Robotic Companions for Long Term Isolation Space Missions*

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***Abstract*— We tested robotic companions for their ability to reduce stress and create emotional bonds in the event of a Mars-analog space mission. Two different robotic companion platforms were programmed with aggressive and passive personalities and given to crew members for a three-day evaluation. Surveys and feedback from crew members were used to evaluate the effectiveness of the robots? ability to reduce stress. Personality traits were examined in terms of the robots? ability to create positive interactions with the crew. Utilizing this information, a new behavioral model is proposed that will provide sufficient complexity and adaptability for a robot companion to interact successfully with humans, and to create emotional bonds and mitigate distress in crew members.**

I. Introduction

Crew members on missions to asteroids, Mars, or other planetary bodies will be separated from friends, families, and social stimuli for many months, or even longer. They will be spending the majority of this time in a mentally and physically demanding environment, often with minimal personal space. This creates an environment of considerable stress. For this reason, it is valuable to provide crew members with outlets that will allow them to reduce stress, not only physically but emotionally. It has been well established that domestic pets can provide a great deal of stress relief and create emotional bonds with their owners [1]. At this time, however, it is impractical for domestic animals to accompany long-term space missions, so it is of interest to examine the potential for providing robotic companions. For personnel in isolated environments, it can be surmised that opportunities for recreation and emotional bonding with robotic pets would be beneficial for the wellbeing of the crew.

The NASA Human Exploration and Operations Mission Directorate [2] has identified a number of risks associated with long-term human space exploration. Many of these can be fruitfully investigated on Earth, in an environment relevantly similar to the target space environment. The Hawaii Space Exploration Analog and Simulation (HI-SEAS) habitat is a planetary surface exploration analog test bed in a rocky lava field at high altitude on the Mauna Loa side of the saddle area on the Big Island of Hawaii [3]. The first HI-SEAS mission was funded by a grant from the NASA Human Research Program, for research focusing on food acceptability and food preparation strategies for long-term space exploration. This mission involved six astronaut-like (in terms of education, experience, and attitude) crew members living together in the habitat for 120 days under Mars-exploration conditions (e.g., in isolation from the rest of the world, with communication latency and blackouts, in close quarters, under strict water-use rules, etc.). The crew was selected from over 700 applicants, and the 120-day simulated mission began in March 2013. We believe that the HI-SEAS mission offers a suitable stage to conduct a pilot study of the effect of companion robots on crew mood and perceived stress levels.

II. HI-SEAS HABITAT

The HI-SEAS habitat is a dome (36 feet in diameter) with two floors. The main floor consists of a work area, kitchen, dining room, laboratory, and bathroom. It is attached to an 8-square-foot airlock that is connected to a 20-foot sea container. There is a portion of the dome blocked off by a back door. This area contains a washer and dryer and the networking/telemetry room. The first floor has 878 usable square feet, with a total of 993 square feet [3].

Figure 1. HI-SEAS habitat with doorway to airlock chamber

The habitat has a large amount of open space on the main floor. This is a shared working area with an area for reading and relaxation. This spot is where the robotic companions were placed for interaction when not assigned to particular crew members.

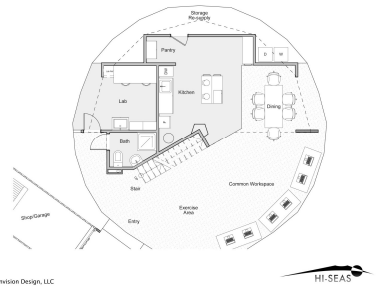

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Figure 2. First floor of the HI-SEAS habitat

The rooms in the habitat are on the second floor. The rooms are private and amply spacious. Each has a small desk big enough to work on a computer. The rooms allow for opportunities for interaction with the robotic companions during working times and while resting or reading in bed.

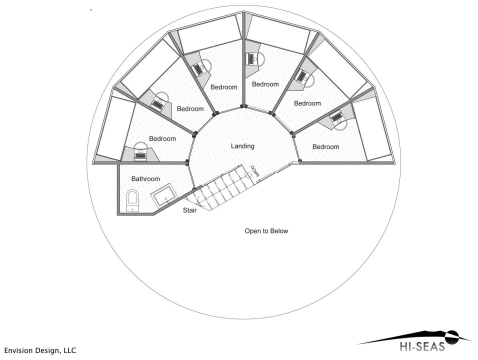

Figure 3. HI-SEAS second-floor plan showing six bedrooms and one washroom.

III. ROBOT COMPANIONS

Two robotic companions were used in this study, respectively named Pleo and Romibo.

A. Pleo

Pleo is modeled after a one-week-old Camarasaurus, a plant-eating sauropod from the late Jurassic period. By studying fossil records of this giant herbivore, and recreating animal motion with technology, INNOVOLABS created this robotic companion to interact with its users in several different ways [4].

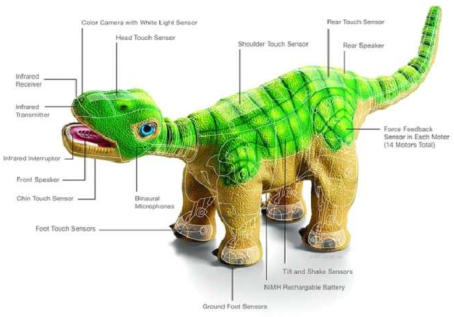

Figure 4. Diagram of Pleo, the dinosaur robotic companion.

The Pleo robot has the following features:

- A camera is located in the nose to allow for localization and basic interaction information.
- Fourteen motors allow the robot to walk and change its posture and orientation.
- A flashcard slot allows users to change the robot's personality and behavior.
- A USB port allows an editor to modify its behavior.
- A C/C++ software developer's kit (SDK) is provided along with the OpenPDK SDK

Pleo is capable of learning over time and of simulating the expression of many different moods and basic animal drives, such as hunger, fatigue, fear, and love. Pleo is capable of exploring its environment and learning from it in limited ways. Pleo's neural net adapts to stimuli from humans, which are part of its environment. In other words, Pleo;s personality and demeanor changes over time in response to the way it is treated. For instance, Pleo will limp if its leg is handled roughly and will remember negative interactions. Pleo can be programmed to frown, smile, shrug, and yowl for food [4]. We expect that Pleo will appeal to crew members on the basis of its complex motor skills, vocalizations, and capacity to explore.

B. Romibo

In line with requirements established in literature and research, Romibo has been designed to convey agency and expression, respond dynamically to changes in the user and environment, and support customization and durability. The internal robot platf Romibo orm is built from durable plastic and utilizes an innovative elastic suspension for actuation. This suspension system allows the robot to gesture and convey emotion and attention, while allowing the robot to be back-driven (physically forced against actuation) without damage [5].

Romibo offers features that enable broad therapeutic practices established by existing successful therapy robots. Romibo responds appropriately to objects in its environment, conveys a believable sense of agency. This is done in part through video motion tracking, and by orienting the robot to the areas of greatest activity in the room. Romibo has no language recognition but is able to respond appropriately to volume. For example, a loud sound, such as a slam or yell, will make Romibo act frightened. Romibo can also communicate through emotive tones or pre-recorded spoken words [5].

Figure 5. Diagram of Romibo, the interactive robotic companion.

Romibo can be programmed, with programs loaded via its USB port. In this study, Romibo was programmed to be a somewhat demanding robotic companion. It demanded attention in a number of ways: stroking its coat, human proximity, etc. If these demands are not met, Romibo will verbalize its needs.

IV. EXPERIMENTAL DESIGN

The goals of this project were to investigate the interactions between the crew and robotic companions in terms of emotional bonding. The two robotic companions are evaluated according to their ability to elicit interactions with crew members and their efficacy in reducing stress. In particular, we compared the nature of crew interactions with robotic companion personalities that display either active or passive interaction. A passive robot personality will require crew members to approach the robot on their own initiative. By contrast, an active or demanding robot personality will have certain needs that must be met. Otherwise it will make noise and seek out crew members for attention. For a portion of the study, crew members were assigned rotating duties to care for a demanding robot companion. Upon initiation of contact by the crew member, all robot companions, both active and passive, interacted socially with the crew member in ways previously shown to elicit emotional bonding behavior from human users.

The study tested two types of personalities within two different robotic platforms: a demanding personality requiring attention, and a passive personality that would wait for crew members to initiate interaction. The crew members were assigned a robot for a period of time, uploaded with aggressive and passive personalities. Each crew member was given a survey to fill out after initially interacting with the robot platform. The survey was used to assess the type of experience the crew member had, and to learn about any changes the crew member recommends.

The idea behind programming the robots with passive and aggressive personalities was to determine whether crew members bond more easily with one personality than another.

A. Experimental Time Line

For the first five weeks after arrival of the robots, crew members were assigned the task of taking care of one of the robotic companions in three-day shifts. During this time, each crew member spent six full days interacting with each platform. After the assignment period ended, crew members were no longer required to spend time with a robotic companion, but the robots were still active and demanding attention from the crew members. We thought that this ?free? time is when any emotional bonds formed with the robotic companion would be revealed, since if crew members found the initial interaction rewarding, they would continue to interact with the robot, and if not, the robot would likely be ignored or even shunned.

At intervals during the mission, the crew held focus group meetings in which they discussed their experiences with the robots and suggest modifications in the robots? behaviors. The first meeting occurred after each crew member completed one three-day shift of caring for a robot companion. The second was two weeks after the five-week 'assigned care' period, immediately before a one-week break from robot companions. It was difficult to tell if people missed the robotic companions or not during this time, but the expectation was that once the robot companion was returned the crew member's morale would be noticeably improved.

Data for this experiment will come in the form of recording the time and duration of human interactions with the robots. A detailed survey at the start and end of the three-day assigned period with each robot companion. This survey assesses whether the crew member had a positive or negative interaction with the robotic companion. It asks crew members to specifically talk about features of the robot companion that they liked or disliked. It asked each crew member to suggest possible changes to the robot companion that they would like to see. Finally, the survey had a number of words listed that indicated positive or negative thoughts about objects and experiences. The crew member was asked to think about the robot and circle each word that they felt they could associate with the robotic companion.

V. CREW ROBOTIC COMPANION QUESTIONNAIRE

A. Survey Questions

The survey questions for each crew member were as follows:

Question 1: Which robot companion did you interact with this past week?

- None
- Pleo
- Romibo
- Both

Question 2: In your estimation, how long in total did you interact with the robot companion today?

- Less than 5 minutes
- Over 15 minutes
- Over 30 minutes
- Over 45 minute
- Over 1 hour

Question 3: On average how often do you interact with the robot throughout the day?

- Never
- A little bit (less than 3 times)

• Only when feeding at meals

• Somewhat frequently (5 times)

• Very frequently (10 times)

Question 4: How much did you enjoy using the robot companion today?

• I did not enjoy it

• I disliked it somewhat

• I don't have feelings either way

• I found it somewhat enjoyable

• I enjoyed it

Question 5: PLEO requires feeding during the day. How many times did you feed him?

• I did not feed PLEO

• I fed PLEO only once today

• I fed PLEO twice

• I fed PLEO three times today

• I fed PLEO more than three times today

Question 6: Romibo is receptive to physical attention. Did you give the robot attention?

• I never gave the robot attention

• I gave some attention

• I gave the robot attention about half the time

• I gave the robot attention almost all the time

Question 7: Do you consider the well-being of the robot to be important to you?

• The robot's well being is very important to me

• The robot's well being is important to me most of the time

• The robot's well being is important only some of the time

• The robot's well being is not important to me

B. Words with Emotional Association

The crew is then given a list of words that are emotionally associated with either good, neutral, or bad feelings. The weight of the overall feelings towards the robotic companion is revealed with the amount of positive, negative, or indifferent words that are associated with the robotic companion. Further to this, the strength of emotion associated with words can carry different weight. These words are derived from work from [7],[8], and [9]. Choosing words such as 'Boring' verses 'unpleasant' are both negative feelings towards the robotic companion, however 'unpleasant' indicates a significantly stronger negative feeling than a robotic companion that is merely boring.

C. Long Answer Questions

Finally, crew members were encouraged to write about their thoughts and experiences with the robotic companions. The thoughts of the crew members were exceptionally important in order to gauge the impact the robotic companion had on the crew member.

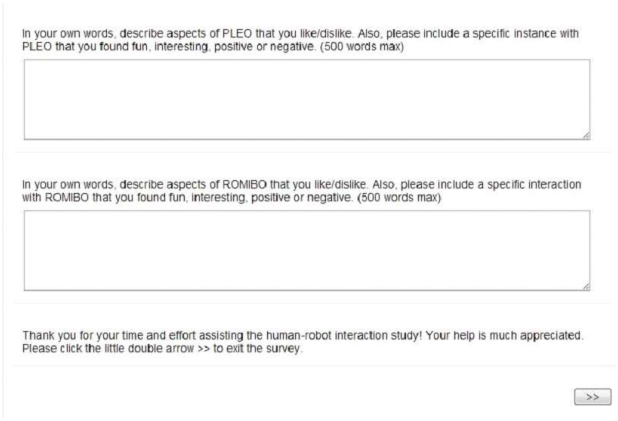

Figure 6. Final (optional) long-answer question.

VI. RESULTS

Survey data was collected from crew members during the 120-day mission. Each robotic platform was given to a crew member for three days. Each crew member filled out the survey after interacting with the robot companion for one hour, and then completed the survey on the last evening with the robot companion.

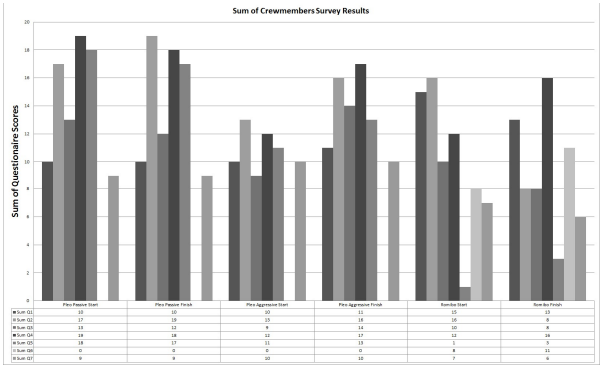

Figure 8. Sum of the crew member's responses to the seven multiple-choice questions.

A. Questionnaire results

Combining the results from the multiple-choice questions, the score from each question was summed to reveal the crew?s overall response to interacting with the robotic companions.

These were broken into the following: passive Pleo start, passive Pleo end, aggressive Pleo start, aggressive Pleo end, Romibo start, and Romibo end, for the start and end of each three-day trial. An analysis of each question shown in Fig. 8 is provided as follows:

The first question can be ignored in this analysis, because it simply asked which robot the crew member interacted with.

The second asked the crew members for the amount of time spent interacting with the robotic companion that day. During the study, the crew members interacted with the robots more after three days than they did initially. Furthermore, crew members spent half the amount of time with Romibo as they did with Pleo.

The third question asked the crew members how often on average they interacted with the robotic companion over an entire day. This was asked to determine the frequency of use. Overall, passive Pleo showed a slight decrease in usage, whereas aggressive Pleo showed a clear increase in usage. By contrast, Romibo showed a clear drop in daily usage.

The fourth question asked crew members how much they enjoyed the interactions with the robotic companion that day. Passive Pleo resulted in a very slight drop in crew enjoyment, from 19 to 18. Aggressive Pleo resulted in an overall increase in crew enjoyment, from 12 to 17. Romibo also resulted in increased crew enjoyment, from 12 to 16.

Question five asked crew members whether they fed Pleo when they felt it was hungry. This question was asked to reveal the level of bonding with the robotic companion, insofar as it indicates that the crew member felt responsible to ensure its wellbeing. Overall, passive Pleo experienced a slight drop in the score for feeding, from 18 to 17. Aggressive Pleo saw a slight increase, 11 to 13. Romibo did not have the ability to eat, and so was not included in this question.

The sixth question asked crew members whether they provided Romibo with physical attention when requested by the robot companion. Romibo saw an increase in physical attention from crew members, going from a score of 8 up to 11. Pleo was not included for analysis in this question.

Finally, the seventh question asked crew members whether the wellbeing of the robot companion was important to them. Passive Pleo showed no change over the trial, scoring 9 overall. Aggressive Pleo also saw no change for this question, scoring 10 at the start and end of the trial. Romibos? score dropped slightly during the trial, from 7 to 6.

B. Emotional Word Association

Taking the list of words and tallying up the crew members? frequency of selecting each word, we were able to gauge the emotional context each crew member associated with the robotic companion before and after the three-day interaction.

Fig. 9 shows a tally of words checked off in the emotional word association, for the start and end of the trial. Looking at the results, there are a few changes of significance. For words with positive emotional context there appeared to be an overall increase in positive words at the end of the trial. Crew members considered Pleo to be more ``cuddly? after the trial ended. The was a slight decrease in the word `fun', but an increase in the word `enjoyable'. Interestingly, neutral words, such as `pet', `robot', and `interactive' showed no score at all, although the neutral word `android' increased slightly over the trial. Increased negative feelings could be seen in words like `unpleasant', and with the word `pleasant' decreasing over the trial. The word `demanding' showed a slight decrease, and strong negative words such as `inconvenient' and `annoying' had no score at all.

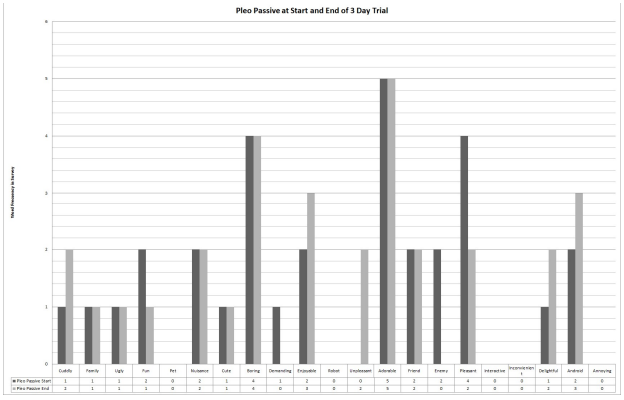

Figure 9. Comparing passive Pleo before and after three days of interaction.

Figure 9 shows the tally of words checked off in the emotional word association for the aggressive Pleo personality at the start and end of the trial.

The results showed positive changes in emotions towards aggressive Pleo. As shown in Fig. 9, the words `fun', `pleasant', and `delightful' remained constant from the start to the end of the trial. The word `friend' was the only word associated with a positive emotion that increased. Words associated with neutral emotions, such as `pet' and `interactive' received no score in the study. Meanwhile, the negatively associated words `nuisance', `unpleasant', and `enemy' showed a slight increase.

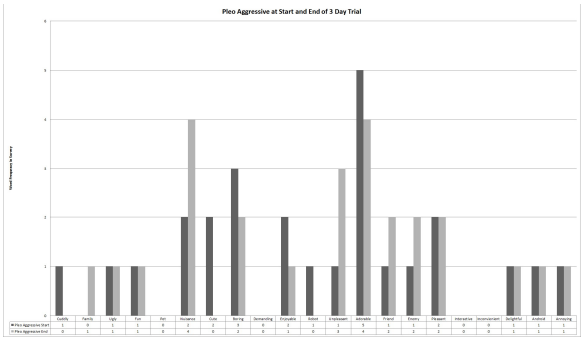

Figure 10. Comparing aggressive Pleo before and after three days of interaction.

Overall, the crew members appeared to have a mixed reaction toward aggressive Pleo. This is most evident by the result that both the words `friend' and `enemy' increased by the same amount over the trial.

With Romibo, the crew members initially reacted negatively toward the robot companion and then grew to have more positive emotions by the end of the trial. This is most evident with the strongly negative words `ugly', `nuisance', and `unpleasant' all decreasing in score over the trial period. Meanwhile, positive words such as `fun', `pleasant', and 'delightful' increased over the course of the trial. It can be surmised the Romibo platform gained a positive emotional bond with the crew members.

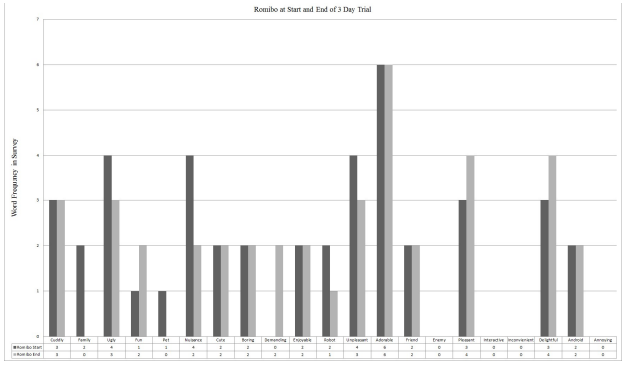

Figure 11. Comparing Romibo's personality before and after three days of interaction.

Figure 7 shows the long-answer questions that each crew member was asked to fill out. The results are paraphrased here. Crew members were asked to describe aspects about the robotic companion that they liked and disliked. They were also asked to relate any interactions that they found fun, interesting, positive, or negative.

C. Crewmember summaries for Pleo

Crew member 1: This crew member indicated never having interacted with pets in the real world and finding it difficult to relate to the robot. Initially, the crew member only saw a machine. However, at the end of the trial the crew member reports having had fun observing the different behavior exhibited by Pleo, as well as a desire to keep Pleo in the lab to derive enjoyment from petting it.

Crew member 2: This crew member indicated that she found it enjoyable to interact with Pleo but felt uncomfortable playing with the robot companion while working and worrying that something bad might happen to it. She tried to teach the robot to walk on its hind legs and walked around with it balanced on her head. The crew member explained that she found it similar to interacting with her cat at home. Overall, this crew member indicated a positive interaction with the robot companion in the long-answer question.

Crew member 3: This crew member indicated a positive interaction with Pleo from the start of the trial, having enjoyed playing with the robot at certain times. However, the crew member noted that requests by Pleo were unwelcome during times when the crew member was working on other projects. This particular crew member seemed to prefer to choose when to interact with the robotic companion. The crew member liked the feature that the robot companion would go to sleep when the room got dark, and that when the lights in the bedroom were turned on the robot companion would wake. Crew Member 2 mentioned that the expressions of the eyes and body language were interesting and pleasant. Crew Member 2 also indicated that the design and pauses in movements were distracting and could be more sophisticated.

Crew Member 4 used Pleo while working and doing chores. This crew member found the robot companion to be distracting during this time, due to its requests for food. The crew member also indicated difficulty trying to understand what the robot companion was indicating by its movements and sounds. The crew member also reported not having animals at home and very limited experience with pets. The crew member indicated that Pleo was not sufficiently complex or interesting.

Crew member 5: This crew member interacted with Pleo in the private room. The crew member mentioned that the robot was not soft and cuddly, and suggested that this would be a good attribute to make Pleo fun to hold.

D. Crewmember summaries for Romibo

Crew member 1: This crew member reported a negative reaction to Romibo in the first entry, indicating the robotic companion was ugly. The crew member found the blinking behavior loud, although it was reportedly good background noise at times. The crew member also found the voice annoying and did not like interacting with the robot. However, the crew member also reported disliking cats and found that cat behavior was annoying.

Crew member 2: This crew member also disliked the overall look of Romibo. The crew member felt that the movement was too limited and that the robot was awkward to hold and not cuddly. The second entry indicated a more positive view of Romibo, where the crew member found it mildly amusing, and reported enjoying the activity of petting it and having it around.

Crew member 3: This crew member indicated that the servo motor sounds were a bit distracting yet served as acceptable background noise. The crew member indicated that the touch sensors were a bit too difficult to press, preferring something more sensitive. The crew member preferred Romibo over Pleo because of the former?s fur. It was nicer to pet Romibo and interact with it in this way. However, some of the more complex behavior exhibited by Pleo would have been desirable in Romibo.

Crew member 4: This crew member indicated that Romibo was not relatable. The crew member did not see the point of it and found its variety of sounds and words annoying. The crew member reported that the robotic companion was too limited in behavior.

Crew member 5: This crew member also found that Romibo was more likeable than Pleo. The crew member indicated that the big eyes and helpless look of Romibo was something that made him feel sorry for the robotic companion. Interactions

were much easier for him to understand and he enjoyed them. The crew member found that the fur was nice to touch and that this generated a stronger relationship. He found that it was nice to use the robot as a pleasant distraction while working alone.

VII. DISCUSSION

In the experiment, Romibo was governed by an FSM with four states. In future research, an FuSM shall be incorporated into the original FSM with a series of probabilistic conditions for entrance into a state. This will allow for the randomization of state initiation, creating more complex and less predictable behavior. This FuSM will also incorporate similar probabilistic conditions for entrance to each type of behavior within a state. This shall induce further complexity into the behavior, making the robotic companion more dynamic and less predictable. For instance, when a user touches Romibo, it might not respond, effectively ignoring the interaction. If Romibo does not ignore the interaction, its response will be different each time, according to a probability distribution. This will make Romibo much less predictable and potentially much more rewarding in terms of interaction. In addition, the development of a system with the recognition of voices and commands can be implemented. With the introduction of more behavior, vocalization, and interaction, Romibo should be able to overcome many of its limitations and convey a stronger relationship with crew members.

VIII. CONCLUSIONS

Overall, the changes in attitude and emotional bonding towards the robotic companion were small but present. There was a general trend toward having a slightly more positive view of the companions, and emotional changes moved in a positive direction. The aggressive-style personalities risked taxing the crew members quickly, and interactions seemed to produce more negative emotion. Passive personalities showed a greater increase in positive interactions and emotions toward the companion. That this change was small is likely due to the short period of time that the crew interacted with the robotic companion directly. The crew was highly engaged with the companion over a short period of time, and the limitations in behavior caused the crew members to lose interest. The fact that the crew did not continue to interact with either of the robotic companions after the assigned period indicates a lack of overall interest in the companions due to a lack of complexity.

What can be taken from this experiment and data is that robotic companions do possess the potential to have a positive emotional effect on a crew member. They also have the potential to create strong emotional bonds. Nevertheless, it is apparent that the complexity and dynamics of a robot companion must increase considerably in order to be able to create a strong positive emotional reaction and bond. Adults are simply not easily entertained and require a wide range of behavior. Thus, our goal to continue developing robotic companions with increased complexity. It is hoped that a range of behavior can determine what kind of personality and behavior will be most suitable to adult crew members.

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