Designing a Socially Assistive Robot for Pediatric Care

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ABSTRACT
We present the design of the Huggable robot that can playfully interact with children and provide socio-emotional support for them in pediatric care context. Our design takes into consideration that many young patients are nervous, intimidated, and are socio-emotionally vulnerable at hospitals. The Huggable robot has a childish and furry look be perceived friendly and can perform swift and smooth motions. It uses a smart phone device for its computational power and internal sensors. The robot's haptic sensors perceive physical touch and can use the information in meaningful ways. The modular arm component allows easy sensor replacement and increases the usability of the Huggable robot for various pediatric care services. From a preliminary pilot user study with two healthy and two ill children, all participants enjoyed playing with the robot but the two children with medical conditions showed caring and empathetic behaviors than the two health children. We learned various types of physical touch occurred during the child-robot interaction, and will continue to develop more intelligent haptic sensory system for the Huggable robot to better assist and support child patients' socio-emotional needs.

Categories and Subject Descriptors
H.1.2 [**User/Machine Systems**]: Human factors

General Terms
Design, Human Factors.

Keywords
Robot Design, Socially Assistive Robotics, Healthcare Robotics, Child-Robot Interaction, Pediatric Care.

1. INTRODUCTION
Most children do not like to be in a hospital or at a doctor's office. They often go through invasive and painful medical procedures and are surrounded by unfamiliar clinical staff. In most big pediatric hospitals, certified child life specialists (CCLS) support children and their family to cope with any kind of stress and anxiety caused from clinical treatments and hospitalizations [9]. CCLS provide developmentally appropriate inventions and medical play to prepare patients for their upcoming clinical procedures and distract them from temporary and/or chronic pain with playful interactions and intervention methods. The demand for the service provided by CCLS is very high but the supply for human resources is limited.

In order to close this gap between the supply and demand of human specialists, researchers are beginning to study how robots could assist young patients in a hospital setting. Beran et al. showed that Nao, a small humanoid robot, could distract children from their physical pain during flu vaccinations by applying cognitive-behavioral strategies for pain reduction [1]. Jeong et al. presented preliminary behavioral evidence on how a socially assistive robot could engage patients in oncology units in their bed space and this type of positive interaction could potentially lead to lower levels of stress, anxiety and pain for the patients [3]. Many robotic platforms had been developed in the past to be used with children for clinical therapy and interventions as well. Saldien et al. designed Probo to be used in hospitals as a tele-interface for entertainment, communication and medical assistance [7]. Stiehl et al. developed a therapeutic robotic teddy bear avatar for affective and relational touch and tele-communication [8]. Other robotic platforms used with young children for therapeutic purposes include Pleo [2], NeCoRo [5], AIBO [6], Paro [10], Keepon [4], Kaspar [6], etc.

While these existing robots are successful in engaging children in positive interactions, each of their application domains is rather limited. Pleo, NeCoRO, AIBO and Paro mimic animal behaviors and are able to generate effects of pet therapy but cannot act as an active social interaction partner or an information provider for patients. Kaspar and Nao are in humanoid forms and appeal to children as peers but their emotional expressivity is restricted for drawing the sense of empathy from the robot. Probo and Keepon are capable of expressing various emotions as well as communicating through speech but Probo could be perceived intimidating due to its big size from children's perspective and Keepon might be deemed small if patients would like to hug or make any emotional physical touch with the robot.

Furthermore, different design principles and criteria apply when developing social and interactive robots for pediatric care. The designer should be mindful of the nature and characteristics of the hospital environment and the lives of patients in it. Many children

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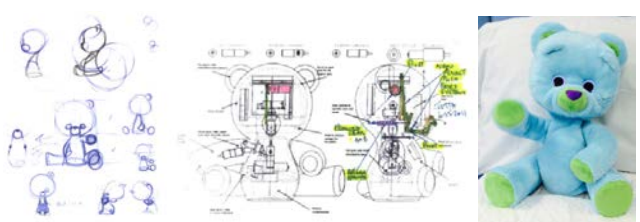
are attached to monitoring devices and often are on medication. Some have trouble moving their bodies due to the clinical conditions. Patients who are immunocompromised or have contagious diseases are on contact precaution to protect them and/or others, and all toys are sterilized between every usage for infection control. Hospitalized patients meet different faces providing care form them because many nurses are on rotations, and every morning a group of medical staff visit for regular clinical rounds. All of these factors need to be considered when designing a robotic platform and the types of interactions it will engage in with young patients.

In this paper, we present the design of Huggable, our socially assistive robot for pediatric inpatient care. Huggable is created to socially and playfully interact with children in various situations in pediatric hospitals. Huggable is perceived by children as a friendly and unintimidating peer character and can be used to distract them from fear and pain, entertain during hospitalization or waiting period, and educate them about upcoming medical procedures. We describe the design decisions made during the development phase, results from early pilot user studies that show effects of our choices and insights learned from real world deployment for future work.

2. ROBOT DESIGN

2.1 Juvenile Appearance

Child-robot interaction in a hospital context is very different from interactions that happen in home or school environment. Children coming into the hospital are not well and are faced with unfamiliar place, unfamiliar people and often painful and intrusive medical procedures. As a result, many of them become very nervous and intimidated, and would not react positively a stimulus that they would have taken well or enjoyed when they were at home or in school setting. Thus, we developed the appearance of the Huggable robot in the form of a teddy bear to be perceived as a cute, friendly and unintimidating interaction partner. The overall contour is in a round and curvy bean shape, similar to the body of young child. This juvenile appearance makes Huggable feel soft and non-threatening, and the roundness of the overall body shape provides comfort when a child wraps his/her arms around the robot. The robot's big head and large eyes intensify the sense of infancy and make Huggable more appealing for young children.



(a) (b) (c)

Figure 1. Huggable's design process started from a professional animator's (a) character sketches, (b) mechanical designs and to (c) the final product as a robot platform.

2.2 Android Smart Phone for Computation

Huggable platform uses an Android smart phone for its computation power. A smart phone runs like a small computer nowadays while equipped with various internal sensors and devices, such as a microphone, a camera, and an accelerometer. The wireless communication feature of the phone is useful for connecting the stream of data coming through internal sensors of the phone to a monitoring device or a teleoperation interface. Connected with SparkFun's IOIO board for Android, the phone receives data from external sensors and communicates with the motor boards for controlling the robot's physical joint movements. Figure 2 illustrates the system diagram of how external sensors, the smart phone and other modules for the Huggable robot communicate with one another. In addition, the screen of the phone displays the eyes of the Huggable robot and enabled more expressive eye animations coupled with the robot's physical motions as well. The compact packaging of various internal sensors and devices of an Android smart phone allowed maintaining the small size of the Huggable robot and simplified the electrical design for the platform.

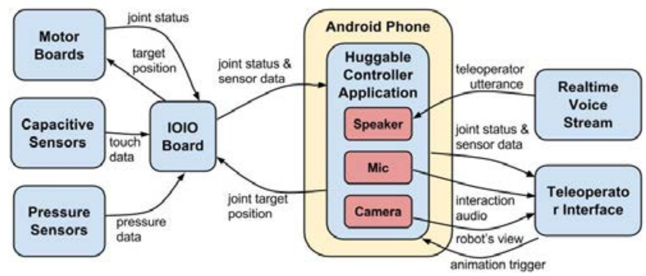


Figure 2. External sensory data and motor control information are sent to the Huggable controller application on the Android smart phone via IOIO board, and the controller application utilizes the internal phone sensors and features to communicate with the teleoperation interface.

2.3 Expressivity in 12 DOFs

The Huggable platform has twelve degrees of freedoms (DOFs) to perform animate and expressive motions: three for the head, two for each shoulder, one for each elbow, one for the waist, one for the muzzle and one for each ear (Table 1). The head can rotate, nod and tilt. The arms can rotate and lift at the shoulders and can bend at the elbows. The ears and the waist can move forward and backward. The muzzle moves up and down when the robot talks.

Table 1. Specifications for each joint

DOF	Range (°)	Est. Applied Torque (mN•m)	Final Speed (rev/s)
Elbow Joint	0, -80	55.27	2.05
Shoulder Rotation	+30, -90	153.04	0.77
Shoulder Lift	+65, -15	153.04	0.77
Head Nod	+15, -25	475.1	0.53
Head Tilt	+15, -15	352.91	0.55
Head Rotation	+60, -60	84.62	0.7
Waist Pivot	+10, -10	881.21	0.43
Ear Wiggle	+40, -40	30.84	3.06
Muzzle Wiggle	0, -60	37.27	2.9

Huggable is capable of manual look-at and point-at behaviors. Given an x, y coordinate command over wireless communication, the robot is able to look at or point at a specific location in the world. This look-at/point-at behavior assists children to believe that the robot is able to form a joint attention when interacting with them and make the social interaction more fluid. Furthermore, in order to protect the joints in case children move the robot's arms manually just as they would do to a stuffed animal, the shoulder and elbow joints have slip clutch mechanisms (Figure 3). When the gears in these joints are over-torqued due to a child's manipulation, the shaft spins within the flower shaped flexure instead of forcing a back-drive on the gearboxes and motors.

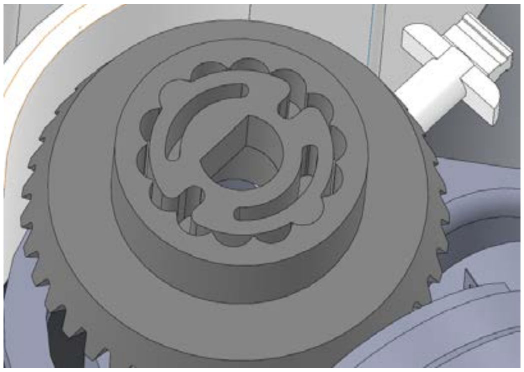


Figure 3. A flexure clutch mechanism was installed in arm joints to prevent gears from being damaged.

With these twelve DOFs along with animated eyes on the Android smart phone screen, the robot is able to express various emotions and nonverbal cues (Figure 4). Each of Huggable's eyes is comprised of a pupil and two upper and lower eyelids. The circular pupils can expand or shrink in its size, and the eyelids can change their positions and closeness to the pupils to create more expressive animations.

Figure 4. Huggable can use 12 DOFs to express various emotional states and social cues with its animated eyes on the Android smart phone screen.

2.4 Haptic Sensors for Physical Interactions

As the name indicates, Huggable invites physical contacts from the child users. Thus, it is important for the robot to respond and react to touch stimuli appropriately in order to maintain the natural and social interaction.

The Huggable robot is equipped with twelve capacitive touch sensors around its body parts (front head, back head, right ear, left ear, left arm inside, left arm outside, right arm inside, right arm outside, right side, left side, left leg and right left) and two pressure sensors on its paws. The capacitive sensors provide Boolean on/off outputs and the pressure sensors outputs analog signal between 0-3.3V to indicate how strongly a child holding the robot's paws. The haptic sensor data are communicated via IOIO board to the Android smart phone to be used for the robot to intelligently reaction the touch or to be the displayed for the remote operator controlling the robot from distance.

Pressure sensors on the robot's paws were implemented for children who have trouble expressing verbally to be able to communicate their level of pain in a more intuitive and fun way. We built the pressure sensors using a Honeywell pressure sensing IC and an Analog Devices Instrumentation Amplifier. The robot's paw is made with soft silicon material to be easily squeezed by small children. When a child compresses the robot's paw, the bladder causes the change in air flu, and the pressure sensor IC measures this change of air pressure. The raw output signal from the IC is in small range so is amplified with the instrumentation amplifier, and then gets transmitted to the Android smart phone via IOIO board.

2.5 Modularity for Easy Sensor Replacement

The pressure bladders in the elbow parts of Huggable are modular from the rest of the robot hardware. This modularity feature was pursued based on our discussions and brainstorming sessions with child life specialists.

One of the suggestions we got from medical staff when brainstorming how social robots could be used in pediatric care context was to use a robot for medical play. In traditional medical play, children take a role of a doctor or a nurse and pretend to apply medical operations on a mock-up patient, which are mostly passive items, such as a doll or stuffed animal. However, if a social robot that can respond and react to the child's pretend treatment is used, the educational effects of the play can enhance and the child could potentially build stronger sense of self-efficacy in coping with the medical procedures.

In various use case scenarios, different types of sensors will be required. For instance, to be used for a medical play that involves an IV injection, the robot would not necessarily need pressure sensors. Instead, it will need a faux injection site in one of the arms for the children to poke the needle into. To allow easy replacement of sensors, we designed Huggable's paw parts to be fixated with two pins (Figure 5). This feature allows quick-change mechanism that enable easy installation of new paw sensors by a simple plugging-in method.

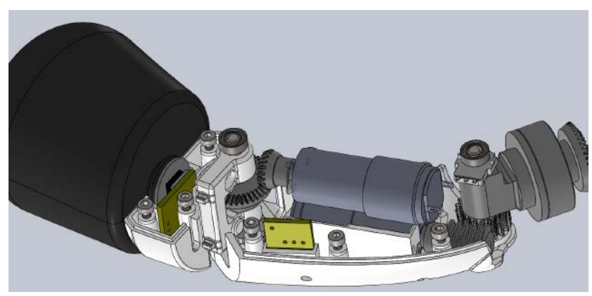


Figure 5. The pressure bladder is attached to the arm with two pins and can be easily replaced with a new sensor.

2.6 Removable and Washable Fur

In order to maintain the warm and fuzzy appeal of the Huggable and at the same time to ensure the infection control policy at pediatric hospitals, we designed Huggable's fur to be easily removable and washable. The fur cover is separated into seven pieces to minimize the hindrance in the robot's physical motions and to simplify the clothing and unclothing processes (Figure 6). The used fur pieces can be washed in normal washing machine in the hospital and be sealed in a bag until the next use.

Figure 6. Huggable's fur pieces can be removed and washed for infection control at the hospital.

3. PILOT USER INTERACTIONS

We ran pilot user studies with four children (one male and three female, age 3-5). Two children were healthy and came to the hospital procedure room to meet Huggable. The other two children were patients in oncology units and the robot was brought into their patient bed space for the play. For all of the four interactions, a remote operator controlled the Huggable robot. The operator was able to see and hear the child, talked through the robot in a pitch-shifted voice and triggered animations on Huggable.

Overall, we observed that all participants responded positively to Huggable and enjoyed interacting with it. They verbally responded to the robot and made physical contact with it. They hugged, tickled, petted and gave high-fives/fist-bumps (Figure 7). However, children with medical conditions made more number of touches and in higher frequency. Participants seemed to perceive Huggable as a peer; they narrated their own experiences at the hospital, showed the robot their person items and conversed as they would with another child. Interestingly, they also petted and scratched Huggable as they would an animal.

Figure 7. Children liked touching Huggable.

There were other interesting behavioral differences between healthy and sick children during the child-robot interaction. The two children with medical conditions showed more caring and empathetic behaviors to Huggable than the two healthy children did. Also, the ill children responded more emotionally when the playtime ended. One of these patients showed much disappointment when she was told that Huggable could not take a nap in her bed space after offering it some books to "sleep on."

4. CONCLUSION AND FUTURE WORKS

This paper presents the design of Huggable, a new socially assistive robot that playfully can engage children in variety of medical care context. We developed the Huggable robot to be perceived as a friendly and unintimidating peer/pet character from its juvenile and furry appearance. The Android smart phone used for computational power and the display of eye animations simplifies the overall software and hardware system architecture and allows the robot to maintain a small size appropriate for child-robot interactions. The haptic sensors enable the robot to be responsive to physical touch, which ill children particularly benefited and enjoyed, and the clutch mechanisms protect the robot's joints when those physical contacts occur. The modularity of arm components increases the usability of the Huggable platform in various educational, entertainment and clinical circumstances in the hospital. The washable fur cover was designed to protect patients from infection. Our initial user studies showed that children, especially ones who were sick, made many types of physical contacts with the Huggable robot, and emotionally and socially engaged in the playful interaction.

As we noticed that touch played a crucial part of the interaction between children and the robot, we plan to develop more intelligent haptic sensory system that would differentiate various types of physical contact made by young children while maintaining the child-friendly form factor of the Huggable robot. Furthermore, we will develop more sensory devices and activities that the robot, a child and perhaps even a clinician could participate together for better support both patients and hospital staff.

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