Captain May I? Proxemics Study Examining Factors that Influence Distance between Humanoid Robots, Children, and Adults, during Human-Robot Interaction

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ABSTRACT
This proxemics study examines whether the physical distance between robots and humans differ based on the following factors: 1) age: children vs. adults, 2) who initiates the approach: humans approaching the robot vs. robot approaching humans, 3) prompting: verbal invitation vs. non-verbal gesture (e.g., beckoning), and 4) informing: announcement vs. permission vs. nothing. Results showed that both verbal and non-verbal prompting had significant influence on physical distance. Physiological data is also used to detect the appropriate timing of approach for a more natural and comfortable interaction.

Categories and Subject Descriptors
H.1.2 [**Models and Principles**]: User Machine Systems—Software psychology; human factors.

General Terms
Human Factors, Design, Experimentation.

Keywords
Human Robot Interaction, Proxemics Study, Young Children.

1. INTRODUCTION
Current limitations in sensor technology make physical distance between robots and humans a crucial factor in human-robot interaction (HRI) to detect and respond to situational factors and user state. Closer proximity will allow better sensor range for facial expression detection, speech recognition, collision detection during collaborative tasks, and allow better choice of expressive communication (e.g., verbal, gesture). This study examines the factors influencing inter-agent distances, and ways to modulate physical distance for safe and effective HRI. The term *proxemics* first introduced by Edward Hall [1] identified proximity zones (e.g., social, personal, intimate), and studied the distances between people when interacting in shared social spaces (Figure 1). Hall found that human sensory perspectives influenced the kinds of communication modalities used. Walters et al. [2] found that people stay further away with synthetic voices opposed to real human voices, and likeability influenced distance. Most proxemics studies are with stationary robots [2, 3] or robots with wheels. If robot movement is more natural and familiar (e.g., walk like a human instead of vehicle), children may respond in ways that influence proxemics. To study proxemics with robots, various metrics and observable behaviors need to be recorded from different perspectives, such as individual pose information, behavioral cues, interpersonal distance and physiological metrics. Our study explores conditions that actively modulate the inter-agent distances by selecting different behavior strategies (verbal and non-verbal) that can influence personal space. Given these metrics, the robot can use these factors to adjust or predict the ideal distance between humans in relation to sensory input, comfort level, and method of communication. The knowledge can also be used to design appropriate verbal and non-verbal behaviors for robots. Given these metrics, the autonomous robot would be able to use these factors to adjust, or predict the ideal distance between humans in relation to sensory input, comfort level, and method of communication.

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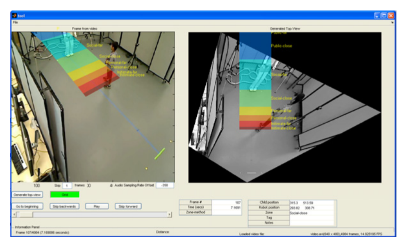

Figure 1. Semi-automatic tool that takes overhead video streams, and annotates the subject's angular orientations, distance from robot, and metric position (Hall's proxemics zones by color).

2. RESEARCH METHOD AND DESIGN
The study examines whether physical distance allowed by humans (adult or child) would differ under two specific situations, 1) *when human approaches robot*, and 2) *when robot approaches human*. Thirty children between the ages 5 to 7-years-old, and twelve adults participated in a one-to-one 20-minute session with Honda's humanoid robot. This study involved two parts. The first part "human approaches robot" was a 2x1 design where Age (adult vs. children) was the direct comparison. The second part "robot approaches human" was a 2x3 design that looked at Age (adults vs. children) and Type of Informing (Announce vs. Permission vs. Nothing). Through a WOZ environment [4] the robot and human engaged in conversation (e.g., hobbies). In part 1, *when human approaches robot*, we include the factor "prompting" to see if the robot's verbal (e.g., Feel free to come closer), or non-verbal prompting (e.g., beckoning) changes distance. In part 2, *when robot approaches human*, we include the factor "informing" like the child's game "Captain May I" to see if informing (e.g., robot makes announcement, asks permission, says nothing) changes distance.

3. RESULTS AND DISCUSSION

3.1 Part 1: Human Approaching Robot

There is a significant difference $t(40)=2.2$, $p<0.05$ between children and adults when initially approaching the robot. Without any prompting, adults show a 46% decrease in distance between themselves and the robot, while children only show a 25% decrease. Additional prompting (verbal and non-verbal) led to a decrease in physical distance for both children and adults where there were no significant difference between children (additional 14% decrease) and adults (additional 17% decrease). Non-verbal prompting (i.e., beckoning) led to another decrease by 12% for children, and %7 for adults. See figure 2 and 3. There was no significant difference at the end of the session between the two groups (Adults M=66% Children M=52%) $t(40)=1.63$, $p=0.11$.

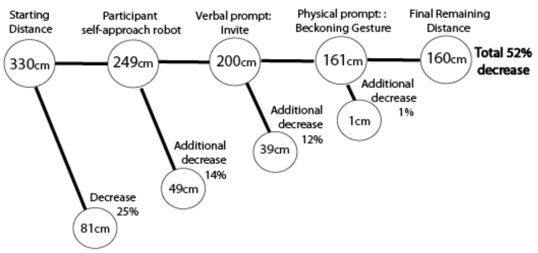

Fig.2. Avg. distance(cm) and %decrease in children

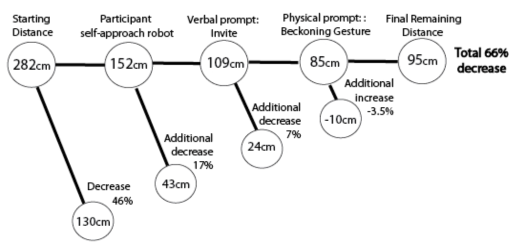

Fig.3. Avg. distance(cm) and %decrease in adults.

3.2 Part2: Robot Approaching Human

Type of Informing made a significant difference in % decrease for children at $F(2, 27)=6.1$, $MSE=0.047$, $p<0.01$. The simple act of "asking permission to take a step" significantly reduced the distance between robot and child compared to "making an announcement to take a step" or "saying nothing when taking a step". No difference was seen in adults (Figure 4). A Post-hoc Tukey's HSD tests showed that "permission" significantly decreased the distance compared to "announcement" ($p<.01$, Cohen's $d=1.47$, effect-size $r=0.59$), and approaching significance to "nothing (no warning)" style ($p=.078$, Cohen's $d=1.16$, effect-size $r=0.50$). See Figure 9. Another trend that we observed was that children seem to play safe by stopping the robot early, and then adjusting by stepping forward. This may have some design implications where the robot can approach a child but stop early to give the child a chance to adjust to give some control. Adults (see Figure 5), needed no adjustment and are quite consistent with the distance set. Skin conductance response (SCR) was used to measure physiological arousal levels in subjects to examine causal factors in participant behavior and physical distance (Figure 6). Video data and physiological data were synchronized to create potential data that can assist robots to predict and anticipate events (e.g., arousal level, robot movement). We are currently looking at SCR analysis in relation to conversations and events.

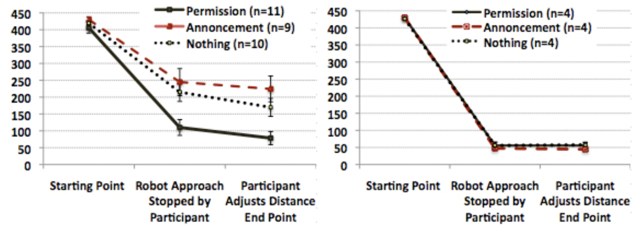

Figure 4. Inform effect on distance(cm) left-children, right-adult.

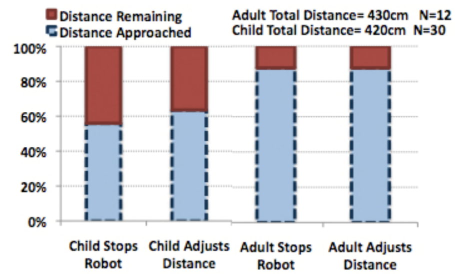

Figure 5. Remaining distance after stopping the robot, and adjustments made by child and adult.

Figure 6. Examining physiological measures

4. SUMMARY AND FUTURE WORK

This human-robot proxemics study examined different factors that reduced distance. Findings employ a variety of strategies to increase the chances for successful detection and delivery of response. As HRI advances, delivery of appropriate behavior and dynamic adjustment in movement will be crucial in maintaining successful communication and collaboration.

5. REFERENCES

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