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Between Legibility and Contact: The Role of Gaze in Robot Approach*

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Abstract— **In this paper, we explore experimentally the possible tradeoff between gaze to the user and gaze to the path in robot approach. While some previous work indicates that gaze towards the user increases perceived safety because the user feels recognized, other work indicates that it is legibility of the robot's actions that put users at ease. If the robot does not drive up to the person in a straight line directly, the robot can either continuously look at the person and thus maintain eye contact, or indicate its path through its gaze behavior, increasing legibility. In an experiment with N=36 participants, we tested the tradeoff between legibility and eye contact. The behavioral results show that users are significantly more at ease with the robot that gazes at them than with the robot that looks where it is going, measured by the number of instances of glances away from the robot. Likewise, the participants rate the robot that looks at them continuously as more intelligent and more cooperative. Thus, participants value mutual gaze higher than legibility.**

I. Introduction

This paper explores the role of robots' gaze in robot approach. Robot gaze has previously been shown to fulfill numerous functions in HRI; one of these functions is the regulation of interpersonal relationships (e.g. Mutlu et al. [1], Andrist et al. [2]), another one is the disambiguation of the robot's intention, where gaze may enhance the legibility of the robot's actions (e.g. Dragan [3]). Regarding the former, it has been found to be generally beneficial if the robot looks at the user, since users take the robot's gaze towards them to acknowledge their presence (Nourbaksh et al. [4], Fischer et al. [5]). On the other hand, robot gaze towards the user may also be perceived as 'staring', and especially women have been found to keep greater distance to a robot that looks at them [6]. Regarding the latter, the direction of gaze can indicate the robot's intention and thus contribute to the legibility of the robot's actions; legibility, in turn, has been found to be highly correlated with perceived safety of the robot; that is, the clearer the robot's intention, the more comfortable people feel (Lichtenthäler [7]). Thus, previous work shows that both interpersonal functions and disambiguating the upcoming action play a considerable role in human-robot interactions, to which the robot's gaze can contribute.

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The question addressed in the current paper is what participants value more highly, to be able to infer the robot's path from its gaze (legibility) or the assurance that the robot perceives them (contact). While in a straight approach the two fall together, in cases in which the path taken by the robot is not direct, legibility and contact to the user may conflict. That is, in this paper we ask whether the robot should look continuously at the user during approach or whether it should rather indicate its way by means of its eye gaze.

II. Previous Work

A. Robot Approach

A study by Satake et al. [8] illustrates the problems robots may have when approaching strangers: The robot's intention may, for instance, not be recognized or ignored. The authors therefore argue to make the robot's intention clearer using more than one modality. For example, in addition to just approaching a pedestrian, the robot should use additional signals such as gesture and eye gaze to indicate to the participant that it is addressing them.

Lohse et al. [9] find that the legibility of the robot's approach behavior can be increased if the robot's speed is not be constant but is slow initially, then speeds up, and ends slow, yet only in combination with functional noise. That is, when both the robot's speed and the accompanying sounds indicate that the robot will stop, participants are able to predict its course. This is in accordance with findings by Kruse et al. [10] on human-human interactions in which not the paths, but the velocity was found to be adjusted to increase legibility.

Besides the problem that the robot's intentions may not be recognized, previous work on robot approach shows that participants may be uncomfortable depending on the direction of approach and in terms of timing, Regarding timing, Huang et al. [11] find that a robot that responds quickly to the user's need for assistance and then moves quickly to fulfill its task is perceived as polite. Furthermore, similar to Lohse et al.'s results [9], Henkel et al. [12] find that the robot is more acceptable if its speed is non-linear. Regarding the direction of approach, previous work yields that the direction of approach matters greatly when users are seated or otherwise immobile; however, it does not matter very much where the robot is approaching from as long as participants are standing (Zlotkovski et al. [13], see also

Dautenhahn et al. [14], Walters et al. [15]), unless the robot is interrupting an activity (see Karreman et al. [16]).

B. Gaze in Approach

Much work on gaze concentrates on gaze in conversation (e.g. Mutlu et al. [1]; Ruhland et al. [17]; Bee et al. [18]; Argyle & Cook [19]) or on its role in disambiguation in close human-robot collaboration (Mehlmann et al. [20], Moon et al. [21]; Srinivasan & Murphy [22]) if the robot's gaze is attended to at all (see Admoni et al. [23, 24]). In these situations, gaze aversion plays an as important role as mutual gaze (Andrist et al. [2]). This concerns on the one hand the danger of 'staring' (Wang & Gratch [25]), on the other several interactional functions: Andrist et al. [2] find human conversationalists to employ gaze aversion for cognitive, floor management and intimacy-regulating reasons.

Regarding robot gaze during approach, Takayama and Pantofaru [6] have found a gender effect in the interaction between robot gaze and the robot's approach behavior: Women tend to stay further away from the robot if the robot looks at them. Thus, gaze seems to play a role in robot approach, yet it is not completely clear what role that is. In handovers, gaze can disambiguate the robot's intentions (Moon et al. [21]), yet it is unclear whether humans use gaze to disambiguate where they are going; Basili et al. [26] have found that human interactants only look at their targets three seconds before they reach it and only for a brief period. Thus, they don't 'stare' (cf. Wang & Gratch [25]) at the target.

C. Legibility

Dragan [3] and Dragan et al. [27] argue that the trajectories of robot movements (in object manipulation) should not necessarily take the shortest path, but in order to increase legibility and to disambiguate the action, the robot should make its trajectories more legible with respect to the goal. Correspondingly, Satake et al. [8] also find that simply approaching the human is not legible enough with respect to robot's intention to initiate contact. In contrast, human-like behaviors, which involve a decrease in velocity (Lohse et al. [9]; Basili et al. [26]), and adding an additional modality (e.g. gaze or sound) to clarify the robot's intention (cf. Satake et al. [8]) increase legibility (Lichtenthäler [7]).

To sum up, previous work indicates that robot gaze plays important roles both regarding indicating the robot's intentions and thus increasing its legibility and as a social cue to initiate or keep in contact. In robot approach in which the robot is directly heading towards the human, the two functions coincide: the robot signals its intention by fixating its target, the human, and at the same time initiates contact. However, if the robot is not heading towards the person in a straight line, keeping in contact and legibility do not coincide. Furthermore, previous work indicates that robots may be found to stare at the person; furthermore, eye gaze during approach may make at least women feel uncomfortable; and humans navigating towards a goal also do not look at their target continuously. These findings leave open what users prefer if the two functions, contact and legibility, are competing. We thus test whether:

(H1): people prefer the robot to indicate its path by means of its gaze, or

(H2): people prefer the robot to indicate by means of its gaze that it perceives them.

III. METHOD

We carried out a between participant experiment in which the robot approached the user in a curve based on the robot's placement at the beginning of the experiment and the user's position (see Fig. 2). In Condition 1, the robot moved diagonally so that it could keep eye contact with the user during the approach, whereas in Condition 2, the robot started off at a 90 degree angle to the participant and looked straight ahead to where it was going. The trajectories are illustrated in **Figure 1**, indicating that the translational parts are identical for both conditions, while the robot's orientation differs, as indicated by the arrows. In order to keep the two conditions comparable, the robot uses constant speed in both conditions.

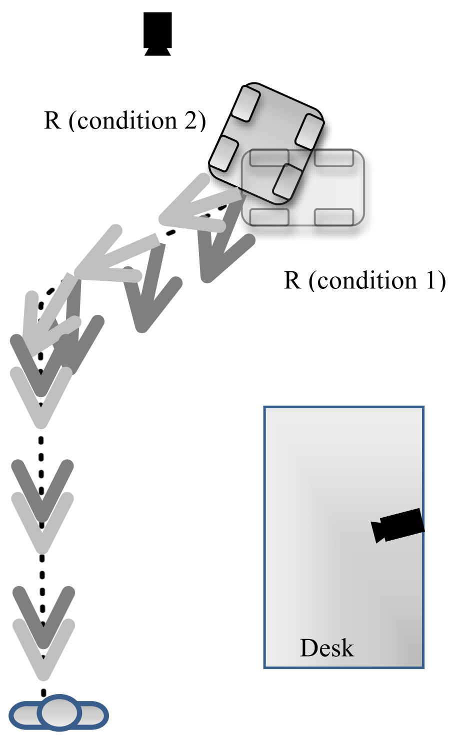

Figure 1: The trajectory of the robot R (dashed line) towards the participant P. Arrows indicate the robot's orientation where dark-grey arrows correspond to Condition 1 (continuous gaze) and light-grey to Condition 2 (legible gaze).

A. Robot

The robot employed in the experiments is the Care-O-bot 3 (Graf et al. [28]) which is an omnidirectional service robot. The design of its base enables the robot to maintain an arbitrary orientation independently from the direction it is driving in – this was utilized for the current experiment. The robot has a footprint of 55 × 75 cm and a height of approx. 1.4 m. Hence most participants were taller than the robot. The sensor used for the experiment was a mockup with some bright LEDs integrated, mimicking an optical sensor. While the sensor was mounted on the arm of the robot, the robot arm was not moved in this experiment.

Since the robot was orienting towards the user in Condition 1, small corrective motions were necessary when approaching the user so that the robot's approach took slightly longer in Condition 1, the gaze condition, compared to Condition 2:

- Condition 1: mean 28.1, median 28, sd 4.6
- Condition 2: mean 17.4, median 18, sd 3.0

The variation is likely to be due to varying battery level (the robot could operate for about 2.5 hours when fully charged), as well as to brief security stops when the users approached the robot and came too close.

B. Participants

We recruited 36 students and staff from the University of Southern Denmark, Campus Sønderborg. Mean age of participants is 30.7 (range 19-59). 24 of the participants are men, 12 are women. There are 19 participants in Condition 1 and 17 in Condition 2, the distribution of participant gender being balanced evenly between the two experimental conditions. Regarding previous experience, about half of the participants (57%) state that they only know robots from electronic media, 35% state they have worked or played around with a robot a few times before, while only 8% (3 participants) state they work regularly with robots. Participants were compensated for their time and participation with chocolate.

C. Procedure

Participants were greeted in the hallway and asked to fill out an initial questionnaire with demographic information and a consent form in another room. Then they were led into the lab; when leading the participant into the room, the experimenter implicitly placed the participant at a certain (safe) location while moving back a little herself, saying: "so this is the Care-O-bot". The robot then introduced itself by a) greeting the participant and thus acknowledging his or her presence and b) by clearly stating its intention to come closer to carry out a medical measurement (using a non-invasive optical sensor): "Hello, I'm Care-O-bot. I can measure your heart rate. I come a bit closer now". Participants were videotaped while the robot was approaching and during the brief interactions following the robot's approach, in which the robot asked the participants to put their hand under the robot's optical sensor attached to the robot's arm. After that, the robot thanked the participant and withdrew backwards, while participants were asked to rate the robot regarding friendliness, competence, intelligence, cooperativeness and scariness in a questionnaire.

Figure 2: Robot approaching participant using continuous gaze (with optical sensor mock-up attached to the arm)

D. Data Encoding

The video data were subsequently analyzed concerning the participants' behavior; Lohse et al. [9] hypothesize that in case a robot is perceived as safe, people would not monitor the robot's behavior all the time but rather glance away, whereas in case they feel unsafe they would 'stare' at the robot. We thus analyzed the video data concerning the number of glances away from the robot as well as the total time in which participants look away. That is, using the videos from the camera that showed participants' faces (see Figure 1), we counted all instances in which participants looked away from the robot, following the procedure by Zheng et al. [29]. In addition, we measured the length of these glances away. Six of the 36 interactions videotaped, three from each condition, were coded by two coders (the first two authors). Inter-coder reliability shows a very high correspondence between the analyses; in particular, Cohen's κ was run to determine if there was agreement between the two coders. Agreement was substantial between the two coders: κ = .714 (95% CI, .29 to .1.10), $p < .0229$.

The questionnaire employed asked participants to rate the robot in terms of perceived friendliness, politeness, competence, intelligence, cooperativeness, and how intimidating and scary it seemed on a 5-point semantic differential scale. Participants responded to the questionnaire on an iPad. Due to a technical error, one participant's responses were not saved.

IV. Results

The results of the behavioral analysis show that participants in Condition 1, in which the robot looks at them continuously during the approach, glance significantly more often and significantly longer away from the robot than participants in Condition 2, in which the robot looked at its own path (univariate ANOVA $F(1,34) = 6.888$; $p= .013$ for number of glances and $F(1,34) = 3.148$; $p= .085$ for glance length, see Table I).

TABLE 1: ANOVA Results for Participants' Gaze Behavior

	number glances M (sd)	glance length M (sd)
condition1: continuous gaze (N=19)	0.526 (0.69)	1.05 (2.12)
condition 2: legible gaze (N=17)	0.059 (0.24)	0.12 (0.48)

Similarly, the results from the questionnaire show that participants in Condition 1, in which the robot continuously gazes at them, find the robot significantly more intelligent (univariate ANOVA $F(1,33=6.3058$; $p=.017)$ and cooperative (univariate ANOVA $F(1,33=7.4855$; $p=.001)$, see Figure 3.

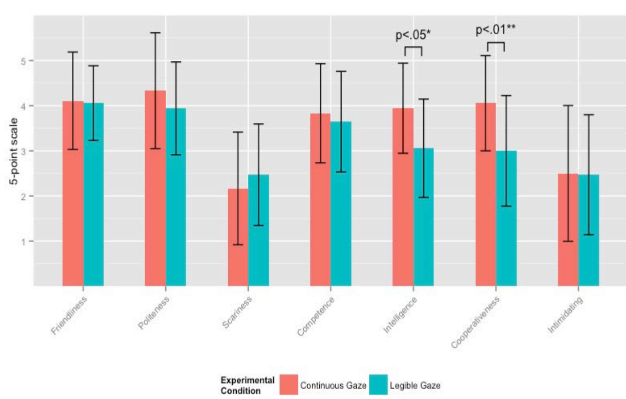

Figure 3: Results of Questionnaire

Given the results by Takayama and Panotfaru [6], which showed a clear gender difference in the way the robot's gaze during approach was perceived, we also investigated our data for gender effects. However, the data show only very weak effects for gender; the questionnaire data exhibit no interaction with gender at all, and the qualitative data show a statistical tendency for number of glances ($F(1,32)=2.9042$, $p=0.09804$) but not for the length of glances away ($F(1,32) = 2.2323$, $p = 0.14495$), see Figures 4 and 5.

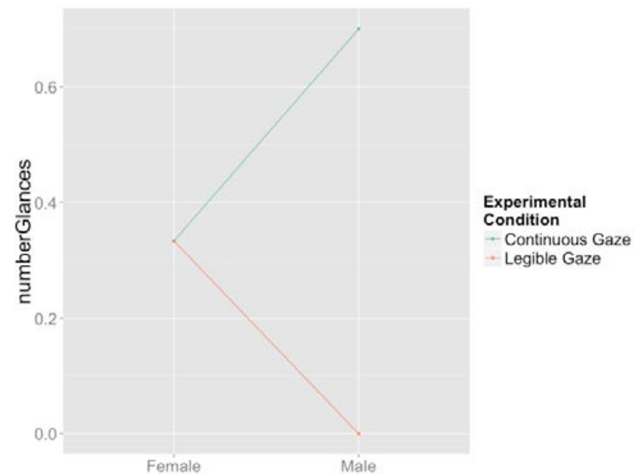

Figure 4: Number of Glances away from the Robot by Gender (p = .098)

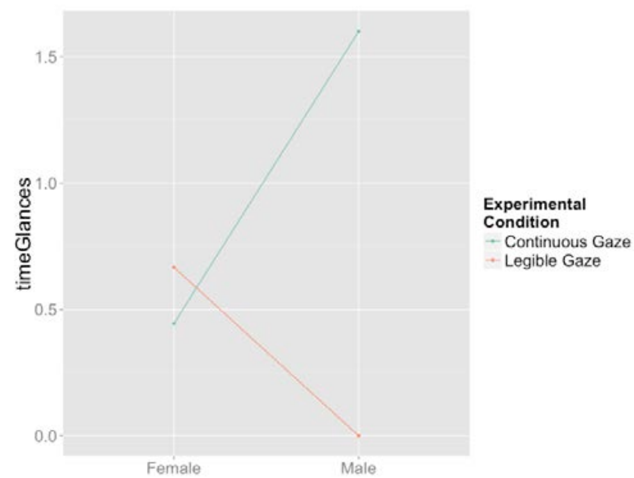

Figure 5: Length of Glances away from the Robot by Gender (p = .145)

The data suggest that, contrary to previous findings, women's gaze behavior is not affected by the different robot behaviors, while the men's behavior differs across conditions such that they tend to glance more often towards the robot in the continuous gaze condition.

V. Discussion

The results from this study suggest that even though in both conditions the robot greeted the participants (and thus indicated that it was perceiving their presence) and indicated its intention to approach verbally, the participants appreciated the robot indicating that it was perceiving them the whole time during the approach, thus confirming hypothesis H2. Given previous work on robot staring (Wang and Gratch [25]) and on women feeling uncomfortable with robots that look at them all the time (Takayama and Pantofaru [6]), it could have been expected that people feel uncomfortable when the robot is constantly looking at them. In contrast, we could not find any negative effects for the robot gazing at the person continuously. This may of course be different in long-term interactions, when it may feel awkward to people if the robot observes them all the time.

Furthermore, given previous work on legibility, we could have expected that people value the transparency of the robot's course of action more, and thus prefer that the robot is looking where it is going (hypothesis H1). That this is not the case may be due to the fact that during robot approach, the only landmark the robot really has to get right is to respect the person's personal space. This may have influenced people's preference for the extended eye contact – even though the robot's intentions were already clear. Nevertheless, these considerations indicate that robots moving around people have to undergo extra efforts to show that they perceive people and that they are in fact safe to interact with.

Future work may investigate how the contact – legibility trade-off develops a) over time and with increasing familiarity with the robot, and b) when legibility is more crucial than it is in the current scenario.

Furthermore, future work will have to show how the robot's gaze behavior interacts exactly with different robot speeds and velocities; previous work (especially Lohse et al. [9] and Henkel et al. [12]) has indicated that non-constant speed may put people at ease by making the robot's behavior more predictable. So it is possible that speed and velocity contribute to making the robot's approach more legible and to making the robot appear more safe; in contrast, the robot's announcement produced in both conditions, to approach the human user, did not have such a comforting effect. It seems therefore that participants value in particular the robot's reassurance that it perceives them *in the moment* (see Takayama [30]).

This consideration then points to further possible alternative scenarios in which the robot's gaze would not necessarily have to be on the participant; given our findings, these would be scenarios in which the robot has successfully built up trust in the user, i.e. in situations in which the human user knows already that the robot perceives them and takes them into account. While possible methods for gaining this trust have to be determined empirically in future studies, one possibility could be to use participants' names to indicate that the robot is really perceiving them. This method has, of course, the limitation that it only works if the robot is moving in familiar territory with a restricted number of users. Another scenario in which the current findings will probably not apply is joint action where the exact execution of the robot's actions needs to be predictable by the person collaborating, or in collaborative scenarios in which the position of the user is given (e.g. behind a table, as in Zheng et al.'s [29, 31] hand-over experiments); here, the robot's gaze is obviously free to play other roles (e.g. Fischer et al. [32]).

Finally, it may also be possible to switch between gaze towards the human and the path taken during the approach; this should combine both an assurance that the robot sees the human user and provide an account of where it is going; future research will have to show how often such glances to the user should occur in order to put human users at ease.

VI. Conclusion

The experiments have shown that participants are considerably more at ease with a robot that looks at them during approach than with a robot that looks at where it is going; given previous work on robot approach and on the perception of continuous robot gaze, this was not necessarily expectable.

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