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Crowd Sourcing 'Approach Behavior' Control Parameters for Human-Robot Interaction

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Abstract— **For service robots to be well received in our daily lives, it is desirable that they appear as friendly as possible rather than some unfriendly characters. While a robot's physical appearance influences this perception, its behavior also has an impact. In order to be sure that a specific robot behavior will be correctly perceived, we propose to its potential users to shape the robot's behavior. In this paper, a specific behavior, "approaching a person", is evaluated with a Robosoft Kompaï robot. To avoid logistics issues associated with having large groups of novice users performing demonstrations on a physical robot, a web-based approach built around a simulation of the actual robot is proposed. The relationship between the robot and the person is described by the two dimensions of the interpersonal circumplex: communion (hostile or friendly) and agency (submissive or dominant). The users can adjust three parameters of the approach behavior (i.e., distance, trajectory curvature, and deceleration) in a manner that corresponds the best to the described relationship. An analysis of the data from 69 users is presented, along with a verification experiment done with 10 participants and the real robot. Results suggest that users associate hostile robots with straight trajectories, and submissive robots with smoother deceleration.**

I. Introduction

Socially assistive robots [1] are integrating our daily lives, especially in elderly care [2]. For an easier integration of such robots, it is desirable that they act and appear as friendly as possible and avoid undesirable actions. It is known that proxemics, or the study of social distance between humans, has an impact on how interactions are perceived [3]. This also applies to human-robot interaction. For instance, Takayama and Pantofaru suggest that influencing factors in human-robot proxemics can be defined according to the robot, the contextual, and human dimensions [4]. In [5], there were indications that humans preferred to approach the robot more closely than they allowed the robot to approach them in a physically restricted area. Furthermore, Koay et al. in [6] argue that the three dimensions proposed by Takayama and Pantofaru will interact with each other in a manner that will vary between participants.

To help decide how a robot should behave, we suggest that its relationship to its users might be used as a starting point. The interpersonal circumplex [7], shown in Fig. 2, is often used to describe person-to-person relationships. This model uses two dimensions: agency, on a submissive to dominant scale, and communion, on a hostile to friendly scale. Knowing where the relationship lies in this 2D space could help shape how a robot behaves in relation to proxemics.

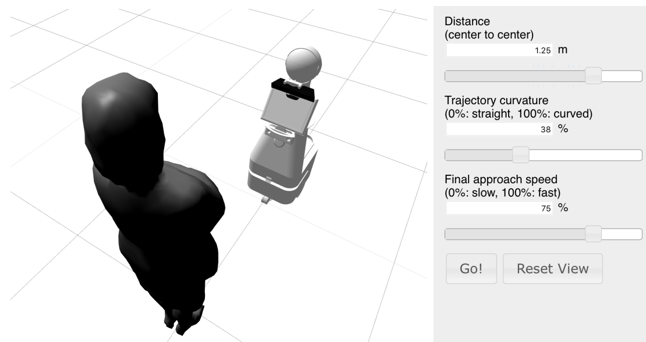

Fig. 1: A screenshot of our web interface used to gather demonstration data. The robot approaches a woman with her arms crossed.

As robot developers, we should avoid having our own preferences bias the behavior of a robot designed for users of varying background and personalities. Traditional survey methods can be used to gather a large amount of data on the opinions of potential robot users, but it can be difficult to translate these results if the public is not already familiar with the capabilities of the robot. On the other hand, we cannot expect users to define the parameters of motor control laws themselves once they acquire a service robot. To ease this process, Learning from Demonstration (LfD) approaches [8], where users are asked to teach new policies by showing them how to achieve a specific task, are popular. While it is very useful to teach complex skills such as trajectories for object manipulation, it can also be a very time-consuming process for a single user to provide sufficient demonstration data to cover a wide range of situations and preferences.

While providing access to physical robots to many people at once can be difficult, robot simulation software can be an interesting alternative, especially if used over the Internet. In the past few years, robot simulators embedded in web applications have been presented for teaching maze navigation [9], manipulation tasks [10], and collecting human-robot interaction demonstrations [11].

In this paper, we present a web-based approach to gather user demonstration data to define the parameters of a person approach behavior depending on the relationship between

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the robot and its user as described by the interpersonal circumplex. Participants are presented with a web interface where they can modify approach trajectory parameters and see in real-time a 3D representation of the robot executing its task.

Our paper is structured as follows: Section II presents the robot used in this work, its context, and how approach trajectories are generated, Section III describes the infrastructure to gather demonstration data, and Section IV analyses the data that has been collected. Section V presents an experiment conducted with the real robot so as to verify the results obtained during the online demonstrations. Finally, Section VI discusses how the data can be used to generate an adaptive approach behavior, and Section VII concludes the paper with suggestions on future work that can be done with our system.

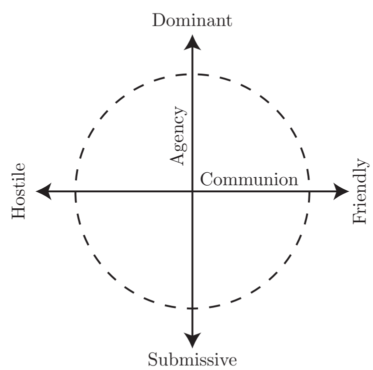

Fig. 2: The interpersonal circumplex.

II. Robot Hardware and Software

The work presented in this paper was done in the context of the EU Horizon2020 ENRICHME project[1], which involves the Kompaï service robot by Robosoft[2]. The project aims at providing an interactive social robot in an assisted living environment for the elderly. The robot itself includes a wheeled differential mobile base with two degrees of freedom (forward-backward and rotation), a touch screen for the interaction, multiple sensors such as a laser range finder and a RGB-D camera, and a non-actuated expressive face.

One goal in the project is to provide natural and adaptive interaction, and the way the robot approaches its users is one of many aspects that can have an impact on how people perceive the robot. For instance, users might be startled by a robot stopping abruptly close to them. Thus, a framework that can alter navigation characteristics, such as deceleration and the shape of a trajectory has to be put in place.

A. Approach Trajectory Generation

While common path planning systems, such as the ROS navigation stack[3] are very good at finding the most efficient trajectory between two points, they do not offer many customization options (outside of obstacle perception for avoidance) to better define how a robot should navigate in its environment, and the default behavior can often be perceived as unnatural. To simplify the development of an alternative, we start with the assumption that this approach behavior will be used in the last few meters of a journey to reach a person, and that this space is guaranteed to be obstacle-free.

The control law used to drive the robot in that space can be found in [12]. The problem definition is shown in Fig. 3, and the control law can be summarized as follows.

$$v = k_\rho \rho \quad (1)$$
$$\omega = k_\alpha \alpha + k_\beta \beta \quad (2)$$

where v is the linear (forward-backward) velocity, k_ρ the control factor on the distance to the target, k_α the control factor on the angle at which the target is, and k_β the control factor on the desired final heading. To maintain local stability, these factors need to respect these constraints:

$$k_\rho > 0 \quad (3)$$
$$k_\beta < 0 \quad (4)$$
$$k_\alpha - k_\beta > 0 \quad (5)$$

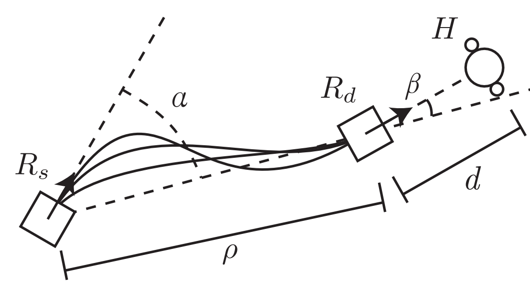

Fig. 3: Approach trajectory: The person to reach (H), the robot starting point (R_s), and the desired end location (R_d). α is the angle between the current heading and the shortest path to the target, β the angle between this shortest path and the desired heading, d the distance at which to stop in front of the person, and ρ the current distance to the target. Possible trajectories are drawn as solid, curved lines.

While these parameters might speak to robot behavior developers, they are not necessarily well understood by common users of the robot. To provide a simpler interface to these parameters, we instead propose these variables:

1) *Distance*, the exact distance at which the robot should stop in front of the person (d);
2) *Curvature*, the overall appearance of the trajectory from straight to S-shaped (c);
3) *Deceleration*, the time period within which the robot slows down before stopping at the desired distance (s).

[1] www.enrichme.eu
[2] www.robosoft.com
[3] wiki.ros.org/navigation

While parameter d is an absolute positive value than can be directly used to generate the target pose of the robot, normalized values between 0.0 and 1.0 are used to describe c and s. To obtain k_ρ and k_α from these normalized parameters, these relations are used:

$$k_\rho = 3.0s + 1.0 \quad (6)$$

$$k_\alpha = 10.0(1.0 - c) + k_\rho \quad (7)$$

Constant values were empirically determined both to guarantee stability and generate reasonable trajectories with the motion characteristics of the Kompaï robot. Furthermore, control velocities v and ω are saturated to their respective limits (0.5 m/s and 1.0 rad/s). This generates trajectories that retain a constant velocity for most of their duration, and the robot decelerates gradually on a time period that depends on s. Curvature mostly affect the trajectory in its beginning, meaning that, depending on c, the robot takes a different amount of time to align with the shortest path. Finally, k_β was fixed to -1.5. This was chosen to simplify the parameterization of the algorithm, but also because k_β has mostly an impact when the target goal is either very far laterally from the robot, or if the final heading is at a large angle from the orientation at the starting point. Because the robot will be in the field of view of the person when this behavior is expected to be used, these situations should not occur. Thus, the impact of k_β would be difficult to perceive in the simulated scenarios.

III. Data Collection Infrastructure

To collect demonstration data from remote users, a web application infrastructure was built. This infrastructure was built to run on a single server and IP address to simplify its hosting and related costs, but could be distributed on multiple servers to increase capacity. The front end is a Node.js[4] web application that manages a simple survey interface and a modified *gzweb*[5] view, which is a Javascript client to the Gazebo server (*gzserver*), a popular robot simulation framework [13]. This interface is shown in Fig. 1. The view presents a 3D model of the Kompaï robot on a flat grid. A static model of a woman is shown 3 meters in front of the robot, 2 meters to the left, and facing the robot. The user can modify the point of view in 3D, and a *Reset View* button is provided to go back to the default point of view. The user is presented three slider controls to adjust the approach parameters. A *Go!* button starts the approach sequence, and the animation is seen in real-time on the client interface.

A. Collected Data

When users first reach the web application, an unique key is generated to anonymously store their demonstration data. Users are first presented with a short demographics questionnaire asking their age, gender, academic background, and familiarity with robots. Then, the user receives instructions on how to use the web interface. The first out of four situations describing the relationship the virtual robot has with the person it has to reach is then shown.

Each situation states the value of each dimension of the interpersonal circumplex on a five point Likert scale. For Agency, the scale is Very Submissive (1), Somewhat Submissive (2), Equal (3), Somewhat Dominant (4), and Very Dominant (5). For Communion, the scale is Very Hostile (1), Somewhat Hostile (2), Neutral (3), Somewhat Friendly (4), and Very Friendly (5). Each situation is randomly generated.

With each situation, users are free to experiment as long as they wish with the interface to demonstrate how the robot should approach the person given the relationship description. When users are done with a situation, they are asked to rate their final satisfaction of the result on a five point Likert scale. Users are also asked to rate the personality of the robot on a five point introverted-extroverted scale. After users have demonstrated the approach for the four situations, they are invited to fill-in a 45 questions personality survey based on the Big Five Personality Traits structure [14]. For entry validation, any data point where interface sliders were left untouched were automatically discarded. This mechanism is used to avoid recording false data points when a user skips a presented situation because of a technical issue, or simply because they chose to.

IV. Online Results

In total, 69 persons provided valid data points to the experiment. Their age ranged from 19 to 62 (average: 30.3), 24 female and 45 male. 57 declared having a background in technical sciences. For each approach behavior parameter, a two-way analysis of variance (ANOVA) was performed. First, to identify if a statistically significant difference could be observed in the values specified by the participants. Each dimension was divided in three levels: Hostile, Neutral, and Friendly for Communion; Submissive, Equal, and Dominant for Agency, respectively. Then, pair-wise Student's t-tests were applied to verify if the three levels could be distinguished for each dimension.

The following sub-sections detail the observations that were made for each of the parameters.

A. Distance

For distance, the two-way ANOVA does not suggest that main or interaction effects from any factor could be observed. However, distance seems to be correlated with how participants rated the robot on the introverted-extroverted scale, as shown in Fig. 4. When divided in three levels (introverted, neutral, extroverted) and applying a t-test, participants were more likely to set longer distances to robots that were rated introverted compared to those rated as extroverted ($p = 0.0230$) and neutral ($p = 0.0420$).

B. Curvature

The two-way ANOVA suggests that a main effect on trajectory curvature could be observed for the communion

[4]nodejs.org

[5]gazebosim.org/gzweb

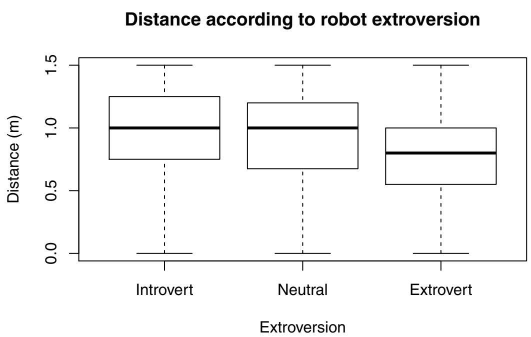

Fig. 4: Distance parameter (d) values according to the rating of the robot extroversion. Results suggest that participants who specified longer distances were also more likely to rate the robot as introverted.

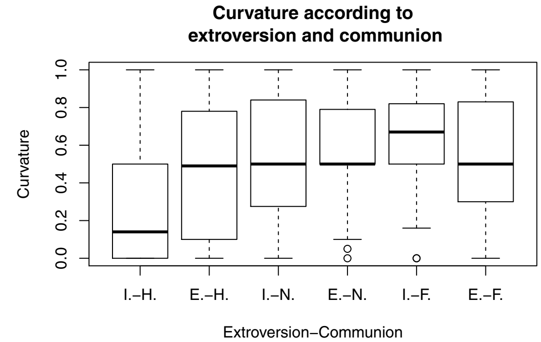

Fig. 5: Curvature parameter (c) according to the extroversion of the participants (I. and E. for Introversion and Extroversion), and communion with the robot (H., N., and F. for Hostile, Neutral, and Friendly).

dimension of the interpersonal circumplex ($p = 0.0008$, $F = 7.341$). Furthermore, the t-test results show that hostile robots can be distinguished from neutral ($p = 0.0251$) and friendly ones ($p = 0.0009$), respectively.

As shown in Fig. 5, this translates into lower values for c when the robot is hostile to its user. This suggests that participants associate straighter trajectories with hostile robots when compared to friendly ones. However, when looking at the effect of the users' personality tests, introverted and extroverted participants (22 and 47, respectively) seem to have a different opinion on how a friendly and hostile robots should act. A multi-factor ANOVA with communion, agency, and extroversion of the participant as factors suggests that an interaction effect exists between communion and extroversion ($p = 0.0247$, $F = 3.753$). Fig. 5 shows the distribution of the curvature parameter values according to extroversion of the participants and communion with the robot. For hostile robots, a t-test suggests that introverted and extroverted participants could be distinguished ($p = 0.0300$), and values are lower for introverted than extroverted participants (means of 0.2994 and 0.4605, respectively). Interestingly, while both participants groups cannot be distinguished for neutral robots, introverted participants gave curvature parameters that were more spread out than extroverted ones.

C. Deceleration

The two-way ANOVA revealed statistically significant main effects on deceleration for both communion ($p = 0.0302$, $F = 3.547$) and agency ($p < 0.0001$, $F = 9.671$) on the deceleration parameter.

Fig. 6 shows the relation between deceleration s and the communion dimension of the interpersonal complex. The t-test on this relation suggests that the values for hostile robots can be distinguished from friendly ones ($p = 0.0330$), but that neutral robots cannot be distinguished from the hostile or friendly robots. The chosen values for hostile robots show that participants clearly preferred stronger deceleration and thus shorter stopping duration in these cases.

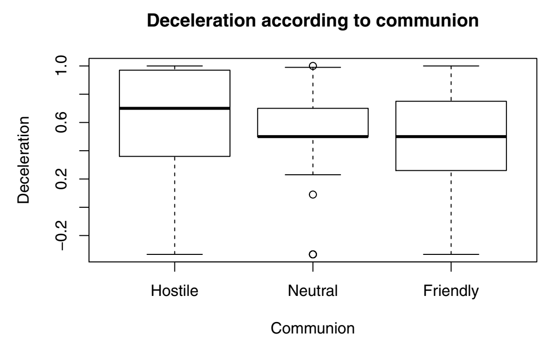

Fig. 6: Deceleration parameter (s) according to the communion dimension of the interpersonal complex.

The relation between deceleration and agency (Fig. 7) is similar. The t-test results suggest that the deceleration values for submissive robots could be distinguished from dominant ones ($p < 0.0001$), but that equal robots (neither submissive nor dominant) could not be distinguished from submissive or dominant robots. For dominant robots, participants chose higher values than for submissive robots, suggesting that participants associate stopping smoothly with submission.

V. Experiment with the real robot

To confirm if the configuration acquired online would be recognizable, an additional experiment with the real robot was conducted. Each participant was presented with 8 different approach configurations for the c and s parameters. Each configuration was randomly generated to sample the parameter space uniformly. Distance d was fixed at 1.2 m. To analyze them as factors, each approach parameter was divided in low ($[0.00, 0.33[$), medium ($[0.33, 0.66[$), and high ($[0.66, 1.00]$) ranges. To counterbalance habituation effects, participants were presented with different sequences of parameter ranges, (e.g., low-mid-high for participant 1, mid-low-high for participant 2, and so on). Participants were instructed to stand on a point in an empty room, the robot

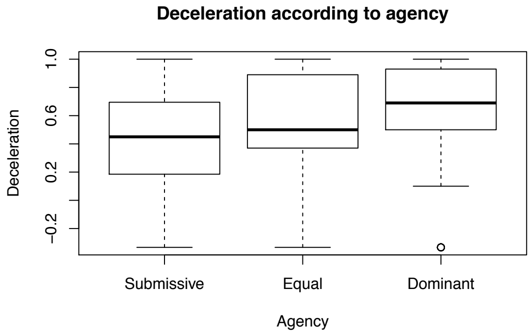

Fig. 7: Deceleration parameter (s) according to the agency dimension of the interpersonal complex.

Fig. 8: Experimental setup with the real Kompaï robot.

starting from the same location as in the simulated environment (see Fig. 8). After each demonstration, participants had to answer how they perceived the personality of the robot on the interpersonal circumplex with the help of a 5-point Likert scale on each dimension (ex. ”very dominant” (5) and ”somewhat hostile” (2)). 10 participants from ENSTA ParisTech (aged 22 to 34, 9 male and 1 female, all with a technical background) participated to this experiment, producing 80 data points. Four of them had previously taken part in the online experiment.

A. Communion

For the communion dimension, a two-way ANOVA revealed a statistically significant main effect for the curvature parameter ($p = 0.0106$, $F = 6.866$). A pair-wise t-test suggests that the effect of low curvature can be distinguished from high curvature ($p = 0.0310$). Fig. 9 shows the distribution of this relation, where higher curvatures are associated more with friendly robots, as with the online data.

B. Agency

For the agency dimension, a two-way ANOVA revealed statistically significant main effects for both curvature ($p = 0.0002$, $F = 15.181$) and deceleration ($p < 0.0001$, $F = 52.913$) parameters. For curvature, a pair-wise t-test suggests that the effect of low curvature can be distinguished from high curvature ($p = 0.0033$), and that medium curvature can be distinguished from high curvature ($p = 0.0026$). Fig. 10 shows the distribution of this relation, where higher curvature are associated with submissive robots. For deceleration, a pair-wise t-test suggests that the effects of low, medium and high deceleration can be distinguished ($p < 0.0001$ between low and medium and low and high, $p = 0.0022$ between medium and high). Fig. 11 shows the distribution of this relation, where high deceleration, and thus small stopping distances, can be associated with dominant robots.

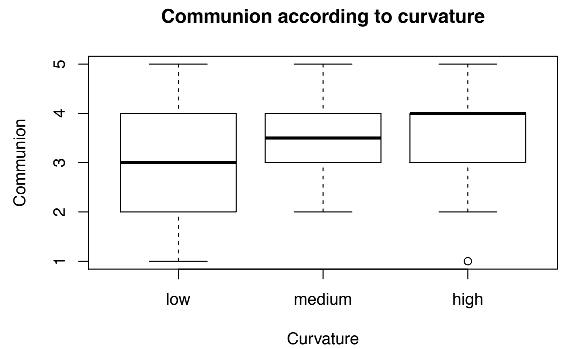

Fig. 9: Perceived communion, from very hostile (1.0) to very friendly (5.0), of the real robot according to the curvature of the trajectory.

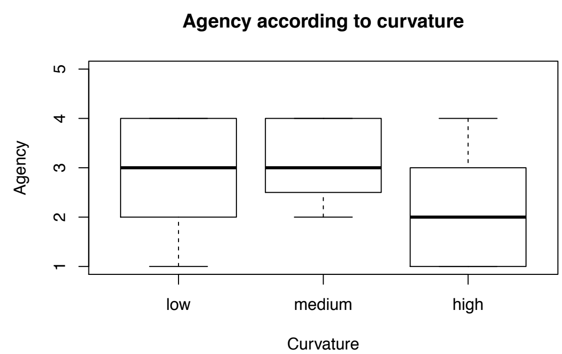

Fig. 10: Perceived agency, from very submissive (1.0) to very dominant (5.0), of the real robot according to the curvature of the trajectory.

VI. Discussion

For the communion dimension of the interpersonal complex, a consensus appears in the data collected online on how a hostile robot should behave when approaching someone in terms of curvature of the trajectory and deceleration. However, the effect of deceleration on communion could not be observed with the real robot. While it is not possible to distinguish preferences between neutral and friendly robots, the mean values of the curvature parameter for these categories of robots can be used as a valid starting point for the approach behavior. By avoiding trajectories that are too

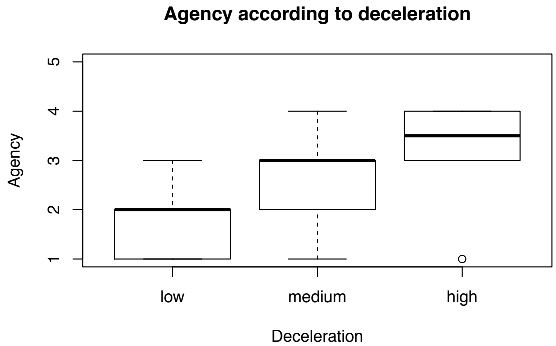

Fig. 11: Perceived agency, from very submissive (1.0) to very dominant (5.0), of the real robot according to the deceleration of the trajectory.

straight, the robot should not appear hostile to the users. A similar observation can be made for the agency dimension. There is a strong consensus between online and real data on the effect of deceleration on the perceived agency of the robot, where short stopping distances are associated with dominant robots. It can be argued that it would be preferable for service robots to appear more submissive than dominant. Thus, choosing lower values for deceleration parameter s appears preferable. However, if a robot needed to appear more dominant and perhaps convincing, results suggest that it could do so by increasing s.

The fact that the distance parameter d does not appear to be influenced by any dimension of the interpersonal circumplex can be seen as a benefit. Indeed, this suggests that the interaction distance in this situation can be entirely defined by other requirements, such as the range of sensors on the robot. For instance, a Kinect RGB-D camera mounted on the Kompaï robot is used to perform tasks such as face tracking and recognition. Because the position and orientation of this camera is fixed, the distance at which the robot needs to be situated to properly perform this perception task depends on parameters such as the geometrical configuration of the robot, the height of the people, and whether they are standing or not. In that situation, results suggest that the interaction distance could be entirely defined by these parameters, without risking having a robot that appears hostile or dominant to the person.

Finally, it does not appear that the personality profile had an overall influence on how a robot should behave when approaching a person, as no statistically significant results were found for that factor. This can also be seen as a benefit, as this suggests that the Kompaï robot does not have to know in advance the profile of unknown people, for instance if they are introverted or not, before selecting an approach strategy.

VII. Conclusion

This paper described a web-based infrastructure to gather a large quantity of demonstration data for a robot approach behavior. Remote users had to interact with an online simulator to demonstrate how a robot should approach a person depending on their relationship as described by the two dimensions of the interpersonal circumplex: communion (hostile or friendly) and agency (submissive or dominant). The results of this demonstration were then verified with a real robot. Results suggest that a hostile robot can be associated to straight trajectories and small stopping distances, and that submission is associated to curvier trajectories and smooth deceleration.

Future work related to this project includes the integration of obstacle avoidance into the approach behavior by defining a cost function for a trajectory planner based on Bayesian inference that would consider the impact of deceleration and trajectory curvature on the perception of the robot behavior.

Acknowledgements

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