Designing a Haptic Empathetic Robot Animal for Children with Autism

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***Abstract* — Children with autism often endure sensory overload, may be nonverbal, and have difficulty understanding and relaying emotions. These experiences result in heightened stress during social interaction. Animal-assisted intervention has been found to improve the behavior of children with autism during social interaction, but live animal companions are not always feasible. We are thus in the process of designing a robotic animal to mimic some successful characteristics of animal-assisted intervention while trying to improve on others. The over-arching hypothesis of this research is that an appropriately designed robot animal can reduce stress in children with autism and empower them to engage in social interaction.**

Keywords - human-robot interaction; socially assitive robotics; animal-assisted intervention; autism; robotic therapy; emotional interaction

I. Introduction

The population of children with autism spectrum disorder (ASD) is large and growing quickly. For example, the rate of diagnosis for American children rose from 1 in 125 in 2004 to 1 in 68 just ten years later [1].

Children with ASD have difficulty with emotional and social communication skills, may not communicate verbally, and may interpret sensory stimuli with a greater intensity than neurotypical children. While much research has been dedicated to understanding and developing positive coping mechanisms for their gustatory (taste), auditory, and visual sensory overload, the sense of touch has been largely neglected [3]. Children with ASD often experience a diminished neural reward response to positive tactile stimuli and an exaggerated response to negative tactile stimuli. This combination may lead to "tactile defensiveness", or wariness of interacting with unfamiliar objects [4]. This experience can cause intolerance to certain materials and aversion to unfamiliar ones, leading to repetitive behavior, self-isolation and heightened stress during social interactions.

Children with ASD are most receptive to new tactile experiences, and may even initiate them, when they feel in control of the situation [5]. For all children, touch is crucial for "social interaction, bonding, novelty exploration and secure attachment" [4]. It is thus important to find ways to help children with autism feel sufficiently calm and secure so that they are willing to engage in social interactions, including those that have a tactile component.

We propose the use of a novel robotic animal platform to reduce stress and empower children to initiate social interaction. The robot animal will aim to serve as a relaxing social agent by interacting with the child, mimicking the behavior of a live animal companion.

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II. Preliminary Studies

A. Deep Touch Pressure

Deep touch pressure (DTP) therapy is the current standard for stress-reducing tactile intervention in the American special needs education system. DTP includes a wide variety of tools such as weighted vests, Wilbarger brushing, and hugging machines. However, these tools do not provide the children with control, nor with opportunities for social interaction. Additionally, DTP intervention methods, despite being the standard of treatment, are not scientifically backed. While the paucity of evidence may stem from a lack of research in the field, presently few studies (if any) offer indications that DTP produces significant benefits for children with ASD [6].

B. Animal-Assisted Intervention

Animal-assisted therapy (AAT) is "a goal-directed intervention facilitated by trained personnel, in which an animal is an integral part of the treatment process" [7]. Animal-assisted activity (AAA) is an opportunity to interact with animals without a specified treatment goal or objective. Both of these strategies are encompassed by the field of animal-assisted intervention (AAI). AAI programs have been scientifically found to decrease problematic behaviors and stress levels in autistic children. Specifically, long-term exposure studies with horses [8], dogs [9], and guinea pigs [7] showed that being in the animals' presence caused children with ASD to exhibit decreased stress, fewer negative behaviors, longer instances of positive behavior, increased independent sensory seeking and increased social contact with peers.

However, the feasibility of AAI for autistic children is limited. Specially trained service animals are costly, are in short supply, and require extended training. Animals may also pose hygiene or allergen concerns. Some other feasibility limitations are due to the child's illness: the child could be afraid of the animal, not understand how to properly treat it, or require constant adult supervision with it.

C. Robot Therapy

Robot therapy continues to grow as a viable method for improving human quality of life. PARO, a robot based on a baby harp seal, has been shown to reduce stress and improve various symptoms in elderly patients with dementia [10]. Huggable, a blue teddy-bear inspired robot, was designed to comfort and entertain children during long-term hospitalization [11]. Robot therapy is particularly intriguing for increasing positive social behaviors of children with ASD. Children with ASD find unfamiliar robots more inviting than human strangers [12]. In [13], Pleo, a commercially made dinosaur robot, elicited more social interaction from children with ASD than an adult human companion did. In [14], autistic children who played with the robotic dog AIBO displayed fewer repetitive or negative behaviors, such as rocking or self-injury, than the children who played with a simple mechanical stuffed dog.

Given these positive results, we also see the opportunity for further advancements in this field of research. The majority of robot animals available on the market are commercially made toys. They cannot be easily reprogrammed, and they lack extensive sensing capabilities, particularly sensors related to physical interaction. PARO, which is an FDA-approved class II medical device, displays adaptive behavior based on its treatment by the user over time. However, its behavior cannot be adjusted externally, so the mechanisms underlying its therapeutic benefits cannot be systematically evaluated or adapted to other possible patient populations.

Autism is a spectrum. Patients can range from low functioning to high functioning, and each person's needs are different. Therefore, an optimal robot animal's personality and behavior should probably be customizable by a therapist or parent, or perhaps even by the end user.

III. System Design

A. Robot Form Factor

Social robots can be divided into four visual categories: Humanoid, familiar animals (pets), non-familiar animals, and new characters / artificial animals. With each of these categories come different behavioral and mechanical expectations from users. If their preconceived expectations are not met, users may find a robot unrealistic and boring [10]. It is therefore much harder to create a realistic humanoid robot, or a dog robot, than a seal robot, because people have strong existing expectations of how a real human or a real dog looks and acts. People have less experience with non-familiar animals and therefore tend to compare such robots less critically to the animal of inspiration. Depending on their design, artificial characters can range from disinteresting, to acceptable, to uncanny. This variability makes it hard to predict how well an artificial design would be received by people.

To determine our non-familiar animal form factor, we conducted an informal survey with 18 adult participants – 9 male, and 9 female. Participants came from 8 different countries: 7 from the United States, 4 from Germany, 2 from South Korea, and 5 more individuals from Belgium, France, India, Iran and Italy. The participants chose from the following list of non-familiar animals: bush baby, chinchilla, groundhog, koala, rabbit, and squirrel. The participants were instructed to pick the animal they felt would be the most comforting to interact with. The participants most favored the form factors of a koala and a baby rabbit.

A koala was ultimately chosen as the animal form factor of choice. Between a koala and a rabbit, the koala is generally a less familiar, more exotic animal. While a rabbit can be purchased as a pet in the United States, one cannot buy a koala. Wild rabbits are also native to some parts of the United States, where koalas are natively found only in Australia and New Zealand. Therefore, most people have fewer preconceived notions of how a koala should move and behave. Some general perceptions of koalas in the media are that they are slow moving, gentle, and huggable. These are positive perceptions that would encourage interaction with a robotic version. The koala form was also chosen due to the ease with which it could be fitted onto a small humanoid robot.

B. Robot Model

A NAO Evolution v.5, Academic Edition (also referred to as a NAO H25) was selected as the commercial robot of choice for the initial robot animal prototype. The NAO Evolution is a small full-body humanoid robot with 25 degrees of freedom.

As previously stated, the majority of robot animals available on the market are commercial produced toys, with limited ability for reprogramming and limited sensor data. In order to develop an initial prototype quickly, it was important to utilize a robot that was easily controllable and had easily accessible sensor data. NAO is an ideal robotic agent for our purposes due to its friendly appearance, small stature, multimodal sensory capabilities, processing power, and ease of use. Furthermore, NAO is often used in robotic therapy studies for children with ASD, giving us confidence in its acceptability for our target audience.

To give the outward appearance of a koala, NAO will serve as our robot animal's "skeleton" and will be covered in a soft koala suit, as shown in Fig. 1. We envision it sitting on the ground near a child, or perhaps being held in the child's lap; for our initial prototype, we plan to fold NAO's legs under the torso and not use any forms of locomotion, so that the interactions are calm, safe, and easy to monitor.

One concern regarding an external fur koala suit is the possibility of the robot overheating. NAO automatically monitors the temperatures of its motors and CPU. If any part of the robot begins to overheat, the LEDs surrounding its chest button glow yellow or red, depending on the severity of the temperature. When the chest button is pressed, the overheating element is identified with an additional audio alert. We will pull this constantly monitored temperature data via wifi connection. NAO will indicate it is tired and needs to rest before it ever reaches an overheated state.

NAO can be programmed with Python, or through a user interface called Choregraphe. These options provide flexibility; body movements can be easily designed and executed through Choregraphe, and more complex utilization of the sensors can be achieved in Python.

Figure 1. A conceptual design of the robot animal, illustrating a NAO robot enclosed inside a soft koala form.

IV. SYSTEM REQUIREMENTS

A. Overview

The following list of core requirements has been developed for the prototype of the robot animal:

- Quick behavioral and physical response to touch input
- Memory of recent events and emotional states
- Tunable personality for customized experience
- Realistic animal movements

B. Quickly Responsive to Touch Input

The robot animal will use a system of tactile sensors to record the duration and intensity of the user's touches, similar to the Haptic Creature [15]. We seek a design that will allow many types of touch to be distinguished (such as poking, petting, or cuddling), enabling the robot to identify the emotional intent being represented and to respond accordingly.

NAO has built-in capacitive sensors on the front, middle, and back portions of its head, as well as capacitive sensors on the left, back, and right portions of each hand; see Fig. 2 for a diagram of the hand sensors. Bumpers on its feet serve as on/off switches. All of these touch sensors return a binary value – either 0 (unpressed) or 1 (pressed). Empirical testing suggests that NAO's capacitive sensors detect a change in contact, rather than measuring the pressure being applied.

Because we do not want to artificially limit the ways in which a child can interact with our koala robot, we invented a new way of extending NAO's physical contact sensing areas. Specifically, we secured silver-coated conductive fabric on its outer shell, directly atop its capacitive sensors. This technique can be used to extend NAO's sensing length from his hand to elbow. By utilizing the onboard capacitive sensors, and by extending the range of these sensors through conductive fabric, we hope to be able to determine the frequency and duration of human contact applied to NAO's lower arms.

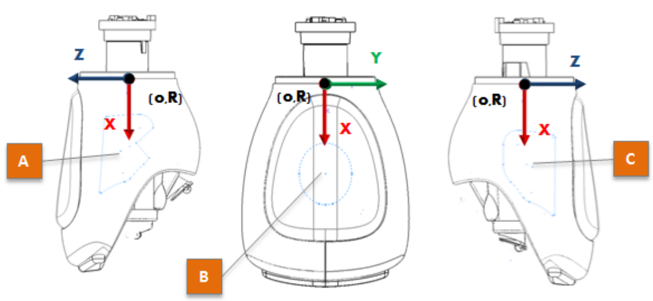

Figure 2. The locations of the three capacitive sensors located inside each of NAO's hands.

We are currently evaluating simple pressure sensors to apply externally to the robot. Pressure sensors would allow us to determine the intensity with which a person touches the robot animal. From this information, combined with touch frequency and duration, the type of gesture performed by the user – such as a poke, pat, or stroke – should be identifiable. Another approach that we are evaluating is to estimate applied force by monitoring NAO's joint angles and/or motor efforts.

C. Memory of Recent Events and Emotional States

As seen in Fig. 3, the koala robot will detect, identify, and record the user's touches. It will then keep track of a preset number of the latest recent touches. The robot's emotional state will change based on the touch gestures that it feels. For example, if the user has predominantly performed gentle patting motions, a single rough poke will not be enough to shift the robot from a positive emotional state to a negative one. We are in the process of selecting an appropriate approach to model these mood dynamics and interactive responses.

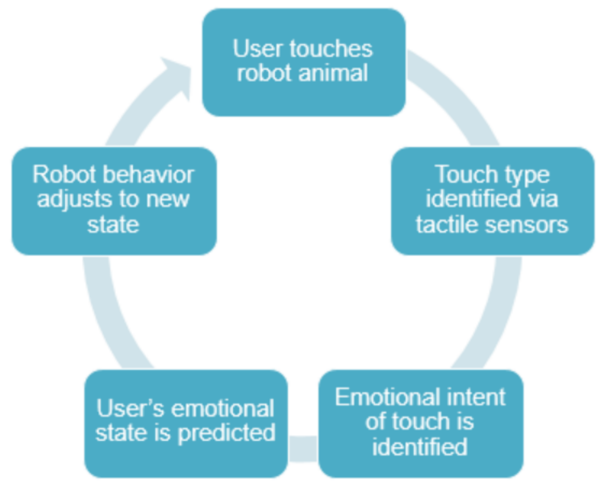

Figure 3. A diagram of touch and emotional interaction between the robot animal and the user.

One of the limitations of a live animal companion is that a child may not be able to safely and responsibly interact with it. In an extreme case, an animal might even be hurt by a child's behavior, such as poking it in the eye. If animal-assisted intervention is initially precluded by such concerns, the robot animal's touch tracking could also be used to observe how the child is treating the robot and whether they may be ready to move on to a live companion.

D. Tunable Personality

It is widely acknowledged that "one-size-fits-all" treatment methods are not appropriate when working with children on the autism spectrum. The child, their parents and their therapist know the child's unique preferences. As such, in order to be most effective, the personality of the robot animal should be adjustable to best fit what the child prefers and/or needs for maximum benefit. For example, an excited, active child might do better with a robot set to a more durable, positive personality – meaning the robot will tolerate rougher movement before its emotional state is negatively impacted. The personality of the robot animal will control the average "resting" emotional state it defaults to, how quickly its emotional state changes, and the level of emotion it expresses.

E. Realistic Animal Movements

As previously stated, it is difficult for robots with a familiar animal form to be considered realistic, due to how much general knowledge people have of the animals' movements and behavior from everyday exposure. While people are more forgiving of non-familiar animal forms, the robot animal must still perform smooth movements similar to those made by living creatures. This requirement will be accomplished using the Animation Mode on Choregraphe, which enables one to develop full-body movements through a series of freeze-frame poses.

Sample emotion primitives for the robot animal will be developed using this Animation Mode method. These will be chosen from Russell's Circumplex Model of Affect [16] to cover a wide range of valence and arousal. Participants will be asked to state which emotion they think the robot is demonstrating, to determine whether and how the robot's performance needs to be modified. This process will be repeated until the robot's emotions are accurately perceived.

V. ONGOING AND FUTURE WORK

The robot koala will initially be tested with a neurotypical adult audience to determine the extent to which interacting with the robot reduces the stress levels of a control population. Next, testing will be done with autistic users in a controlled lab setting. Finally, the robot will be tested in a more natural environment, such as the participants' homes or a therapy clinic. If these results are promising, we also aim to upgrade from our NAO skeleton to a custom-developed robot in future iterations.

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