C:** Yeah.
**M:** Yeah, **<u>we</u>** had a blood test. And what did **<u>we</u>** get after that?

Later on, the mother broke off her own identity and voice from those of the child, and started referring her daughter separately from "we" as the child became more competent in conversing with the Huggable on her own. She used "she" or used her daughter's name to address the child's actions or feelings. The contents and intentions of her utterances toward the robot still remained similar, expanding or providing more details on the topic of what is being said.

**M:** Yeah, the blood test. **<u>She</u>** was scared.
…
**M:** Yeah, **<u>she</u>** was brave. Very brave. Where did they get the blood?
…
**M:** **<u>Noga</u>** wants to touch Huggable

### 6.3.3 Non-verbal Behaviors of the Child

The child visually looked very nervous and uneasy in the beginning. Her body barely touched the bed and she was sitting on her mother's lap while leaning away from the robot. However, gradually she started putting herself closer to the robot as the conversation continued and finally was able to voluntarily sit at the edge of the bed on her own.



(a) (b)

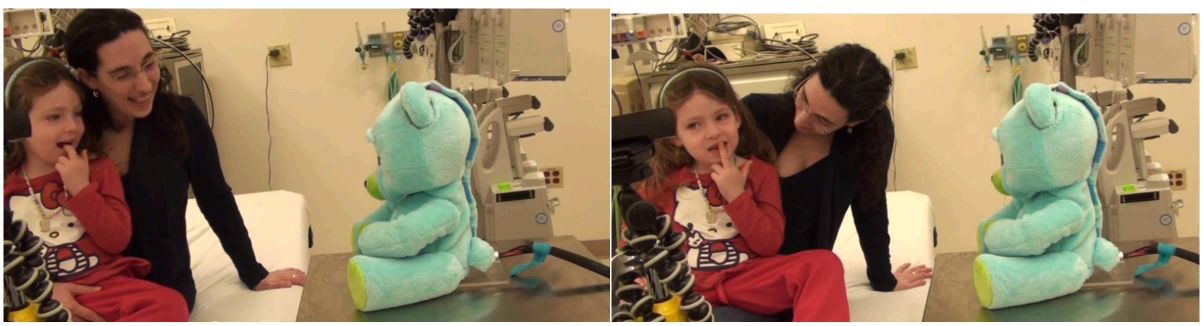
Figure 6-2. Change in the child's posture and distance from the Huggable robot.
(a) Initially, the child sits far from the Huggable and leans backward. She bites her finger and does not gaze straight at the robot. (b) Later on, she leans toward the robot and directly gazes at the robot's arm, which is the topic of conversation at the moment.

The loudness of her voice changed over the session as well. The child's voice was very soft initially during the session, which made it hard for the teleoperator to hear her utterances, and thus the mother had to remind her to speak up several times at the beginning.

**C:** *(softly)* Noga…
**M:** Say louder. *(in Hebrew)* Say louder, he didn't hear you.
…
**H:** I live in the hospital and play with children like you. Have you been to a hospital before?
**C:** *(smiling)* Yes.
**M:** Speak louder. Ok? Because he doesn't hear you.

However, over the course of time, the child seemed more confident in expressing herself and did not need any reminder or assistance from her caregiver to speak up after the first half of interaction.

The child was not wearing any Q-sensor device in this pilot session so we could not formally measure local peaks of the arousal level. However, her nervousness was shown through her habit of putting fingers in the mouth or placing them around the lips from time to time throughout the session. When asked to talk about previous medical procedures she had and how she felt during them, the child put her finger(s) in her mouth almost instantaneously as if the questions brought back the negative feelings from the experience at other hospitals. She also seemed nervous and started biting her finger when she was asked by her mother to speak louder for the robot or was told to say words or phrases she did not know in English. The times she put down her hand either on her lap or on the bed were when the topic of the conversation was about stickers or balloons she got after the procedures and when the Huggable robot commented that she was very brave. Interestingly, she was able to put down the hand when she was answering "no" to the robot's question whether she was scared during the ear operation even though the she put her hand around the mouth right after when her mother started talking about the operation.



(a) (b)

Figure 6-3. Pictures of the child with her finger around her mouth. (a) The child and the mother just sat on the bed and the robot is introducing itself. (b) The mother translated the robot's question "what did you do at the hospital?" and told the child to talk about her ear operation.

The child was asked by the mother to gently touch the robot twice. The first time was at the beginning of the interaction right after they sat on the bed together, and the other time was at the end of the session when the robot shared about its experience of getting a blood test on its right arm. When asked the first time, the child did not obliged to her mother's request but she was much willing to make a physical contact with the robot at the second time she was asked. She seemed as if she was empathetic to what the robot said at that moment, touching the arm it claimed to have gotten the blood draw from. In addition, the child showed a mirroring behavior, smiling when the robot giggled, when she was touching the robot again the second time with the intention of tickling it. When asked at the end of the session what she liked the most about the

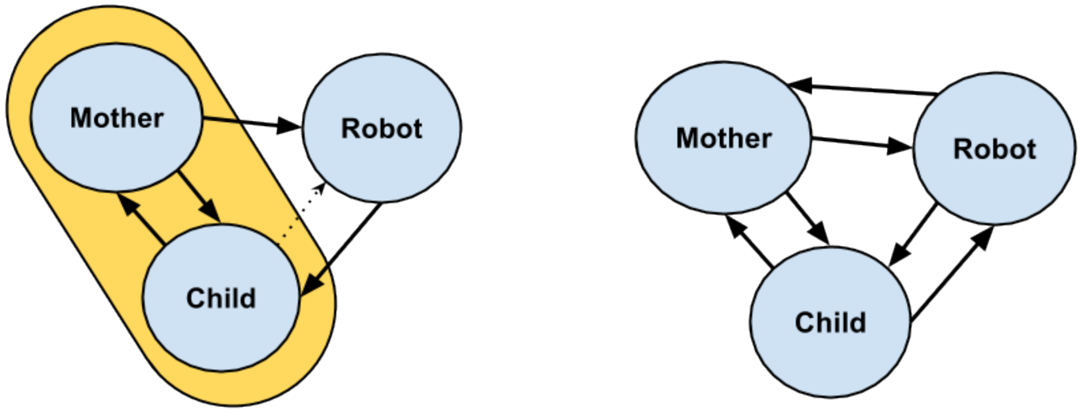
Huggable, the child answered that she liked touching the robot and thought it was funny when it got ticklish.

Figure 6-4. The child tickled the robot, which made it giggle and say “it tickles!”

### 6.3.4 The Triad of Child-Parent-Robot Dynamics

The relation among the child, the mother and the robot changed over times as the child grew more relaxed in the environment and about communicating with the Huggable. As discussed in the previous session, the child was more reluctant to communicate directly to the robot and therefore her mother had to convey the message she wanted to deliver instead. In the caregiver’s language, it seemed as if she was sharing her identity with that of her child, by using “we” multiple times in her utterances instead of “she” for describing events that only the child experienced. When the robot asked a question or made a comment directing to the child, the child and the mother would discuss about what is to be said in response and then the mother would answer back to the robot as a representative for both. This relationship can be represented in a directed cyclical graph of three nodes. (Figure 6-4a)

However, as the child became more confident on talking with the robot, the shared identity broke off and each of them was able to maintain their own voice separately. The mother started using “she” in her sentences to repeat or expand what her daughter had just said. The dynamic between the three became more balanced as the child started talking more to both her caregiver and the robot. The communication among the three was more even and not skewed in any particular direction.




(a) (b)

Figure 6-5. The triad relationship among the child, the mother and the robot. (a) Earlier in the interaction session, the mother and the child share an identity and the communication flow is directed: from the robot to the child, between the child and the mother, and from mother to the robot. (b) Later on, each three agent found their own voices and were able to communicate directly to one another evenly.

### 6.3.5 Discussion

Overall, the pilot session showed a promise of what the Huggable robot system had wished to deliver. The robot was able to distract a child who was anxious and nervous about the scary "hospital bed" through a playful and positive interaction, and successfully built a friendly relationship with the child over a short period of time. The mother reported later that the child called the Huggable "sweetie" as they were leaving the hospital and said that she wanted to come back to the hospital to play with the robot. Also, the child showed clear evidence on how physical contacts can accommodate building stronger and faster emotional bonding between the robot and a child. The teleoperation interface could deliver smooth and contingent reaction behavior for the robot so that the three could maintain a fluid social interaction with one another. Another noteworthy finding was that how the caregiver's behavior changed based on the child's behavior. From only one pilot session, the author could not reason exactly why the child's mother to share the identity and voice when the subject was more stress and anxious. The mother unconsciously could have felt and resonated the stress her child was feeling during previous procedures and therefore talked as if she went through them as well as the child. Or it could be that the caregiver wanted to provide extra emotional and social support for the child by grouping the two as one identity since the child was very nervous. This is something that needs to be more deeply observed and analyzed in the future experiment.

# Chapter 7

# Conclusion

## 7.1 Contributions

This thesis has developed a socially engaging robotic platform that is designed to support children to feel less distressed and fearful of the hospital environment and/or the medical procedures. The hardware components enable the robots to perform expressive facial expressions, fast and smooth body gestures and pointing behaviors altogether. In addition, the modularity of Huggable's arm allows equipping the robot with various other sensors and features and potentially creating different kinds of interactions. The robot controller was designed to perform robustly despite severe interference among wireless networked signals at the hospital site. The thesis work has also identified several components and strategies, such as humor for an icebreaker and physical contact with the robot, that are effective in quick emotional bond.

## 7.2 Future Work

This thesis work was the first step in creating a robotic companion that socially and emotionally advocate young patients in pediatric environment. Through Wizard-of-Oz control of the Huggable robot, the team was able to observe an ideal and optimal interaction between a robot and a child patient. Although the robot was not running autonomously, this experiment should expose insights on the nature and characteristics of interactions between a child and a companion robot in healthcare environment. In that sense, the most urgent future work is to finish running the study with patients and analyzing the data from all the sessions.

Once all the required experiment data were collected, the natural next step is developing the Huggable robot to become more autonomous. Various bio-physiologic sensor data, facial expressions and prosodies from child's utterances along with the followed behaviors triggered on the robot can be used to train a computational model of a socially and emotionally contingent behavior for the Huggable. A number of different approaches, such as reinforcement learning and/or POMDP, can be applied explored as a tool for training the planning algorithm for the Huggable robot. [66, 67]

Also, more activities available to engage in for the child and the Huggable robot can be created in the future. In the experiment, there were not many options available for the children to do with the Huggable robot. The participants mainly engaged with the robot via conversations, singing songs and/or I spy game. These activities were possible because there was a human teleoperator in the loop. With the current object recognition and speech recognition technologies in the field, it is not feasible to put a robot in any patient bed space and be able to perform a successful I spy game or hold an elongated conversation with the child. Instead, a play material for the child and the robot can be introduced on a tablet device as a form of Android or iOS application, which equips the robot to be able to have more control and knowledge about the play activity. That way, the robot can maintain control over the play material and "know" what is going on in the play context.

One candidate of activity the Huggable robot can engage with children at the hospital is a pretend play in the context of medical procedures patients take. During a brainstorm session with child life specialists, one member commented that the team often used "Mr. Vein" for a child patient to model the procedure he or she goes through with a medical staff. Mr. Vein is merely a pouch with red colored water wrapped with a towel and symbolizes an imaginary patient in the pretend play. The child is then provided with the same set of tools that the doctors and nurses use, and with the assistance of the child life specialist step by step operates a blood draw or some other medical treatment on Mr. Vein; tying rubber band, rubbing alcohol with the cotton ball, etc. The child life service members commented that these types of modeling activity provides children a sense of control and had been helpful in getting patients stay calmer and mentally ready at the next medical operation.

Lastly, more technologies and tools for the robot to computationally assess emotional and affective states of children and an overarching system that transfers and shares the information with medical staffs and caregivers can be developed. Unlike animal assisted therapies, the interaction between the patient and the robot can be computationally analyzed either in real time or after the session, and can potentially offer significant information about the patient's mood and reaction to certain events or things at the hospital. With this type of information, medical staffs can be more aware of the fear factors of the specific patient and tailor the appropriate behavior and intervention methods accordingly.

# Appendix A

# Child-Mother-Huggable Interaction Transcription

*M: the mother of the child, C: the child, H: the Huggable robot, R: the research associate*

*From 0:00 to 3:52 in the recording, **M** tries to convince **C** to sit on the patient bed but **C** refuses. One of the research associates sits on the bed as a model. At the end, **M** pulls **C** up to the bed and sits next to each other.*

**M:** *(in Hebrew)* Do you see this? They're video taping us. Remember they'll videotape us? What's that? Camera. … Look. Do you see him [Huggable]? Sooyeon says she's going to another room.

**M:** Bye, Sooyeon. Thanks.

**M:** *(in Hebrew)* If you're worried, let me know. What's wrong? Isn't he cute? He's so cute right? Sit on the bed so you can reach him.

**C:** *(in Hebrew)* No.

**M:** *(in Hebrew)* Can I sit on the bed? *(touching the Huggable's arm)* I pet the bear. It's a hospital bed because remember we said Huggable helps kids at the hospital. Remember when you were at the hospital? *(in English to **R**)* Yes, we're ready. I want to ask Noga something. *(in Hebrew)* Do you mind sitting on the bed? It's just Sooyeon set up the camera so that they will see you here. … Do you want me to show you? I'm just showing you. Do you see the camera here? Do you see?

**M:** *(to **R**)* Can you sit on the bed so she'll see you on the bed? *(in Hebrew)* Do you see? We're just seeing her on the camera. I will also be with you. You'll sit on the bed with me. Do you want to sit on the chair? …. If you really want to, you can sit on the chair. But I think it'd be fun for you to sit on the bed. You can stay with your shoes. We're not lying on the bed. We're sitting on it. We're not doing anything. There's no doctor that's coming here. …. Maybe we can tell him [Huggable] that we once were on bed where we did the operation. We'll just tell him, alright? You can sit with me and on me all the time. Ok? … *(sitting down on the bed)* on me, on me, on me.

***C** looks nervous and keeps her middle finger in her mouth during initial part of the interaction.*

**M:** So, Noga. She doesn't want to sit on the bed much, right? *(in Hebrew)* You don't want to sit on the bed, right?

**H:** Hi!

**M:** Ah, he's talking to us!

**H:** Who is this?

**M:** *(in Hebrew)* Who is this? He's asking you.

**C:** *(quietly)* It's Noga… It's Noga.

**H:** Hi, I'm Huggable. What's your name?

**C:** *(softly)* Noga…

**M:** Say louder. *(in Hebrew)* Say louder, he didn't hear you.

**C:** *(loudly)* Noga!

**M:** Noga! Now you've told him.

**H:** Oooh, that is a pretty name.

**M:** *(in Hebrew)* He said your name is beautiful.

**H:** I like it. It's very nice to see you.

***C** takes the finger out of her mouth and puts her hand down on her lap.*

**M:** *(in Hebrew)* He said it's very nice to see you. Let's touch him.
**H:** I live in the hospital and play with children like you. Have you been to a hospital before?
**C:** *(smiling)* Yes.
**M:** Speak louder. Ok? Because he doesn't hear you.

***C** puts her finger back in her mouth.*

**C:** *(loudly)* Yes.
**H:** I see. What did you do at the hospital?
**M:** *(in Hebrew)* What did you do at the hospital? Tell him ear operation.
**C:** *(in Hebrew)* You [tell him].
**M:** *(in Hebrew)* do you want to tell him?
**C:** *(in Hebrew)* No. You.
**M:** *(in Hebrew)* try to tell him. He wants to talk to you.
**C:** *(in Hebew)* No. You.
**M:** Ok. She says mommy will tell it. So we had an ear operation. Can you show him where?

***C** grinds her teeth while keeping her middle finger on her lips.*

**H:** Oh no! You got an ear surgery! How was it?
**M:** *(in Hebrew)* How was it? Tell him how you felt. Do you want to talk to him?
**C:** *(shaking head)*
**H:** Were you scared?
**C:** (shaking head) No….. No!

***C** takes out her finger from the mouth and lays her hand down.*

**H:** Oh, wow. You're so brave.
**M:** *(in Hebrew)* You're brave. What is "brave"?
**C:** *(in Hebrew)* I don't know.
**M:** *(in Hebrew)* He's cute.
**H:** Did it hurt when the doctor was fixing your ear?
**C:** No... No!
**H:** No? Wow, you're so brave. Did you get any sticker or candy after the surgery?
**C:** Yes.
**M:** *(in Hebrew)* Tell him what you got.
**H:** That's great!
**M:** What did you get? *(in Hebrew)* tell me in Hebrew.
**C:** *(in Hebrew)* balloon.
**M:** Balloon.
**C:** *(in Hebrew)* You [tell him].

***C** puts her finger in her mouth*

*(in English to **H**)* I got balloon.
**H:** What did you get?

***C** takes her finger out from the mouth.*

**C:** I got balloon!!
**H:** Wow, a balloon! I got a train sticker after a blood test.
**M:** *(in Hebrew)* did you ever do a blood test? *(in English)* Did we have a blood test?
**C:** Yeah.

***C** puts her finger in the mouth.*

**M:** Yeah, we had a blood test. And what did we get after that?

***C** takes the finger out of her mouth.*

**C:** Stickers… Three stickers!
**H:** Three stickers!!! Oh my goodness. You are a very brave girl.
**M:** *(in Hebrew)* In the blood test, were you scared? Tell him.
**C:** *(in Hebrew)* No… Yes.

***C** puts her index and middle fingers in the mouth.*

**C:** I was scared. I was scared. Scared.
**H:** You were scared?
**M:** Yeah, the blood test. She was scared.
**H:** Oh, I was scared too when I got my blood test. But I got a train sticker after that.
**M:** *(in Hebrew)* He got one sticker. Tell him you got three stickers.

***C** puts her fingers out of the mouth.*

**C:** I got three stickers.
**H:** You got three stickers? Good job!
**M:** *(in Hebrew)* tell him you were brave. *(in English)* I was brave.
**C:** I was brave.
**H:** (raising one arm toward **C**) High five!
**M:** Yeah, she was brave. Very brave. Where did they get the blood?

***C** shows the arm and points to the spot*

**M:** You see, from here. You see where they got the blood?
**H:** Oh, on your arm. Mmmm. I got a blood draw on my arm too.
**M:** Which arm?
**H:** (raising its right arm) This one.

***C*** *touches the arm that the robot showed to her.*

**M:** Noga wants to touch Huggable
**H:** Of course, you can touch my fur. It's very soft.

***C*** *touches* ***H****'s arm and leg.*

**H:** *(giggling)* That tickles!
**M:** *(in Hebrew)* He laughed. Tickle him. *(laughing, in English)* That tickled?
**C:** *(in Hebrew)* I feel like stopping.

***C*** *tries to get down from the bed.*

**M:** Noga feels like finishing.
**H:** Thank you, Noga. Bye!
**C:** Bye!!
**H:** Let's play again next time.
**M:** Bye!
**C:** Bye!

***M*** *and* ***C*** *gets down from the bed, and* ***R*** *comes back to the room.*

**M:** Did you like him?
**R:** What did you like about Huggable?

***C*** *talks in Hebrew to* ***M****.*

**M:** She liked to pet him. She liked to touch him.
**R:** You liked to touch him. Was it fun when he was ticklish?
**M:** Was it fun when he was laughing after you tickled him?
**C:** Yeah.
**R:** That's great. Would you like to come again and see the Huggable next time you visit the hospital?
**C:** Yeah.
**R:** Are you friends with him?
**C:** Yeah.
**R:** Ah, that's great! I think Huggable likes you too. Thanks so much for playing with Huggable.
**M:** Ok. We had fun. We'll play with him again. Yes? Ok.

# Appendix B

# Huggable Operator Survey & Patient Interview Questions

**Huggable Teleoperator Questionnaire**

**1. Background Information (Q2-4 in scale 1-7)**
(1) How much do you know about robotics, compared to average US citizen?
(2) How much do you know about computers, compared to average US citizen?
(3) How much time do you spend playing video games in a week?

**2. General Questions (scale 1-7)**
(1) I was able to easily look around the environment.
(2) I felt aware of the real world surroundings while operating the robot.
(3) I was easily distracted.
(4) I felt comfortable during the interaction.
(5) The child felt comfortable during the interaction.
(6) I felt detached from the interaction.
(7) When the interaction ended, I felt like I came back to the "real world" after a journey.
(8) What was your overall enjoyment level in the interaction?
(9) How strong was your sense of presence, "being there", when interacting with the child?

**3. Measuring social presence for the operator**
**(from *Networked Minds Social Presence,* Scale 1-7)**
3-1. Isolation / Aloneness
(1) I often felt as if I was alone.
(2) I think the child often felt alone.

3-2. Mutual Awareness
(1) I hardly noticed the child.
(2) The child didn't notice me in the room.

3-3. Attention Allocation
(1) I sometimes pretended to pay attention to the child.
(2) The child sometimes pretended to pay attention to me.
(3) The child paid close attention to me.
(4) I paid close attention to the child.
(5) The child was easily distracted when other things were going on around us.
(6) I was easily distracted when other things were going on around me.
(7) The child tended to ignore me.
(8) I tended to ignore the child.

3-4. Empathy
(1) When I was happy, the child was happy.
(2) When the child was happy, I was happy.
(3) The child was influenced by my moods.
(4) I was influenced by the child's moods.
(5) The child's mood did NOT affect my mood/emotional-state.
(6) My mood did NOT affect the child's mood/emotional-state.

3-5. Mutual Understanding
(1) My opinions were clear to the child.
(2) The opinions of the child were clear.
(3) My thoughts were clear to the child.
(4) The child's thoughts were clear to me.
(5) The child understood what I meant.
(6) I understood what the child meant.

3-6. Behavioral Interdependence
(1) My actions were dependent on the child's actions.
(2) The child's actions were dependent on my actions.
(3) My behavior was in direct response to the child's behavior.
(4) The behavior of the child was in direct response to my behavior.
(5) What the child did affected what I did.
(6) What I did affected what the child did.

**4. Measuring engagement of the operator (from Van Baren's *Measuring Presence*)**
(1) How engaging was the interaction?
(2) How relaxing or exciting was the experience?
(3) How completely were your senses engaged?
(4) The experience caused real feelings and emotions for me.
(5) I was so involved that I lost track of time.
(6) I found the control mechanism distracting.
(7) How well could you concentrate on the interaction rather than on the mechanisms used to perform the interaction?

**5. Measuring Robot's Viability**
(1) How enjoyable was your experience controlling Huggable?
(2) I found controlling Huggable to look at a certain place intuitive.
(3) I found controlling Huggable to point at a certain place intuitive.
(4) I can easily make Huggable play an animation appropriately during the interaction.
(5) I found that the Huggable's motor noise distracted me from the interaction.
(6) I found that the Huggable's physical movements distracted me from the interaction.
(7) I found the virtual representation in the interface helpful to know what Huggable was doing.
(8) I found the Huggable to be intuitive to control overall.

**6. Measuring Cognitive Load (from *NASA-TLX questionnaire*)**
(1) How mentally demanding was the task?
(2) How physically demanding was the task?
(3) How hurried or rushed was the pace of the task?
(4) How successful were you in accomplishing what you were asked to do?
(5) How hard did you have to work to accomplish your level of performance?
(6) How insecure, discouraged, irritated, stressed, and annoyed were you?

**7. Measuring Usability of the Teleoperator Interface Software (from SUMI)**
**Choose Agree, Undecided or Disagree**

(1) The teleoperator interface responds too slowly to inputs.
(2) I would recommend the interface to my colleagues.
(3) The interface has at some time stopped unexpectedly.
(4) Learning to operate through this interface initially is full of problems.
(5) I sometimes don't know what to do next with this software.
(6) I enjoy my sessions with this software.
(7) If this software stops, it is not easy to restart it.
(8) It takes too long to learn the software commands.
(9) I sometimes wonder if I'm using the right command.
(10) Working with this software is satisfying.
(11) The way that system information is presented is clear and understandable.
(12) I feel safer if I use only a few familiar commands or operations.
(13) Working with this software is mentally stimulating.
(14) There is never enough information on the screen when it's needed.
(15) I feel in command of this software when I am using it.
(16) I prefer to stick to the facilities that I know best.
(17) I think this software is inconsistent.
(18) I would not like to use this software every day.
(19) I can understand and act on the information provided by this software.
(20) This software is awkward when I want to do something, which is not standard.
(21) Tasks can be performed in a straightforward manner using this software.
(22) Using this software is frustrating.
(23) The speed of this software is fast enough.
(24) It is obvious that user needs have been fully taken into consideration.
(25) There have been times in using this software when I have felt quite tense.
(26) The organization of the menus or information lists seems quite logical.
(27) Learning how to use new functions is difficult.
(28) There are too many steps required to get something to work.
(29) I think this software has made me have a headache on occasion.
(30) It is easy to make the software do exactly what you want.
(31) I will never learn to use all that is offered in this software.
(32) The software hasn't always done what I was expecting.
(33) The software has a very attractive presentation.
(34) It is relatively easy to move from one part of a task to another.
(35) It is easy to forget how to do things with this software.
(36) This software occasionally behaves in a way, which can't be understood.
(37) This software is really very awkward.
(38) It is easy to see at a glance what the options are at each stage.
(39) I have to look for assistance most times when I use this software.

**Pre-Interview Questions for Study Participants**
(1) How old are you? When is your birthday?
(2) Do you know what an iPad or tablet is? A smartphone? A computer?
(3) Have you played with an iPad or tablet before? A smartphone? A computer?
(4) How often do you play with it?

(5) Have you seen or played with a robot before?
(6) What do you think robots are like?
(7) What do you do when you're scared?
(9) What do you do when you're bored or lonely?

**Post-Interview Questions for Study Participants**

Engagement
(1) Did you have fun?
(2) Do you think Huggable had fun?
(3) What was your favorite part of Huggable?
(4) Was there anything you didn't like about Huggable? I promise not to tell…
(5) If you were lonely, do you think you might want to play with Huggable?
(6) If you were scared, do you think you might want to play with Huggable?
(7) What would you do if Huggable were sad?
(8) Do you think you could tell Huggable a secret?
(9) Is Huggable your friend? If not, can Huggable be your friend?
(10) Would you want to talk more with Huggable in the future?
(11) If you meet with Huggable again, what would like to do with Huggable?

Perception
(12) Is Huggable a boy or a girl?
(13) How much is Huggable like you?
(14) Is Huggable alive? How alive is Huggable?
(15) How much like a machine or a computer is Huggable?
(16) Can Huggable be happy?
(17) Can Huggable be sad?
(18) Can Huggable get sick?
(19) Do you think Huggable understands how you feel?
(20) Does Huggable eat?
(21) Does Huggable grow?
(22) Can Huggable think?
(23) Do you think Huggable is ticklish?
(24) Can Huggable break?

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