Follow me: Communicating Intentions with a Spherical Robot

Conference Paper · August 2016

DOI: 10.1109/ROMAN.2016.7745189

4 authors:

Miguel Faria
Technical University of Lisbon

Andrea Costigliola
Technical University of Lisbon

Patrícia Alves-Oliveira
ISCTE | INESC-ID | Cornell University

Ana Paiva
Instituto Superior Técnico, Inesc-ID

25th IEEE International Symposium on
Robot and Human Interactive Communication (RO-MAN)
August 26-31, 2016. Columbia University, NY, USA

Follow me: Communicating Intentions with a Spherical Robot

Miguel Faria[1], Andrea Costigliola[1], Patrícia Alves-Oliveira[2] and Ana Paiva[1]

Abstract— **In recent years, robots have gradually become incorporated in our society and therefore play more relevant role in social environments. These robots vary in form, some being more anthropomorphic than others. This, creates a need to study their interaction with the world. In this paper we used Sphero and BB-8, two robots with a simple spherical body devoid of verbal and other complex communication methods, to investigate how they can communicate intention to people. A set of behaviors based on pet behaviors was designed and tested in a controlled experiment, where the robot's aim was to convince a participant to follow it. We concluded that the use of these behaviors allows a robot to effectively communicate intention as well as create a bond with the participant, who would treat it as an equal, thereby engaging it in social interactions such as playing with it or talking to it.**

Index Terms— **Non-anthropomorphic robots, Communicate intention, Non-verbal communication, Non-verbal behaviors, Limited expression, Animal behavior, Sphero**

I. INTRODUCTION

Nowadays, the field of robotics is not only concerned with making robots that are able to perform tasks, but is also interested in developing robots capable of participating in social life. The study of socially interactive robots has gained a relevant role in robotics and it is an important area of research within the field of Human-Robot Interaction (HRI). With robots becoming more socially integrated in society, there is a need to explore effective modalities of expression to enable them to communicate and interact with humans. It is known that human communication is complex and that comprises a myriad of modalities (*i.e.*, speech, gestures, facial expressions, among others). Robots, on the other hand, have limited expressions due to their embodiment and characteristics. This results, in a different expressiveness, according to the robot's physical design. Due to this, it becomes crucial to investigate expressiveness and communication of intentions not only in human-like robots, but also in robots with simple embodiments that rely on more primitive and limited means of communication.

The underlying motivation for this work emerged from the following question, *How can a robot convey intentions if it cannot talk, use facial expressions, or even gestures?* With this question in mind, communicative and expressive behaviors were developed for a simple robot, one without arms or hands, only capable of moving around on the floor and emitting lights or nodding its head. Subsequently, an experiment was conducted to explore the effects of this robot's behavior whilst interacting with humans, and specifically, if the humans were able to recognize the intentions of the robot. The participants would interact with two non-anthropomorphic robots (possessing limited communication means) that used behaviors inspired on pets as the basis of their communication behavior. In the case of this study, the objective was to persuade people to follow the robot to a room where chocolates and sweets sweets were displayed for participants to eat. The study was conducted in a lab facility and nothing was transmitted to the participants regarding actions towards the robots, nor any instruction was given related with the robot's intention, leaving an open space for the emergence of natural and spontaneous interactions with the robots.

We hypothesize that the robot's behavior, based on behaviors demonstrated by pets, will lead people to understand the robot's intentions during the interaction.

II. RELATED WORK

Interactions between humans and non-anthropomorphic robots that use non-verbal communication is not a novel topic in HRI; however, it is one with many aspects left unexplored.

A. Behavior Design for Robots

Communication with robots is a topic in HRI with an abundance of research, as it is crucial for an interaction to occur smoothly between a human and a robot. Previous work in the field of HRI has shown that a robot can use non-verbal explicit and implicit communication methods to interact with a human in collaborative and teamwork tasks [1]. Further research has also been carried out on how to improve a robot's readability using animation principles (such as forethought and reaction) and action anticipation, making the robot more expressive and the interaction more fluent [2], [3]. The use of non-verbal communication has also been studied by Brooks and Arkin (2007), where they explore the application of non-verbal communication behavior, including the use of proxemics, for an autonomous humanoid robot [4]. They observed that the presence of some non-verbal communication channel affects the way people interact with the robot and their proxemic behavior. Of particular interest is Bethel's (2009) work which was focused on non-facial and non-verbal affective expressions. In particular, she divides robot's implementations using affective expressions in three categories: non-anthropomorphic and appearance-constrained robots using non-facial and non-verbal expressions, anthropomorphic robots which rely on

[1]Miguel Faria, Andrea Costigliola and Ana Paiva are with INESC-ID and Instituto Superior Técnico, Universidade de Lisboa, Portugal miguel.faria@tecnico.ulisboa.pt, andrea.costigliola@tecnico.ulisboa.pt, ana.paiva@inesc-id.pt

[2]Patrícia Alves-Oliveira is with INESC-ID and Instituto Universitário de Lisboa (ISCTE-IUL), CIS-IUL, Lisboa, Portugal patricia.alves.oliveira@inesc-id.pt

non-facial and non-verbal expressions and traditional anthropomorphic robots using those expressions in addition to conventional facial expressions [5]. In Sirkin et. al. (2015) work, it was explored how a robotic footstool uses non-verbal communication to convince people to rest their feet on top of it. Many communication modalities have been explored with this robot, enabling the emergence of different behaviors in people when interacting with it. They showed how such a limited expressive robot can approach and interact with people, enabling the creation of a natural interactions with it. Moreover, the authors highlighted that almost all the participants that interacted with the robot treated it like a pet. The improvisation session that guided the behavior design included a pet-like interaction that was later embedded in the design [6]. Saerbeck and Bartneck (2010) conducted a study using a Roomba robot in order to discover a relationship between motion characteristics and perceived affect. Motion can be a useful non-verbal communication channel, and their work showed how modifications on acceleration and curvature in robot motion affected the attribution of affect [7]. Guy Hoffman and Wendy Ju have also shown, in [8], how to create a non human-like robot, which can play music stored in a device and then move accordingly to it, interacting with people and expressing its intentions using only movements.

B. Proximity Between Robots and Humans

The management of the social space is a fundamental aspect in human-robot interaction. It is important to design robots capable of moving around humans without making them feel uncomfortable. The different interpersonal space zones form the concept of *proximity*. This concept was first introduced by Hall (1966), who identified four general zones to divide the continuous space of interpersonal distances during interactions between humans [9]. Human usage of these spaces in their relationships has been later applied in robotics to design social robots that display an appropriate proxemic behavior. Yamasaki and Anzai (1995), studied how a mobile robot should place itself at an ideal distance from a human for a better speech recognition. This work demonstrated that the awareness of personal distance consideration improved the quality of the interaction [10]. Walters et al. (2005), conducted a research to demonstrate the validity of the spatial zones defined by Hall in human-robot interaction [11]. Their work partially confirmed the validity of the spatial zones in HRI with a 60% of participants preferring approach distances similar to those expected in social interactions between humans.

It is known that a robot able to modify its spatial behavior is more effective when interacting with humans, and also humans feel more comfortable around it. This aspect was highlighted by Smith in his Master's thesis, who designed a robot that could autonomously learn the personal space preferences of a human [12]. Moreover, Takayama and Pantofaru (2009), proposed an experiment to evaluate the influences of proxemic behaviors in HRI and the results showed that personal experiences with pets and robots have an impact on the distance people tend to keep from the robot [13]. Additionally, Mumm and Mutlu (2011), designed an experiment to assess how manipulation of gaze and likability of a robot affect the proxemic behavior of the participants [14]. Their results showed that participants who disliked the robot compensated for the increase in the robot's gaze by maintaining a greater physical distance from the robot, whilst participants who liked the robot did not change their proxemic behavior across the gaze condition.

In this study Sphero 1.0 and BB-8 will be used, two fairly recent robots that have had little utilization in research, being Sphero the most used. Examples of the usage of Sphero are seen in the work done by Sanders et. al. (2015), in [15], where they tested the influence of the robot's embodiment on the user's trust level. Shiomi and Hagita (2015) also use Sphero, where they studied people's acceptance of a childcare support robot system by designing an intelligent playroom in which they placed a Sphero robot to interact with the children [16]. So far, no work has been performed to research if people can understand the intentions of Sphero by using only its limited means of expression.

III. DESIGN

In this work two robots from *Sphero* (`http://www.sphero.com/`) were used, the Sphero 1.0 and the BB-8 (see Figure 1). These robots are non-anthropomorphic and spherical, with 3 Degrees of Freedom (DOF). Sphero is also capable of emitting lights, using LEDs placed inside the encapsulation, while BB-8 can nod its head by moving its body in the opposite direction. These robots were designed as toys, meant to interest kids in robotics and to explore what is possible to do with robots. At the time of this study, only Sphero 1.0 has support for the implementation of new behaviors, because BB-8, themed after *Star Wars VII: The Force Awakens* blockbuster movie, does not have any licenses allowing its API to be used by the public.

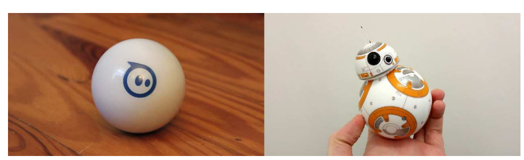


Fig. 1: Sphero 1.0, on the left, and BB-8, on the right, from Sphero

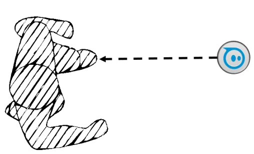
Both robots work with a combination of motors to generate the ball's movement, as well as a gyroscope and accelerometer used to maintain its orientation (in the case of BB-8 the gyroscope is also responsible for keeping the head always on top of the robot). Although both robots have a spherical embodiment and can move in every direction in a 2D plane, they have some differences regarding their expressive abilities: Sphero has controllable lights and BB-8 is capable of moving its head. The two robots are very similar, however, BB-8 has a head, which could improve its readability. Therefore, both were used in the study to see if their differences would impact the results. Since these robots are only capable of communicating with humans through motion, using lights or nodding the head, a way to communicate intentions using these restricted means on expression and interaction had to be developed. This communication was inspired by the way pets interact with humans and how the humans associate the respective intentions. Following the approach proposed in the book on dog behavior by Miklósi (2014), the communication interaction of visual signals can be divided into four stages [17]:

1) The sender produces signals to initiate the interaction.
2) It recognizes that the receiver is in a state of *attention*.
3) The sender sends further signals.
4) The sender might receive a response from the receiver.

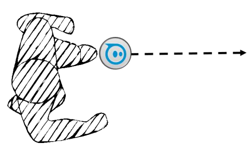
In practice, dogs often use such attention-seeking behaviors: a dog performs movements *to* and *away* from a person as an invitation to play or to be followed, or can bark to get attention.

Taking into account the expressive abilities of the robots and the research on pet behavior [17] and on lights used with non-anthropomorphic robots [18], the following behaviors were developed:

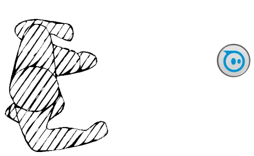
- Flashing or nodding the head to get attention (based on Baraka's work [18]), depending if we were using the Sphero or BB-8.
- Square-type or eight-pattern movement based on [17] to get attention.
- Movements *to* and *away* from a person to convey the intention that the robot wants the person to follow it (inspiration from [17], see Figure 2).
- Expressing happiness and sadness. These two emotional behaviors are a combination of both lights or head nodding and movement.



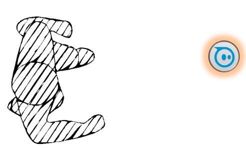
(a) The robot goes towards the person.



(b) The robot bumps into the person and walks away.



(c) The robot stops.



(d) The robot flashes/nods its head.

Fig. 2: Behavior: robot asks a person to be followed

Considering the constraints imposed by the robots' expressive abilities differences, the used behaviors were adapted to each robot.

A. Implementation

Due to the limitation of the absence of a pre-existing public API to program new behaviors for BB-8, the implementation was limited to using the behaviors and control mechanisms offered in the application released by the Sphero company. So, for BB-8, the group used the "Yes" and "No" head nods to interact with the participants. Also, the group used the "Square" and "Eight" programmed movements to obtain the participants attention. Regarding the robot's movements around the room and the *to* and *away* from a person, to convey the intention that the robot wants the person to follow it, both were done using the virtual joystick present in the application.

In Sphero, an Android application was developed using its public API. Like with BB-8, Sphero was moved using a virtual joystick. However, all the other behaviors used to interact, get attention and convey intentions or emotions to humans were encoded using Java. The programmed routines were previously described: flashing behavior, the robot flashed for 0.25s with random colors; move in and away from person, like Figure 2, and in each repetition the robot moves further away; square-type movement and expressing happiness and sadness: for happiness a light yellow was used, which is generally associated with joy, and the robot's speed was increased; for sadness the displayed color was greatly dimmed and the speed was heavily decreased.

IV. USER STUDY

The main goal of the user study was to test if the robots could correctly communicate with the participants and convince the participants to follow them. To test if the participants understood the robot's intentions, they would need to follow the robot from room where the interaction was initiated and head towards a stand in another division of the lab. This stand had three bowls with candies on top of it and a congratulations message for participants.

A. Sample

The study was conducted with 31 participants, 20 males (65%) and 11 females (35%). The mean age of subjects was 22 years (range: 18-26). 90% of the participants were students and 10% student workers. 84% of the subject sample studies in the area of Science and Technology, 3% studies Economics, 2% in the Social Sciences field and 2% study Art. Seventeen participants (12 males) were allocated to the condition where they interacted with Sphero 1.0. Of these seventeen participants, nine (53%) had previous experience with robots but only four (24%) knew Sphero 1.0. Also, three participants (18%) had already interacted with Sphero 1.0. The other fourteen participants (8 males) interacted with BB-8. Ten of them (71%) had previous experience with robots, and seven of them (50%) knew BB-8. However, none of the participants had already interacted with the BB-8 robot. All the participating subjects signed an informed consent previous to the experiment.

B. Procedure

The study took place in a lab room, which resembles a living room of a home. The same scenario was used both for Sphero 1.0 and for BB-8 conditions (see Figure 3). The study was conducted with one participant at a time, which interacted with one of the two robots mentioned above, allocated randomly to each condition. The experience was done using a Wizard of Oz, with the robots being controlled by one of the researchers. The subject starts the experience

Fig. 3: Experiment's room setup.

seated in a chair and answers to a pre-questionnaire. When the participant finishes, the robot enters the room from an open door located in front of the participant. One of the researchers is in the same room as the participant during the experiment, who is told that the researcher is there only to monitor the experiment. The researcher remains the whole time at a considerable distance from the participant and the robot, providing privacy for their interaction. Moreover, the instructions provided to the participant are that this work aims at testing how people and robots interact together. Henceforth, no other clues are provided on the intention of the robot's following behavior, allowing the participants to freely interact with the robot in whatever way they feel like. The interaction takes place mainly in the central part of the room, where the robot can move easily. In Figure 4 we can observe the layout of the entire interaction and the standard robot's trajectory.

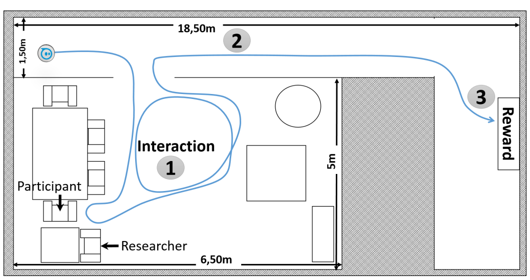


Fig. 4: Experimental scenario: 1) Robot and participant meet; 2) Participant steps outside the room to the corridor to follow the robot; 3) The participant finds the stand with candies and a congratulations message, saying the experience was over.

To ensure a standard interaction and that using a Wizard of Oz setup would not affect the results, a script detailing how the interaction would unroll was elaborated. The script encompassed the following stages of interaction:

1) **Robot and participant meet**
The robot enters the room, approaches the participant and flashes (in the case of Sphero) or nods the head (in the case of BB-8). Afterwards, the robot starts moving around the room and tries to interact with the participant. However, this stage can not be guaranteed to happen in the same way for all the participants, since it depends on two important aspects: the way the participant decides to interact with the robot and the difficulty in consistency of interaction given the Wizard of Oz.
2) **Robot tries to convince the participant to follow it**
The robot starts to communicate that it wants to be followed by performing the sequence of behaviors illustrated in Figure 2. The robot does three attempts at most to convince the participant to follow it. If the participant does not follow the robot at the third attempt, it continues interacting with the participant for a while and then it leaves the room, ending the experience. The extra time for interaction after the ending of the experiment was controlled to ensure that each session approximately lasted the same time.
3) **Participant follows the robot and gets the reward**
The robot guides the participant through an external corridor towards the reward and the experiment ends when the participant finds the stand with some candies and chocolate, and a sign congratulating them and signaling the end of the study.

C. Measures

In order to evaluate the interaction between the participants and the corresponding robot, each participant was asked to fill a post-questionnaire, adapted for each robot. The questionnaire was composed of questions about the proximity experienced with the robot, based on [19], and also of two dimensions of the standard Godspeed questionnaire: Perceived Intelligence and Likability dimensions [20]. Further specific questions were asked to the participants to assess the readability of robot intents. The participants had to select one from five options in order to associate robot's behaviors to intents. We also analyzed the behaviors of the participants during the interactions and measured how long it took them from the moment when the first contact with the robot was established to the moment the participant decided to follow the robot.

V. Results

The results are described in terms of questionnaires and behavioral analysis.

A. Behavior

Different factors were considered for the behavioral analysis. We analyzed the effectiveness of the robot in persuading the participants to follow it. In the Sphero trial, 12 of 17 participants followed it, as did 13 of 14 participants that interacted with BB-8. This results in 80,65% of the total number of participants following the robots. In order to test if our results were significant, we performed a Binomial Test, which proved that the proportion of participants that followed the robot was higher than a random distribution with a p = 0.001. The time that participants took to follow the robots was also measured. The interaction time of the experiments that involved Sphero, was, in general, shorter than in the experiments with BB-8. In particular the average time that the participants took to follow the robots was 2m38s for Sphero, and 3m13s for BB-8. Although this is an intriguing result there is no data that gives a reason for this difference.

To test if the participants understood the other behaviors displayed by the robots, they were asked a couple of questions in the post-questionnaire about what intention they associated to some of those behaviors. Although there was no correct answer for these questions, when the behaviors where designed and implemented they aimed at achieving certain responses and those initial notions were used as the most correct answers.

The questions asked were:

- To "When the robot touched me and moved away was for:" the expected answer was"ask to follow it". However the most common answer, with 48% of answers, was "ask for attention" followed by "ask to follow it", with 32% of the answers.
- To "When the robot flashed was for:" the expected answer was "ask for attention". In this case, most of the participants, 74%, answered as expected, followed by "displaying happiness", with 23% of the answers.

These results, although not conclusive, indicate that overall the participants that interacted with the robots in this experiment understood what the robot meant to communicate, albeit the fact that most of the participants did not associate the behavior of touching and moving away as a request to follow. The fact that said association was not made in most cases is interesting, because most of the participants understood that the robot wanted them to follow it. As such, this may indicate that a request, such as asking to follow, needs more than a simple action of moving in, touching and moving away from a person. As referred above, interactions were very different from one participant to another, but an interesting aspect was that the majority of the participants tended to perceive the robot as a "social entity". In fact, some of the participants engaged in conversation with the robot while others tried to communicate with it through gestures. In Table I some interactions between the participants and the robots in terms of speech, physical and behaviors are displayed.

Speech	Physical	Behavior
"Are you human?" "Hi, I'm André. Nice to meet you!"	Pick the robot up and examine it.	Play hide-and-seek.
"I'm going to teach you a game."		Play football.
"Are you running away from me, BB-8?"	Push the robot away with the feet.	
"Are you afraid of me?" "Do you like your creators?"		Play catch.
"What is your purpose? Just to exist?" "How can we play if you do not stop?"	Grab the robot on the floor and stop it.	Wave goodbye to the robot.
"Come here! Come here! Why are you running away?"	Put the robot on the table.	Call the robot like it was a dog.

TABLE I: Example of interactions between the participants and the robots.

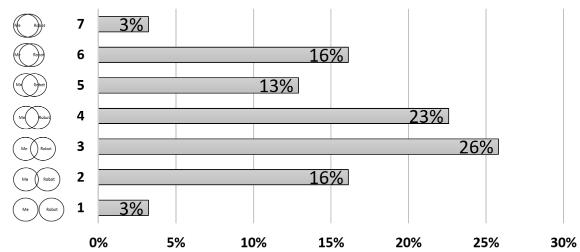


Fig. 5: Results of the proximity felt by the participants with the robots, using the Inclusion of the Other in the Self Scale [19].

B. Proximity

The participants were also asked to evaluate the proximity they felt to the robot, with the intent to assess if people felt close to the robot and if they perceived it as a "social entity" (see Figure 5). Since two robots were used when performing the experience, it was decided to test if the proximity that participants' felt towards the robots was affected by the robot they interacted with (BB-8 or Sphero). So, we performed a Pearson's chi-square test and we observed a weak association between the robot interacted with and the proximity felt, $\chi^2(6) = 5.547$, $p = 0.476$. The results obtained also show that the participants feel some connection with the robots, see Figure 5, grading the proximity, more frequently, as a 3 or a 4 in the scale.

C. Perceived intelligence and likability

In terms of the Perceived Intelligence and Likability the results of the questionnaires show that the participants liked the robots they interacted with (Sphero: M = 4.40, SD = 0.50; BB-8: M = 4.60, SD = 0.90, in a scale from 1-5), and thought that they were fairly intelligent (Sphero: M = 4.0, SD = 0.61; BB-8: M = 3.8, SD = 0.75). A One-way ANOVA was performed and showed that the participants did not notice a significant difference between both robots, with the perceived intelligence being $F(1,29) = 0.401$, $p = 0.53$ and the likability $F(1,29) = 0.009$, $p = 0.92$.

VI. DISCUSSION AND CONCLUSIONS

In this work the goal was to discover if it is possible for a robot, that could not use usual means of communication like speech, gestures and gaze, to communicate its intentions in an understandable way. In order to investigate that two robots were used, Sphero 1.0 and BB-8, since both have a spherical shape and can only communicate using movement and colors/head nods.

With that goal in mind, a Wizard of Oz experiment was designed, where the participants would interact with one of the robots and the robot would try to communicate that it wanted the participant to follow it, using pet-like behaviors. The results show that most of the participants understood what the robot meant to communicate and both robots were effective in communicating intentions. This lead us to conclude that the use of behaviors inspired in pets is useful when developing communication between humans and robots that rely only in simple ways to communicate. However, not all of the participants understood what the robots' meant to communicate. Observing the data recorded, no conclusion about the reason for this fact could be extracted, since the results of the questionnaires are similar for both cases where the robots' were followed and when they were not. For both groups both the perceived intelligence and likability had similar scores and also the proximity created with the robots revealed similar for both cases. When talking with some of the participants that did not follow the robots, they reported that they did not understand that they could leave the room and because of that they did not follow it. Besides this fact, one other reason, that seems to us as the motive for people not following the robots, is that perhaps humans do not associate only the physical movement to the intention of the movement and so some participants did not associate the intention to the movement.

The results about the proximity, similar in both the followed and not followed cases, are interesting, since they show that these simple robots, can not only communicate but also trigger a bond with people, which is a helpful feature not only for people to understand robots more easily, but to open a new spectrum of applications for robots of this kind.

Thus, this study showed that using implicit communication based on behaviors and actions associated to other beings with similar communication capabilities (e.g. pets), lets people understand what a robot wants to communicate, even when the robot lacks the usual means of communication. This fact is of great importance because sometimes it is not viable to use a robot capable of talking or moving arms, to communicate and interact with people, and with a model of communication like this it is possible to use a simpler robot to achieve similar communication outcomes.

In the future, we intend to extend the approach developed in this work - using pet like behaviors - with other non-anthropomorphic robots like aerial drones or Ollie (the other robot from Sphero), since these robots have different constraints and offer new interaction possibilities. This has special relevance since there seems to be an increased use of aerial drones in everyday tasks, like the Amazon Prime Air delivery system. Henceforth, it is important to study how these drones can communicate with people in a fluid and natural way, without having to resort to external devices like smartphones. Another aspect that is interesting to study related with how people react to this type of robots in an open space when they are not expecting to be approached by a robot.

VII. ACKNOWLEDGMENT

This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2013. P. Alves-Oliveira acknowledges a FCT grant ref. SFRH/BD/110223/2015.

REFERENCES

[1] C. Breazeal, C. D. Kidd, A. L. Thomaz, G. Hoffman, and M. Berlin, "Effects of nonverbal communication on efficiency and robustness in human-robot teamwork," in *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. IEEE, 2005, pp. 708–713.

[2] L. Takayama, D. Dooley, and W. Ju, "Expressing thought: improving robot readability with animation principles," in *Proceedings of the 6th international conference on Human-robot interaction*. ACM, 2011, pp. 69–76.

[3] G. Hoffman, "Anticipation in human-robot interaction," in *2010 AAAI Spring Symposium Series*, 2010.

[4] A. G. Brooks and R. C. Arkin, "Behavioral overlays for non-verbal communication expression on a humanoid robot," *Autonomous Robots*, vol. 22, no. 1, pp. 55–74, 2007.

[5] C. L. Bethel, "Robots without faces: Non-verbal social human-robot interaction," Ph.D. dissertation, University of South Florida, 2009.

[6] D. Sirkin, B. Mok, S. Yang, and W. Ju, "Mechanical ottoman: how robotic furniture offers and withdraws support," in *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 2015, pp. 11–18.

[7] M. Saerbeck and C. Bartneck, "Perception of affect elicited by robot motion," in *Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction*. IEEE Press, 2010, pp. 53–60.

[8] G. Hoffman and W. Ju, "Designing robots with movement in mind," *Journal of Human-Robot Interaction*, vol. 3, no. 1, pp. 89–122, 2014.

[9] E. T. Hall, "The hidden dimension," 1966.

[10] N. Yamasaki and Y. Anzai, "Active interface for human-robot interaction," in *Robotics and Automation, 1995. Proceedings., 1995 IEEE International Conference on*, vol. 3. IEEE, 1995, pp. 3103–3109.

[11] M. L. Walters, K. Dautenhahn, R. Te Boekhorst, K. L. Koay, C. Kaouri, S. Woods, C. Nehaniv, D. Lee, and I. Werry, "The influence of subjects' personality traits on personal spatial zones in a human-robot interaction experiment," in *Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on*. IEEE, 2005, pp. 347–352.

[12] C. Smith, "Behavior adaptation for a socially interactive robot," Master's thesis, KTH Royal Institute of Technology, Stockholm, Sweden, 2005.

[13] L. Takayama and C. Pantofaru, "Influences on proxemic behaviors in human-robot interaction," in *Intelligent Robots and Systems, 2009. IROS 2009. IEEE/RSJ International Conference on*. IEEE, 2009, pp. 5495–5502.

[14] J. Mumm and B. Mutlu, "Human-robot proxemics: physical and psychological distancing in human-robot interaction," in *Proceedings of the 6th international conference on Human-robot interaction*. ACM, 2011, pp. 331–338.

[15] T. L. Sanders, W. Volante, K. Stowers, T. Kessler, K. Gabracht, B. Harpold, P. Oppold, and P. A. Hancock, "The influence of robot form on trust," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 59, no. 1. SAGE Publications, 2015, pp. 1510–1514.

[16] M. Shiomi and N. Hagita, "Social acceptance of a childcare support robot system," in *Robot and Human Interactive Communication (RO-MAN), 2015 24th IEEE International Symposium on*. IEEE, 2015, pp. 13–18.

[17] Á. Miklósi, *Dog behaviour, evolution, and cognition*. OUP Oxford, 2014.

[18] K. Baraka, A. Paiva, and M. Veloso, "Expressive lights for revealing mobile service robot state," in *Robot 2015: Second Iberian Robotics Conference*. Springer, 2016, pp. 107–119.

[19] A. Aron, E. N. Aron, and D. Smollan, "Inclusion of other in the self scale and the structure of interpersonal closeness." *Journal of personality and social psychology*, vol. 63, no. 4, p. 596, 1992.

[20] C. Bartneck, D. Kulić, E. Croft, and S. Zoghbi, "Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots," *International journal of social robotics*, vol. 1, no. 1, pp. 71–81, 2009.