

The Ins and Outs of Socially Assistive Robots: Sensors and Behaviors of a Therapeutic Robot for Depression Management

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Abstract - Using socially assistive robots (SARs) as specialized companions for those living with depression to manage symptoms provides a unique opportunity for exploration of robotic systems as comfort objects. Moreover, the robotic components allow for specialized behavioral responses to particular stimuli, as preferred by the user. We have conducted semi-structured interviews with 10 participants about the zoomorphic robot's Therabot™ desired behaviors and focus groups with five additional participants regarding the preferred sensors within the Therabot™ system. In this paper, using the data from interviews and focus groups, we explore SAR input and output for depression management. While participants overall expected the robot to respond in much similar ways as a well-trained service animal, they expressed interest in the robot understanding unique information about the environment and the user, such as when the user might need interaction.

I. INTRODUCTION

Depression is the most common mental health condition worldwide [1], with approximately 280 million individuals living with the illness [2]. Depression can bring complex healthcare needs, stemming from the direct symptoms such as fatigue, suicidal ideation and feelings of worthlessness [3] or the common comorbidities such as generalized anxiety disorder [4] and heart disease [5]. Various tools and interventions have been developed and tested to manage depression symptoms, including cognitive behavioral therapy (CBT) [18] and animal-assisted therapy [6]. While the use of animals within a therapeutic context has shown positive effects, such as the reduction of feelings associated with depression in older adults within a nursing home [7], having a live animal may not always be realistic for each individual. As such, the exploration of a robotic stand-in, socially assistive robots (SARs) may provide similar comforts without the need for continuous animal care or concerns of allergies.

SARs have been used within the context of depression management, acting as a form of therapeutic companion, such as the use of Paro in the homes of older adults which resulted in a reduction in depression symptoms [8]. Other SARs, such as PlantBot have been utilized to encourage

therapy tasks as indicated by clinicians to aid in the management of depression symptoms and life activities [9]. As these robots continue to be developed for the task of depression management, it is crucial that the robots act appropriately, based on the needs and desires of the individuals utilizing the robot.

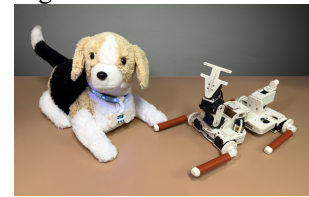


Figure 1: Therabot Robot Exterior and Interior

An important aspect when utilizing a social robot is the appropriateness of its behavior in regard to the input of the user upon the robot's sensors. In the past, it has been found that robots that bear too much resemblance to familiar animals may lead to expectations among users that the robots may not be able to meet [10]. The behaviors presented by zoomorphic robots also change what perceived abilities the robot possesses and can change how those interacting with the robot ascribe animacy. The perceived abilities and behaviors of the zoomorphic robot MiRO by children lead to them viewing harming the robot as unacceptable, as it was relationally identified as a stand-in for a live animal [11]. In order to achieve realistic behaviors in response to the user, it is also essential to employ the appropriate sensors to facilitate interaction. While the sensors provide triggers for behavior patterns (such as making a sound when being touched), the use case for sensors within a healthcare context also has the potential to provide insights into the daily lives of the user to be reflected with their care team [12]. In this way, SARs provide the potential for care via a service animal while monitoring aspects of the individual and their environment for personal reflection and use in therapy as the data is presented on a robot-connected phone app [28].

In order to better understand how the zoomorphic Therabot™ (figure 1) robot should behave, following the optional cat or dog model and adapt its behaviors to the user for personalization, we conducted two studies. One study

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utilized one-on-one interviews focused on the desired behaviors of the robot within different contexts of the home and interaction with the user, such as petting or talking to the robot. Our second study brought participants into focus groups to discuss what sensors the robot should have equipped in order to get the best understanding of the user and their environment. Through the combination of these two studies, we present aim to provide guidelines for encouraging comforting, appropriate interactions with the zoomorphic robot to be used in depression management. We discuss these behaviors and sensors as the input and output of the robot, where the robot behaves as a traditional service animal via appropriate intervals as suggested by the sensors.

II. BACKGROUND

A. Depression and Symptom Management

Depression is a serious mental illness that affects a large portion of the worldwide population, with an estimated 21 million adults over the age of 18 having a depressive episode in the United States within the last year [13]. Depression has a variety of symptoms, ranging from those that affect the body, such as fatigue or over/under eating [14], to more specific mental symptoms, such as feelings of worthlessness or suicidal ideation [15]. Depression can be quite difficult to manage, as many individuals who live with the condition also live with other comorbidities, including substance abuse disorder [16], or weight difficulties [17], conditions which can be exacerbated by the symptoms of depression.

In order to treat the symptoms of depression, many individuals adopt various management strategies such as the traditional use of medication [19], psycho-social interventions like cognitive behavioral therapy, which encourages belief change in the individual's daily life [18], or the use of animals through animal-assisted therapy [7]. Animal-assisted therapy is known to bring together various treatment modalities. With an animal as a therapeutic medium, these interventions provide comfort and engage the client, helping them improve cognitive, emotional, and social functioning [6]. While animal-assisted therapy has been shown to be an effective intervention for depression management, many individuals may not have the ability to care for a live animal or can be in its vicinity (i.e., allergies). One such alternative may be the use of a socially assistive robot (SAR), which can function as a companion.

B. Socially Assistive Robots and Depression

Socially assistive robots (SARs) have been shown to be useful and effective tools in many varying types of treatment settings, such as a hospital setting, where they have been found to positively support children in these stressful environments [20], and within care homes for the elderly, acting as mediators between individuals to encourage interactions [21].

SARs have also been used specifically with those living with depression in a care home in Taiwan, where SAR Paro contributed to a reduction in depression symptoms [22]. Paro has also been used over the period of a month in the homes of older adults living alone and led to a reduction in depression symptoms within a home setting as well [8]. However, not all uses of Paro have been shown to be beneficial with less than

half of reported uses showing a reduction in depression symptoms [23]. This suggests that while there is the potential for SARs within this space, the robot Paro may not be a one-size-fits-all case.

Other researchers have developed SARs specifically for the management of depression, such as the robot eBear which increased the happiness mood for older adults [24], PlantBot which was developed to remind the user of therapy activities [9], and Ryan, which is a robot which delivers cognitive behavioral therapy and was accepted as such [25].

III. METHODS

In order to develop the behaviors of the Therabot™ robot for those living with depression to be appropriate within home contexts, based upon the information collected by the sensors onboard the robotic system, two studies were performed.

A. Participants

In total, 10 participants completed the behavior interviews (see table 1).

P#	Gender	Race	Age	Education	PhQ-9
P1	Other	White	21	Some college	13
P2	Female	White	58	College Degree	10
P3	Female	Asian	25	Post Grad	13
P4	Male	Asian	25	Some College	15
P5	Female	White	33	Post Grad	10
P6	Male	White	51	College Degree	8
P7	Male	White	27	Post Grad	12
P8	Female	White	39	Some College	14
P9	Female	White	62	High School	22
P10	Female	White	26	College Degree	20

Table 1: Behavior Interview Participant Demographics

All five participants (Table 2) who participated in the sensor focus groups had previously participated in design studies regarding socially assistive robots, so they were familiar with current designs and potential uses for these systems. Two participants (P1 and P2) participated in the behavior interviews as well. P1, P2, and P3 were in one focus group together, and P4 and P5 were in a separate focus group together.

P#	Gender	Race	Age	Education	PhQ-8
P1	Female	White	62	College degree	4
P2	Female	White	58	College degree	5
P3	Female	White	39	Associates	22
P4	Male	White	21	High school	24
P5	Female	Black/African American	20	High school	10

Table 2: Sensor Focus Groups Participant Demographics

Participants who were recruited for this study all identified as being adults living with depression. All participants who participated in either study completed the PhQ-9 (behavior interviews) or PhQ-8 (sensor focus group) depression questionnaire, as well as general demographic questions. Those who completed study one (behavior interviews) were only asked to confirm that they had a previous depression diagnosis. Those who completed the sensor-based focus group were asked additional questions in a private interview regarding their experiences with depression, such as common symptoms and coping strategies. Participants reported various symptoms, such as low mood, lack of light in their environment (i.e. opening windows), and struggling with daily activities such as cleaning.

Both studies were approved by Indiana Universities Institutional Review Board (IRB).

A. Behavior Interviews

Study one focused on the desired behaviors of the Therabot™ robot within six contexts that could take place in the home, as defined in our previous studies regarding ecological momentary assessment of the Joy for All robot being used in the home [26]. These scenarios included petting the robot, playing with the robot, talking to the robot, consuming media (such as T.V./YouTube or listening to music) with the robot, moving the robot, and cooking or eating with the robot. Participants were invited to the R-House lab on the Indiana University campus and were introduced via prior use case descriptions as well as handling and interacting with various socially assistive robots, including the Joy for All cat and dog, Paro the harp seal, and a stuffed animal version of Therabot™ in its beagle form. Previous uses for these robots were explained, and the explanation was provided of the primary sensors that exist on each platform. The researcher began the interview by asking participants to provide input on which form they might want their own Therabot™ to take, and participants were asked to keep this form in mind while they answered questions that followed regarding the robot's behavior. Throughout the study, participants were asked to hold the stuffed animal version of Therabot™, which presented the initial form factor without the internal electronics or mechanical structures, to allow them to point out any aspects of the robot's physical form that they may focus on while answering the prompts.

For each of the five prompts, participants were asked specific follow-up questions regarding the particular scenario. For example, after the interviewer asked the participants to think of a time they might pet the robot, the following questions were asked: What does the robot feel like when you touch it? What movements is the robot making? What sounds is the robot making? Where would you be in your home that you might stop to pet the robot? What movements or noise would the robot do that would make you want to stop petting it? What information do you think the robot is collecting while you pet it?

Once participants had completed all six scenarios, they were given time to ask any follow-up questions and provide any additional comments.

B. Sensor Focus Groups

Study two focused on the potential sensors that may allow the robot to collect information about the user and their environment via focus groups. Before the focus group, a researcher interviewed participants individually in a private room, and the concept of socially assistive robots was explained during this interview. Once the pre-interview was completed for each participant, they were brought to the main room within the lab, and the researcher presented the Hummingbird robotics kit. Through this kit, participants were shown three sensors, including a light sensor, sound sensor, and ultrasonic sensor, which, when triggered, would turn on or off an LED light. They were invited to touch and interact with the sensors in order to get a better understanding of how these sensors function and collect information about the environment.

Participants were then asked to discuss four human senses, including touch, hearing, sight, and smell, within the context of the Therabot™ robot. They were prompted to discuss how the robot should achieve these senses and how they should not achieve these senses, as well as discuss specific sensors (i.e., camera, ambient sound, sensing carbon monoxide). Once this was completed, they were asked about sensors more generally, such as what other things the robot should be able to sense about the user specifically or their environment. After discussing sensors, participants were asked about the data collected by the sensors, such as who should have (or not have) access to the data and if having access to the data would be helpful to them. Finally, participants were given a chance for any final thoughts or comments before ending the study.

IV. RESULTS

Both the semi-structured interviews regarding the Therabot™ robot's behavior, as well as the sensor focus groups, were coded inductively by the first author. All audio recordings were automatically transcribed before being reviewed and corrected by another research assistant, and then codes were applied based on common themes (i.e., specific behaviors under each condition, specific sensors based upon human senses). All codes were reviewed by a secondary member of the research team, and any code discrepancies were discussed and recoded appropriately.

A. Behavior Interviews

Form. When asked what form the participants were interested in their Therabot™ taking, four indicated that they would be most interested in a cat (including one interested in a llama that acted as a cat), three were interested in a dog, one was interested in a seal, and two were unsure, choosing to think about the behaviors independently of form.

Petting the robot. When petting the robot, the most common behavior that participants have identified was both the feeling of vibration to mimic purring ($n = 5$) and sounds

of purring or rumbling (n = 5) - P10 “So probably kind of not like a vibrating, but something to tell me like it's alive kinda.”; P4 “Well, animal appropriate, but yeah, like a purring sound or like a satisfied rumble.” If the robot displayed aggressive movements or sounds, such as growling or hissing, participants indicated that they would stop interacting with the robot, particularly if the sounds were loud - P6 “Just any loud or sudden, you know, like a bark or sharp unexpected noise.” Also, jerky movements were identified as being off-putting (n = 5).

Talking to the robot. Interestingly, when indicating how the robot should behave when the user is talking to the robot, just a few sounds were requested (purring n = 5, whining n = 1), rather it was the robot's movement of turning its head toward the user or tilting its head that was most requested (n = 8) - P7 “I must say that a lot of engagement through sort of like moving his head around, maybe cocking his head.” Excessive noise or continuous noise from the robot would be off-putting for the user and dissuade them from talking to the robot in the future (n = 7).

Watching media with the robot. If the robot were to be present when the participants were consuming media, they indicated that the robot should be in a resting position, potentially asleep (n = 4), and if it were to play sounds it should only play quiet purring sounds (n = 4). P8 describes this as a resting cat that occasionally moves to show lifelikeness: “I imagine as like a sleeping kind of curled up where, like, her tail kind of twitches and she kind of meows and readjusts, but not like face me and meow or anything like that.”

Playing with the robot. Playing with the robot was the hardest scenario for participants to imagine. However, the robot's ability to move its head, such as tracking a toy, was requested (n = 6). P9 “And I know it doesn't have a mouth to fight a ball or anything like that, but usually it's playing with the toy and back and forth and back and forth and tickle, you know, things like that.”

Cooking with the robot. Many participants indicated that they did not want the robot present while they were cooking (n = 6) and that the robot should go to sleep during this period (n = 4). P5 mentions that this is because the robot could get dirty, and P1 mentions that they would find it overstimulating to have the robot present: “I know that for me, I would get overstimulated so quickly trying to cook. And then having, you know, dog or cat making noise in the background. I'd be like please stop.”

Moving the robot. While most participants indicated that they would move the robot around their homes (n = 7), many were unsure if the robot should react at all to being picked up and moved. Three participants indicated that the robot should go limp or let its legs dangle, and three indicated it should make soft sounds in recognition of being moved.

B. Sensor Focus Groups

Touch. When discussing the robot's ability to sense the user's touch, all participants indicated interest in the robot being able to feel touch, but in particular, being able to

sense the amount of pressure applied to the robot (n = 2). Such as P2, who said, “That it would sense, OK, I need to cuddle into that source of pressure. It's not a moving pressure. It's a solid pressure against me. Therefore, I should cuddle against that pressure.” Another aspect of feeling that participants expressed interest in was the robot being able to sense a change in temperature (n = 2), such as P1, who mentions the connection between temperature and heart rate changes “Like if I cuddle it against me, if it can sense if I'm hot or cold, but I don't know if that would lead into like my heartbeat. Like it could tell that my heart's beating really fast or really slow...”

Sound. For auditory information, participants mentioned being uncomfortable with the robot collecting audio data continuously (n = 2), and preferred that the robot begin audio recording with the introduction of trigger words or phrases (n = 4) - P5 “I think that's really smart because I originally I was like, I don't want it listening to me all the time, but if it can pick up like certain keywords and then record after that, that would be really, really cool.” The robot being able to identify tone was also listed as important for identifying user needs (n = 2), as mentioned by P3 “Yeah, like whether it's (behavior is) right, depending on the mood or the tone of my voice, that whether I need a hug or whether to play.”

Vision. When discussing vision, participants were overall neutral or comfortable with the idea of a camera (n = 3), though they mentioned that it might make other users or visitors uncomfortable (n = 2) - P2 “And they don't want someone checking in. They're afraid that somebody's going to check in or that they have to behave a certain way because somebody could be watching them. So, I don't know that a camera would be good for the anxiety part of depression.” Alternatives to a camera were discussed as potential options, such as LiDAR (n = 1), thermal (n = 1), or general temperature sensors (n = 1) to mitigate this.

Smell. Participants had an interest in the robot being able to sense “smells” in the environment that may prove to be safety hazards, such as carbon monoxide (n = 1) or smoke (n = 2). However, there was also interest in the robot being able to pick up negative organic smells that may provide insight into the individual well-being as well, such as body odor (n = 1) or food mold (n = 1), as mentioned by P5 “If people difficulties doing dishes and there's like possibly food leftover in the bowls or on the plates, and there's mold growing robot could sense maybe this isn't so good and these need to be taken care of because there's mold in the environment.”

Other sensors. When discussing other areas that the robot should be able to sense, participants mentioned aspects of being able to tell the cleanliness of the environment in particular clutter (n = 3) But the most common sensing ability for the robot not mentioned within the other contexts was the ability to address the user's heart rate, to aid in the calming process as mentioned by P2 “I would like the response to the if you've got a rapid heartbeat, I need to be in a calming mode to help that heart rate come down.”

Data Access. All five participants mentioned that they would be comfortable with sharing the data collected by the sensors with their therapists and care teams.

V. DISCUSSION

Understanding how a robot should behave under different conditions can influence how and when the robot is used by the user while implementing specific sensors allow for appropriately timed responses. Participants desired recognition behaviors by the robot during times of direct interaction, such as petting or talking to the robot, whereby the robot would react to them in a similar way as a live animal might. However, during periods of focus (such as cooking) or relaxation (watching media), the robot should instead fall into a “sleep mode” whereby the robot is not causing distraction or disruption to the user’s routine. Thus, the robot should be able to recognize and respond to direct cues by the user and differentiate these cues from environmental factors (such as talking to the robot versus continuous noise from a TV). This mimics the training of animals used within the context of therapy, trained to be attentive to the user without causing disruptions unless triggered by the presence of a required alert (such as the presence of anxiety cues by the owner) [27].

While previous co-design studies showed that a camera is not wanted [28], the participants in the sensor focus groups were overall neutral to the idea. The potential utilization of a camera, however, did encourage participants to consider not just their own privacy with the robot but the privacy of guests within their environment. Therefore, the importance of the robot being able to “see” the user visually remains important, and thus alternatives to the camera should be explored.

Petting the robot and feeling its vibration of contentment, as well as the importance of the robot’s ability to recognize and respond to touch, reiterates that participants are viewing this robot as a comfort object. The sound and feeling of a cat purring have been shown to reduce stress [29], and the soft vibration of a comfort object may also relate to a reduction in heart rate [30].

Considering the preferences of those participants, we will implement new behaviors into the Therabot™ robot based on form. Assessing both cat and dog behaviors per robot type, as well as the implementation of sensors that may achieve these behaviors in an acceptable way. Using the insights gathered through these workshops, the Therabot™ robot’s hardware and software are undergoing revisions to facilitate the experiences envisioned by participants.

In prior studies focused on identifying useful sensors for understanding context, machine learning models were developed to allow the identification of the six contexts explored in the behavior workshop. The sensors identified through these studies have been integrated into Therabot™ and will be tested via in-home deployments.

Related to participant desires for the robot to respond to their physiological signals, Therabot’s™ existing haptic heartbeat has been updated to allow data from a user’s

wearable device to modulate its behavior. An ongoing study is investigating approaches for slowing a user’s high heart rate by adjusting the robot’s heart rate progressively. As participants also expressed a desire for the robot to sense the level of pressure applied to it (e.g., squeezing or hugging), efforts are underway to use a combination of existing soft capacitive and resistive touch sensors, inertial measurement units, and additional methods of detecting shape deformation in order to better characterize the user’s tactile interactions.

As highlighted by participants, the ability of the robot to orient towards the user and have a general awareness of its surroundings is critical to its integration into daily life. In order to achieve this functionality without the use of RGB cameras, we are currently conducting technical evaluations using ultrawideband radar sensing and sound localization to achieve this ability. Current sound sensing abilities are limited to characterizing the intensity and frequency of sound with rate-limited sampling to reduce the risk of capturing sensitive content. Furthermore, increases in onboard computational power will facilitate the future development of onboard audio processing and speech recognition, providing the ability for the robot to respond to keywords (e.g., its name) and react expressively to speech without the need for transmitting or saving captured audio.

Sensor-collected data, recorded via the interactions presented (talking to the robot, touching the robot, etc.), provides the opportunity to inform ongoing care continuously. Through onboard machine learning and connection to other devices (such as wearables), the SAR can potentially alert to changes regarding ongoing depression symptoms via a data-driven approach [31]. We are also developing a robot-connected phone application to pair with the robot and monitor its onboard sensors. Previous studies have shown that participants are interested in receiving access to the sensor data collected by the robot [28] to be used as a reflection tool regarding their depression symptoms, as well as sharing this information with their care team. This application could also be paired with wearable devices to monitor more physiological sensors when away from the robot to aid in insights into the user’s daily life.

While SARs have been explored previously within various contexts for those living with depression, such as in the homes of older adults [8] and with students managing their mental health routines [9], our work further explores the specific requests of these adults regarding the utilization and behavior of these robots. Through specific sensors requested by these participants, we can develop a more specialized and personalized robot that functions both as an animal-like companion while also providing data and context to be used within and without traditional therapeutic techniques.

VI. CONCLUSION

Through interviews regarding the Therabot™ robot’s behaviors, as well as focus groups regarding the sensor requirements, adjustments will continue to be made to the

prototype. Appropriate sensors per the individual will be active within the robot to provide a tool for understanding the user's home environment and activities and to be used as a reflection tool within the context of therapy with the home.

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