Goal-Predictability vs. Trajectory-Predictability – Which Legibility Factor Counts

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ABSTRACT

With the work at hand we investigate the legibility factors goal-predictability and trajectory-predictability in a human-robot path crossing scenario and their correlation with other HRI properties like safety, comfort, and reliability in order to assess which factor is more important for a safe and comfortable interaction.

Keywords

Legibility, Social Navigation, Human-Robot Interaction

1. INTRODUCTION

One important factor for a smooth, efficient and also safe human-robot interaction is the legibility of the robot's motion [4]. A great deal of work has been carried out so far in order to develop legible robot motions [5, 2] as well as to investigate the legibility of different kinds of movements in experiments [1, 4]. Based on our previous work [4, 3], where we mainly focussed on human-robot path crossing scenarios, we define robot behavior as legible if: (1) a human observer or interactor is able to understand its intentions, meaning that a human is able to predict the goal (goal-predictability) and the motion trajectory (trajectory-predictability), and (2) the behavior met the expectations of the human observer or interactor (met-expectation).

In a work presented by Dragan et al. [1] the authors investigate the differences of goal-predictability, in their work they call it legibility, and trajectory-predictability, which they call predictability, and found that *"both are fundamentally different and often contradictory properties of motion"* [1]. They investigated robot arm motions without any human interaction. Based on their findings, we want to examine if this applies also to a human-robot path crossing scenario. Furthermore, when both factors are different, the question came up, which factor is more important in terms of its influence on other HRI properties like safety or comfort?

Research Question: The objective of the work at hand is (1) to compare the legibility factors goal-predictability and trajectory predictability in a human-robot path crossing scenario in order to explore if we could find similar results to Dragan et al. [1] and (2) to investigate the correlation between the legibility factors and the interaction properties safety, comfort, and reliability.

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2. METHOD

We re-analyzed data of a between-subject questionnaire-based experiment. In the experiment we showed the participants videos of a robot crossing the path of a human and measured legibility as well as the HRI properties safety, comfort, and reliability.

In the following we briefly describe the conducted experiment focussing on the relevant informations for our new analysis. A more detailed description of the experimental setup and the former findings are given in [3].

Design.

We recorded short movie sequences using the MORSE simulator, where a human is crossing the robot's path in an office environment. The video clips were divided into two parts. The first part of each video shows the robot behavior before the paths of human and robot cross up to the point where the robot is only at a short distance to the human. The second part shows the robot behavior during the crossing event, like crossing before or behind the human, colliding with the human, spinning around, or waiting until the human passes by. We compared two variations of a Human-Aware navigation [2] (HA-TP, HA-WF) with two variations of the state-of-the-art navigation method Move-Base (MB-WF, MB-DWA).

Conditions With three tables as possible goal positions and four navigation methods, we tested $(3 \times 4) = 12$ different observation tasks.

Dependent Measures.

In order to quantify legibility we measured the factors *goal-predictability*, by asking to predict the robot's goal, *trajectory-predictability*, by asking to predict the future direction of the robot, and *met-expectation* by asking if the robot met the participants expectations by using a yes/no scale. Furthermore, we measured the HRI properties surprise, safety, comfort, and reliability by using a five-point Likert scale.

Participants.

16 participants with the average age of 26.6 years took part in our experiment - thereof 3 women and 13 men.

Procedure.

We showed the participants each two-parted video clip once in random order. After the first part we asked the participant to judge which table the robot is aiming at (goal-

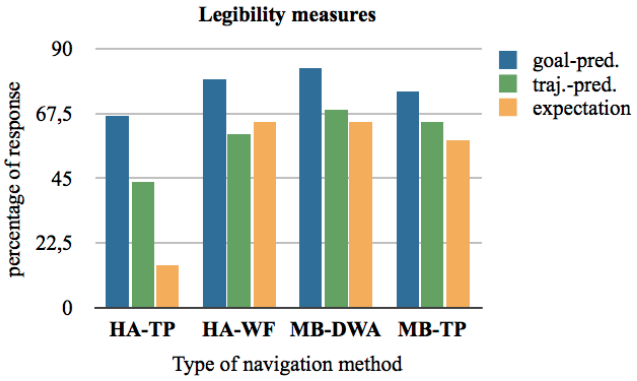

Figure 1: Frequency of correct goal- and trajectory-predictions and how often the behavior met the participants expectations.

predictability) and how it will change its direction (trajectory-predictability). Then we showed the second part and the participants were able to observe the actual behavior of the robot. Afterwards, the participants were asked to tell whether the robot's actual behavior was expected and if not to rate how surprising this was. Additionally we asked for ratings on perceived safety, comfort, and reliability.

3. RESULTS AND DISCUSSION

Regarding our aforementioned research question we found the following results by (1) considering the factor trajectory-predictability[1] and (2) by performing a correlation analysis. The results of correct predictions for goal-predictability and trajectory-predictability are shown in Fig.1. Most correct answers regarding goal-predictability were given for MB-DWA (83.3%) and HA-WF (79.2%) compared to MB-TP (75.0%) and HA-TP (66.7%). Results of the correct predicted directions (trajectory-predictability) are showing a slightly different ranking regarding the navigation methods, here also the most correct answers regarding the direction were for MB-DWA (68.8%) and MB-TP (64.6%) followed by HA-WF (60.4%) and HA-TP (43.8%). Pearson's Chi-Square tests did not reveal any significant association between type of planner and number of correct responses for goal-predictability $\chi^2(3) = 4.00$, $p = .261$, but a marginally significant association between type of navigation and trajectory-predictability $\chi^2(3) = 7.17$, $p = 0.067$. By looking at the charts in Fig. 1 one can presume a slightly difference in the number of correct responses between trajectory- and goal-predictability and an association between trajectory-predict-ability and the met-expectation factor, but contrary to Dragan et al. [1] we found no contrariness as Dragan et al. [1] found, that one algorithm revealed a high value for one and a low value for the other factor. One reason for these opposite findings can be that Dragan et al. [1] generated motion trajectories by optimizing one of the two factors and we compared different navigation algorithms, which are mainly differing in their reaction to a human interactor.

In order to investigate the relationship between the measurements we calculated the point-biserial correlation coefficient, r_{pb} for the discrete dichotomous variables goal-predictability, trajectory-predictability, met expectation and the Pearson's correlation coefficient r for all other variables.

[1]In [3] we analysed only the factor goal-predictability

Results are shown in Table 1. One can see that all measurements are significantly correlated with each other, except for goal-predictability with the HRI-factors safety, comfort and reliability. The low, but significant correlation between goal- and trajectory-predictability , $r_{pb} = .16, p < 0.05$ also shows, that for our human-robot path crossing scenario, the two legibility factors are related and not contradictory. Furthermore, the correlation values for trajectory-predictability are considerably higher than for goal-predictability, which let us assume that trajectory-predictability has a higher impact on how the interaction was perceived. Additionally, the former assumption of an association between trajectory-predictability and the met-expectation factor is supported by a highly significant correlation, $r_{pb} = .54, p < .001$.

Table 1: Pearson's correlation coeffecients r and point-biserial correlation coefficient, r_{pb} calculated for all measurements.

	traj-p.	exp.	surp.	safe	comfort	reliable
goal	$.16^{*}$	$.37^{**}$	$-.26^{**}$	-.08	.03	.001
traj.	1	$.54^{**}$	$-.52^{**}$	$.24^{**}$	$.23^{**}$	$.28^{**}$
exp.	–	1	$-.85^{**}$	$.30^{**}$	$.36^{**}$	$.41^{**}$
surp.	–	–	1	$-.32^{**}$	$-.39^{**}$	$-.46^{**}$
safe	–	–	–	1	$.90^{**}$	$.87^{**}$
comf.	–	–	–	–	1	$.87^{**}$

*. $p < 0.05$, **. $p < 0.001$

4. CONCLUSION

To conclude, with our results in a human-robot path crossing experiment at hand we could not support the finding of Dragan et al. [1] that goal- and trajectory-predictability are contradictory factors of a motion. Quite the opposite, we found that the two factors are coherent. Furthermore, our results let us assume that trajectory-predictability is the more important factor in a human-robot interaction scenario when considering the factors safety, comfort, and reliability. However, the experiment at hand was a pilot-study with a low number of participants. Therefore, the results are showing us a direction, which has to be further investigated in the future preferably with a real world experiment.

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