Establish Trust and Express Attitude for a Non-Humanoid Robot

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Abstract

In recent years, there has been an increasing interest in designing social robots to interact with people to provide therapy and companionship. Most social robots currently being used are light-weight and much smaller in size compared to people. In this work, we investigate designing interactions for larger and more physically capable robots as they have more potential to assist people physically. A modified version of Baxter robot was used, by sitting Baxter on top of an electronic wheelchair. Two experiments were designed for studying the role of facial expressions and body movements in establishing trust with the user and for expressing attitudes. Our results suggest that the robot is capable of expressing fine and distinguishable attitudes (proud vs. relaxed) using its body language, and the coupling between body movements and speech is essential for the robot to be viewed as a person.

Keywords: Robot Human Interaction; Gesture; Trust

Introduction

In recent years, there has been an increasing interest in designing social robots to interact with people, as a tutor or a companion. For example, Sony's AIBO robotic dog has been used for improving autistic children's play, reasoning, and affective skills (François, Powell, & Dautenhahn, 2009). Autom is a humanoid robot, which is capable of establishing eye contact with the user and making small talk. It was used for helping people keep track of their weight loss history (Kidd & Breazeal, 2008). Nao and Hanson robots have also been widely used for research, tutoring, and entertainment purposes.

Most social robots currently being used are light-weight and much smaller in size compared to people. This makes them naturally look non-threatening. On the other hand, they have limited movability and physical strength, which limits their potential for physically interacting with and assisting people. In this work, we want to investigate designing interactions for robots, which are larger and more physically capable. We start this exploration using a modified version of Baxter, a dual-arm robot by Rethink Robotics. The robot by itself is 3'1" (93.98 cm) in height. With modification, the robot sits on top of an electronic wheelchair. Its actual height is similar to an adult sitting on a chair. The robot's arm can reach 41" (104 cm). Its body looks sturdy, with a weight of 165 lbs (75 kg).

To enable long-term natural interaction between robots and users, we strive to not only rely on safe, dependable robotic movements but also leverage existing research studying human-computer interaction and human social interaction to create a positive experience with trust and comfort. Furthermore, we want to have the capacity of creating different "personalities for the robot. Here we do not necessarily need to build an active or intriguing character, but rather to present meaningful and consistent behavior patterns that the user can infer from the robots actions for enhancing the believability of the robot as a human-like character. Breazeal studied the requirements to "promote the illusion of a socially aware robotic creature and found that to socially engage a human, its behavior must address issues of believability such as conveying intentionality, promoting empathy, being expressive, and displaying enough variability to appear unscripted while remaining consistent" (Breazeal, 2000). Similar arguments have been given for creating digital companions (Bickmore & Rosalind, 2005), and for assistant robot. It has been found that even though assistant robot does not need to represent a social character, having a "personality helps the user to understand and predict its behaviors (Severinson-Eklundh, Kerstin and Green, Anders and Httenrauch, Helge , 2003).

Both facial expressions and non-verbal behaviors play important roles in social interactions. In particular, it has been shown that for human-like robots, showing appropriate non-verbal behaviors such as gaze, head nod, and gestures can improve people's performance in a collaborative task because people can better understand the robot's intention (Breazeal, Kidd, Thomaz, Hoffman, & Berlin, 2005). Many robots used by rescue teams, law enforcement, and the military are designed with functionality as a higher priority, and thus, they do not appear humanlike and have limited means to support natural human-robot interaction. While these robots are often modified to have a facial display to express affect, researchers have found that their body movements may play a more important role (Bethel & Murphy, 2008). Our modified Baxter robot belongs partially to this category. We face the challenge of the robot not having an exact human-like shape. Because of the robot's physical strength and size, potential negative misinterpretations of the robot's intentions will become particularly problematic.

In this work, we designed two experiments for studying the expression of attitudes using the robot's body movements. In the first experiment, we examined how using human-informed gestures and social dialogue, and having a digital face can make people feel more comfortable to interact with the robot. In the second experiment, we further investigated expressing two different attitudes relaxed and proud using

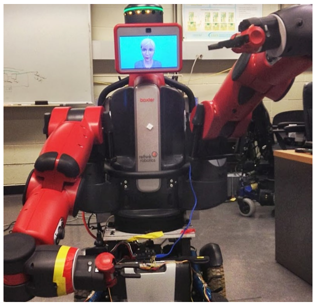

Figure 1: Baxter with Virtual Human Face

the robot's body movements.

Experiment 1

In this experiment, we examined how placing Baxter's movements into a social context with its dialogue affects people's perceptions of its safety and friendliness. We studied the importance of having meaningful gestures and a face display. In particular, it is natural that people feel more comfortable interacting with a novel device after seeing how it operates or moves. To study whether there is a difference between this phenomenon and the effect of viewing the robot as a person, we designed an experimental condition in which the robot's arm movements are not coupled with its speech and compared the participants' responses in this condition against other conditions.

Experiment Design and Subjects

Forty-three undergraduate students from Rensselaer Polytechnic Institute were recruited to participate. Their participation was compensated by giving course credits. The independent variable is the way the robot interacted with the participants, which has four conditions.

Common to all the conditions, we designed an interaction routine in which the robot talked about the research projects it is involved with and its various capabilities. Baxter's introductory statements consisted of fifteen sentences. Baxter then asked the participants ten questions about his/her personal interests, e.g. what kind of music do they like (to which they replied verbally on 7-point Likert scales) and commented on the participants' responses after all questions had been answered. The interaction with each participant lasted approximately five minutes. Afterward, Baxter prompted the participant to approach it and shake its right hand but assured the participant that he/she could decline to shake hands if he/she felt uncomfortable doing so. Then as the participant approached, Baxter extended its arm towards him/her. Before this gesture, the participant had not physically touched or been touched by the robot. Therefore, though extending one's arm towards the other person is natural for handshakes, it could be perceived as an unexpected event from the robot. We expected the participants to feel less apprehension – measured by how much hesitation they had to continue the handshake – if they treated the robot like another person.

Guided by research in proxemics (Hall et al., 1968), we positioned the participants within the social zone of Baxter, between 4' and 12' away: specifically, 9' (2.7 m) away. When the participants approached Baxter to shake hands, they left the social zone and entered the intimate zone. For safety reasons, the experimenter was in the same room during the interaction.

Two control groups were used: one in which participants saw no arm movement during the routine (No Gestures, $N = 9$) and one in which participants saw arbitrary arm movements at the start of the routine, not tied to any particular behavior or gesture (Arbitrary Gestures, $N = 8$). Neither control group saw a virtual face on Baxter. The first control group is a baseline to compare against all other groups that add a form of gesture to the routine. The second control group is used to determine whether any arm movement elicits the same response as arm movements that are performed to couple with the dialogue.

Two experimental groups were used: one in which participants saw meaningful gestures without a face (Meaningful Gestures, $N = 13$), and one in which participants saw meaningful gestures accompanied by a virtual human face (Meaningful Gestures with Face, $N = 13$).

We adopted a between-group design, and the participants were randomly assigned to one of four different groups. For dependent variables, we measured a categorical dependent variable, "hesitation," which represents how much the participant hesitated before approaching Baxter when prompted to shake hands. A score of "low" was given to the participants who waited less than one second to approach Baxter. A score of "medium" was given to the participants who waited between one and two seconds, and a score of "high" was given when the participants waited more than two seconds or looked to the experimenter for clarification that they could approach Baxter if needed. This measurement was taken by the experimenter.

For the participants' subjective reports about the robot, we used three dependent variables. During the interaction, one of the questions asked by Baxter was how friendly it was ("friendliness"). After the interaction, all participants responded to two additional questions asked by the experimenter during the debriefing phase: how comfortable would the participant be interacting with Baxter at a close distance ("comfortability closeness"), and how comfortable would the participant be letting Baxter touch them with one of its arms ("comfortability touch"). Similar to answering Baxter's questions, the participants answered these two questions using a 7-point Likert scale.

Implementation

Figure 2 shows the system architect we used to create the Baxter "character" in this experiment. The robot's gestures were created manually to complement each line of the dialogue, informed by human nonverbal behaviors, in particular, McNeill's work on hand gestures (McNeill, 1992). Baxter uses deictic gestures such as pointing to the participant

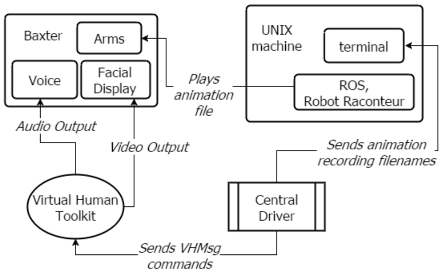

Figure 2: System Architect

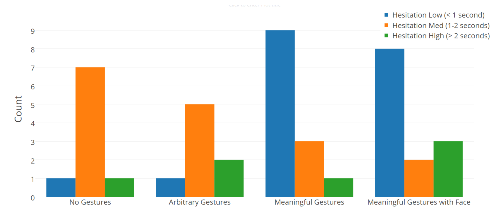

Figure 3: Hesitation before Handshake

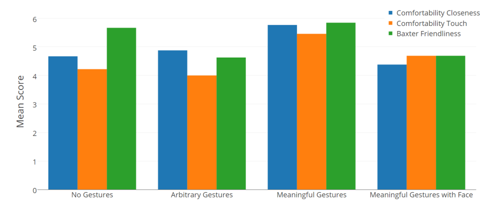

Figure 4: Mean Ratings of “Comfortability Closeness”, “Comfortability Touch”, and “Friendliness”

or pointing to the general gesture space. Baxter uses iconic gestures when talking about activities. For instance, Baxter asks the participants, ”To what extent do you enjoy working on pieces of art, or writing?” and moves its left hand in small circles as if it is writing on imaginary paper. It uses metaphoric gestures when discussing concepts like creating and expanding by bringing its hands together and then moving them apart. Finally, beat gestures are used with greetings and exclamations to punctuate Baxter’s emotional intent.

We recorded Baxter’s arm movements using ROS “Robot Operating System” and Robot Raconteur, a communication library for robotic systems (Wason & Wen, 2011). A ROS service records the joint positions of Baxter’s arms as we manually manipulate the positions of the arms. We then systematically reduced the recording files down to keyframes to reduce any jittery movement, and stored the result of interpolating joint positions between key frames to be used for driving the robot’s movements during the interaction.

In the condition which included a virtual face on Baxter’s display screen, we utilized the Virtual Human Toolkit (VHT) (Hartholt et al., 2013). We used the face of a female character named Rachel, shown on Baxter as in Figure 1. During the interaction, Rachel’s facial expressions remained mostly neutral. Rachel’s voice was generated using Text-to-Speech.

We created a custom Windows Forms application written in C#/.NET as a driver for VHuman and Baxter during the interaction. It sent arm movement, speech, and facial expression commands to their respective destinations for each segment of the routine. This system also allowed the experimenters to utilize a “Wizard of Oz -style approach. When the participants were asked questions by Baxter, the experimenters could enter their answers into the application for Baxter to comment on later in the routine.

Results

A chi-square test of independence was conducted to examine the relation between the experiment condition and amount of time that participants hesitated before approaching Baxter to shake hands. The test showed a significant relationship between which version of the routine participants observed and their amount of hesitation to approach Baxter, $X^2(6) = 15.46$, $p = 0.02$. No participants declined to shake hands with Baxter, but they differed significantly in the amount of time to approach Baxter after the request.

Of the standardized residual values, shown in Table 1, the differences were significant at the 0.05 level between the “Meaningful Gestures” condition and “No Gestures” and “Arbitrary Gestures” conditions for participants in the low and medium hesitation categories. Overall, participants in the “Meaningful Gestures” condition hesitated least in approaching Baxter, and participants in the control groups “No Gestures” and “Arbitrary Gestures” hesitated more. A comparison of hesitation measures of all conditions is shown in Figure 3.

One-way analysis of variance(ANOVA) tests were conducted to evaluate the differences between all groups on three ordinal measures: comfortability interacting with Baxter at a close distance (“comfortability closeness”), comfortability letting Baxter use its arm to touch the participant (“comfortability touch”), and how friendly the robot seemed during the routine (“friendliness”). A summary of the ANOVA tests can be found in Table 2, and the mean scores for each condition in all measures can be seen in Figure 4.

There was a significant difference among groups on how comfortable the participants would be interacting with Baxter at a close distance after having seen the routine, $F(3,39) = 3.154, p < 0.05$. Post hoc comparisons using the Fisher LSD test indicated that the mean score for the “No Gestures” group ($M = 4.67, SD = 1.12$) was significantly lower than the “Meaningful Gestures” group ($M = 5.77, SD = 1.09$), $p < 0.05$. The mean score for the “Meaningful Gestures” group was significantly higher than the “Meaningful Gestures with Face” group ($M = 4.38, SD = 1.33$), $p < 0.01$.

Groups differed significantly with how comfortable the participants would be letting Baxter touch them with one of its arms after having seen the routine, $F(3,39) = 3.865, p < 0.05$. Post hoc comparisons using Fisher LSD indicated that the mean score for the “Meaningful Gestures” group ($M = 5.46, SD = 0.88$) differed significantly from the “No Ges-

Table 1: Standardized Residual Values of Participants Hesitation in Experiment 1

	Low	Medium	High
No Gestures	**-1.5**	**1.8**	-0.4
Arbitrary Gestures	**-1.3**	1.0	0.6
Meaningful Gestures	**1.4**	-0.9	-0.8
Meaningful Gestures w. Face	0.9	**-1.4**	0.6

Table 2: ANOVA Tests for Experiment 1

Measure	*df*	*MS*	*F*	*p*
comfortability closeness	3	4.54	3.15	.035
comfortability touch	3	4.51	3.86	.017
friendliness	3	4.45	3.74	.019

tures" group ($M = 4.22, SD = 0.67$), $p = 0.01$, and from the "Arbitrary Gestures" group ($M = 4.00, SD = 0.76$), $p < 0.01$.

The final ANOVA test revealed a significant difference among groups with how friendly participants perceived Baxter to be, $F(3,39) = 3.742, p < 0.05$. Post hoc comparisons using Fisher LSD indicated that the mean score for the "No Gestures" group ($M = 5.67, SD = 1.00$) was significantly higher than the "Meaningful Gestures with Face" group ($M = 4.69, SD = 1.18$), $p < 0.05$. Additionally, the mean score for the "Meaningful Gestures" group ($M = 5.85, SD = 1.07$) was significantly higher than the mean scores for both the "Arbitrary Gestures" group ($M = 4.63, SD = 1.06$), $p < 0.05$, and the "Meaningful Gestures with Face" group, $p = 0.01$.

Discussion

In this study, the participants were more likely to approach Baxter without hesitation when they witnessed gestural arm movement beforehand, with or without the addition of a virtual human face on Baxter's display screen. Introducing irrelevant, arbitrary arm movement in the second control group demonstrated either no impact (when comparing to the first control group) or a negative impact (when compared to the two experiment groups) on the participants' hesitations, suggesting that meaningful arm movement was key in reducing the participants' hesitations. This confirms our hypothesis that gestures associated with a social context are most effective in increasing people's trust and feeling of comfort in interacting with the robot. We want to point out that the positive impact of accompanying speech with meaningful gestures took place after just a few minutes of interaction. This provides strong evidence for the benefit of embodying a robot as a social character.

Although the "Arbitrary Gestures" group reported a mean score for "comfortability closeness" similar to the experimental groups, this behavior negatively impacted ratings of how likely participants would be to let Baxter make physical contact with them. Participants in both control groups reported lower scores for "comfortability touch" than participants in the "Meaningful Gestures" group.

Finally, the participants rated Baxter as being friendlier when they saw meaningful gestures instead of arbitrary gestures or when the virtual face was not present. There are many possible explanations for this result. The digital human like face might introduce the uncanny valley effect. Moreover, because the rest of the robot's body is not human like, the participants might experience a disconnection between the face and the body. Combining with the fact that displaying the virtual face did not help reduce the participants' hesitations to approach Baxter, this result suggests that we should use caution when using a 3D realistic virtual face for this robot.

Experiment 2

This experiment evaluates whether people can differentiate and appropriately label the robot's attitudes based on the robot's body movements. Unlike in Experiment 1, we utilized the software CrazyTalk Animator by Reallusion to create the facial animations. An original face was drawn as a boxy, outlined appearance that is much less realistic than the human face in Experiment 1.

Experiment Design and Subjects

We modeled two routines for Baxter: a Proud routine (sterner and more bragging) and a Relaxed routine (more relaxing and soothing). We picked these two attitudes because they are likely to be useful in health care, and educational domains. Moreover, the difference between these two attitudes is subtler than more commonly perceived emotions like happiness or anger, and therefore, the success of this experiment will provide us more confidence in using the modified Baxter robot to express emotions and attitudes in the future. Similar to Experiment 1, in these routines, Baxter talked about student life on campus and the many things that the university offers.

Twenty-four undergraduate students were recruited to participate. This time, we used a within-group design. The participants observed the dual-arm Baxter robot equipped with a cartoonish face discuss a topic twice, using different nonverbal behaviors in each routine. Each participant saw both routines in random order. Each routine lasted approximately one and a half minutes. Baxter's speech was controlled to be similar between routines, with the main differences being the displayed nonverbal behavior and facial expressions.

For each routine, the participants need to pick the most appropriate emotion/attitude label from a list. HUMAINE Emotion Annotation and Representation Language (EARL) consolidates emotion labels into ten categories (Schröder, Pirker, & Lamolle, 2006). Pride and Relaxed belong to the "Positive Thoughts" and "Quiet Positive" categories respectively. We also picked one relevant label from each other categories. The ten options for the participants are anger, fear, relaxation, frustration, sadness, shock, happiness, affection, pride, and surprise.

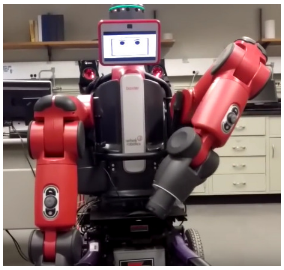

Figure 5: Baxter with CrazyTalk Cartoonish Face

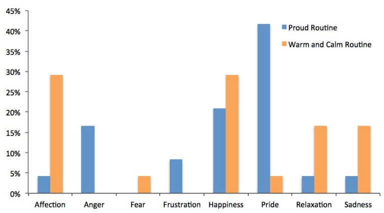

Figure 6: Emotion Labels for Each Routine

Implementation

As in Experiment 1, we recorded Baxter's arm movements using ROS and Robot Raconteur (Wason & Wen, 2011). When modeling pride, we want the robot to seem highly aroused and actively engaging the participant during most of the routine (Ekman & Friesen, 1967). Therefore, in the Proud routine, gestures using Baxter's arms were more focused toward the observing human participant. For example, during the initial introduction, Baxter says, "Hello, I am Baxter, one of the amazing robots in the robotics department, raises its right arm, and pats its torso in a highly precise, confident manner. In contrast, the Relaxed routine was associated with positivity (Ekman & Friesen, 1967). Movements for the Relaxed routine included sweeping the arms in slow arcs and keeping the hands rotated inwardly toward Baxter's body, with more frequent pauses and less overall movement than the Proud routine. For example, the initial greeting includes a small, tentative wave of the hand.

Similarly as in Experiment 1, we identified keyframes for each recorded file and interpolated the joint positions for creating smoother animations. Figure 5 shows Baxter with one of the faces from CrazyTalk. This face has limited capacity of expressing emotions with subtle differences. Also, we wanted to prevent the participants from forming their judgments mainly based on the robot's face. Therefore, the facial expressions remained mostly neutral for both routines. We used a male Text-to-Speech voice for the robot.

Results

A chi-square test of independence was performed to examine the relation between the designed routine and the attitude associated with it by participants. The labels shock and surprise were not chosen by participants for either routine, so we do not include them in the results.

The test showed a significant difference for which emotions were chosen for each routine based on the Pearson Chi-Square value, $X^2(7) = 22.80, p = 0.002$. Of the standardized residual values, the differences were significant at the 0.05 level among the three labels – pride, affection, and anger. Pride accounted for the largest amount of difference in the distribution, with affection second and anger third.

Figure 6 shows the distribution of chosen emotions for each routine among the twenty-four participants. The participants mostly matched the Proud routine to the intended proud emotion at 41.70% (10 participants), with happiness second at 20.80% (5 participants) and anger coming in third at 16.70% (4 participants). For the Relaxed routine, participants mostly matched the routine to both happiness and affection at 29.20% (7 participants) each, with relaxation and sadness at 16.70% (4 participants) each.

Discussion

The spread of participant labels for Baxter's emotional intent was more even for the Relaxed routine than for the Proud routine. In the Proud routine, the gestures were firmer and more aggressive and were more tightly coupled with precise moments in the dialogue, which may have contributed to this result. In post-experiment interviews, many participants reported that Baxter spoke about itself and the university with high praise and that the audience should agree with Baxter's comments – as opposed to the perceived inclusive, friendly tone of the Relaxed routine. Also, being relaxed can often be a secondary element of another perceived primary emotion such as joy (Ekman & Friesen, 1967). Relaxed and calmness is conveyed through slow, flowing movements, often associated with voice tone in ratio to the face and body (Ekman & Friesen, 1967, 1969). Pride, on the other hand, can be displayed more readily through use of nonverbal behavior. Therefore, the relaxed attitude may have been too vague to be successfully identified. In our previous work using a TurtleBot, we have observed that the noise made by the robot when it is moving can intensify the expression of negative and high dominance emotions such as anger, and affect the expression of low dominance emotions such as shyness (Barron & Si, 2013). Though the participants did not specifically comment on the noise as a factor affecting their impressions about the robot, we suspect the noise played a similar role in this study, i.e. lead some participants to believe the robot was angry.

We also observed an interesting ordering effect. The participants were more likely to see a greater contrast when they saw the Relaxed routine first and then labeled the Proud routine with a negative emotion. Feedback from these participants mentioned that Baxter seemed less friendly in the second routine. Labels applied to the Relaxed routine were more consistent regardless of the ordering of the routines.

Another interacting observation was that several participants mentioned hearing a change in the voice inflection between the two routines even though we used the same Text-to-Speech engine. Though not exactly the same as the McGurk effect, this also demonstrates what people see can affect what they hear, even in such a brief and simple social interaction scenario.

Conclusions and Future Work

In this work, we examined the effects of designing meaningful arm movements for a modified version of Baxter robot. Our results suggest that it is feasible to create a social character using this robot even though it does not have an exact human-like shape. We demonstrated that designing body movements that are timely coupled with the robot's speech makes people more likely to trust the robot and feel comfortable in its presence comparing to demonstrating the robot's arm movements independently from its speech or not demonstrating how the robot movements at all. Moreover, this difference takes place in just a few minutes. Finally, the Baxter robot can use body language in a similar way as humans for expressing distinguishable attitudes, more specifically, being either proud or relaxed. However, its proud manner has the danger of being misinterpreted as anger, and its relaxed attitude is very easily confused with other positive emotions such as happy and affection.

Future work would further examine how using meaningful arm and face movements to express emotional intent affects people's willingness to approach and interact with Baxter in close proximity and over a longer period. Right now the robots body movements are planned independently from the participants. In real life, when two conversational partners have established rapport, their body movements are often coupled (Cassell, Gill, & Tepper, 2007). For example, one will often nod when the other pauses in his/her speech. One of our future directions is to enable such interactions for the robot. Secondly, we want to observe how people's attitudes toward the robot change over longer terms of interaction, and at moments when the robot makes a seemingly threatening action. In the latter case, we want to investigate whether the same techniques people use for recovering trust can be applied to the robot. Finally, compared to digital characters, when working with a physical robot, there is always the additional challenge of synchronizing the movements of its various parts, such as the two arms, or between the face and the arms. Even with the same set of commands, it is possible the movements become out of sync for a variety of reasons, which may break the image of the robot as a social character. We are interested in developing a software framework for helping with this challenge. When the robots body movements are delayed, we can also slightly delay its facial expressions and speech, or replan for another set of body movements, facial expressions, and speech.

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