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Perceived Appropriateness: A Novel View for Remediating Perceived Inappropriate Robot Navigation Behaviors

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ABSTRACT

Robots navigating in social environments inevitably exhibit behavior perceived as inappropriate by people, which they will repeat unless they are aware of them; hindering their social acceptance. This highlights the importance of robots detecting and adapting to the perceived appropriateness of their behavior, in line with what we found in a systematic literature review. Therefore, we have conducted experiments (both outdoor and indoor) to understand the perceived appropriateness of robot social navigation behavior, based on which we collected a dataset and developed a machine learning model for detecting such perceived appropriateness. To investigate the usefulness of such information and inspire robot adaptive navigation behavior design, we will further conduct a WoZ study to understand how trained human operators adapt robot behavior to people's feedback. In all, this work will enable robots to better remediate their inappropriate behavior, thus improving their social acceptance.

CCS CONCEPTS

• **Human-centered computing** → **Social navigation**; *Empirical studies in interaction design*; *Interaction design process and methods*; • **Computing methodologies** → **Cognitive robotics**.

KEYWORDS

Human-Robot Interaction, Social Navigation, Perceived Appropriateness, Social Signal Processing, Adaptive Behavior

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1 INTRODUCTION

As robots increasingly navigate into social environments, they inevitably encounter, interact, and cooperate with people to complete their tasks, which requires them to exhibit appropriate navigation behavior to ensure human safety and comfort such that they can be socially accepted [5].

To ensure that robots' navigation behaviors are perceived as appropriate by both the general public and interacting individuals, various models and algorithms have been proposed and applied for robot social navigation. These include prediction of nearby people's trajectories and planning of robot social navigation behavior [6, 15], estimating and respecting peoples' dynamic personal and social space [10, 14], as well as detecting and responding to peoples' various physical (activities, social interactions) and psychological states (emotion, intention, dominance) [7].

However, current robots still exhibit navigation behavior perceived as inappropriate by people, and we adopt the term "perceived (in)appropriateness" instead of mistakes as such experience is purely subjective. This involves difficulties concerning: understanding and applying complex social norms, modeling dynamics of human-robot interactions, and distinguishing individual differences in perceiving, interpreting, and interacting with robots [9, 11]. While these inappropriate behaviors strongly hinder robots' social acceptance, correcting them might allow robots to compensate for people's negative perceptions, resulting in improved social acceptance [8].

Yet despite rich research in designing appropriate robot social navigation behavior, there are limited efforts in understanding inappropriate robot navigation behaviors. Therefore, we propose to get a more in-depth understanding of inappropriate robot social navigation behaviors [13], thus contributing to detecting and remediating them to improve robot social acceptance.

2 STUDIES

We first conducted a systematic review, which identified the importance of understanding perceived appropriateness (Section 2.1) for robot social navigation. As perceived appropriateness is most pertinent in (potential) conflicts, we conducted a field study to explore factors that affect conflicts and perceived appropriateness (Section 2.2). To detect perceived appropriateness, we conducted data collection and build a dataset. Our analysis of the dataset identified the importance of emotion and attention in detecting perceived appropriateness (Section 2.3). Based on these understandings, we plan to conduct a Wizard of Oz study, by exploring ways human operators experience and utilize such information (Section 2.4), thus drawing inspiration for robot adaptive behavior design.

2.1 A Systematic Review: Importance of Perceived Appropriateness for Robot Social Navigation

Robots are increasingly navigating into our living environments, yet they often struggle to process and utilize social information like humans do—which hampers their acceptance. We conducted a systematic literature review to survey the state of robot social

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navigation with respect to the following research question: *What and how social cues have been used to communicate different social information for robot social navigation?*

For this purpose, we have collected and filtered 139 papers from sources of Scopus and Web of Science. We identified three roles of social cues; informing predictions of future states, indicating internal states, and otherwise signaling cue-related behavior.

We found that despite rich insights into communicating social information between people and robots, there is limited research in understanding feedback from people, especially concerning people's perceptions specific to robots' navigation behavior. Without such an understanding, robots will continue and repeat their inappropriate behavior as they are unable to identify and remediate them. Therefore, we urge more research to look into understanding and detecting the perceived appropriateness of robot navigation behavior, thus paving ways for robots to adapt better to human preferences and needs for higher robot social acceptance.

2.2 Field Observations of Conflicts

We first looked specifically into conflicts between people and robots, where rich perceived appropriateness of robot navigation behavior arise. More specifically, we wanted to explore factors that affect conflicts (thus perceived appropriateness), and gain insights into collecting a dataset of rich perceived appropriateness for machine learning.

We conducted a field study in which a robot controlled by human operators navigates in social environments and deliberately triggers conflicts with people to investigate how people responded to and yielded in conflicts with the robot [12]. We found that a narrow passageway is an important setting for robot social navigation, where a rich set of reactions and perceptions of the robot were triggered. Specifically, we found that robot behavior of sudden changes of speed (including stop) and direction, and blocking and squeezing people's path are typical behaviors that could trigger a rich set of perceived appropriateness.

2.3 Data Collection and Analysis: Detecting Perceived Appropriateness of Robot Social Navigation Behavior

Based on insights from appraisal theory [3, 4], social signal processing approaches [2, 8], as well as our field observations, we made the assumption that emotion and attention serve as important intermediate features for detecting perceived appropriateness. Based on our previous observations of factors that affect perceived appropriateness, and taking into account realistic robot behavior in a narrow passageway, we chose 8 robot behavior (sudden accelerations and stop, sudden direction changes, block, squeeze, and non-moving) to trigger a rich set of perceived appropriateness of robot social navigation behavior. With 31 participants, each interacting with all 8 robot behaviors of a medium-sized clearpath husky robot in a relatively narrow passageway of 90cm that balances the richness of reactions and human safety, we built a dataset of perceived appropriateness of robot social navigation behavior (1005 datapoints) [16]. The dataset contains computed social cues and human-robot relative features collected from a 3D ZED2 camera and robot odometer, and people's self-reported emotion, attention, and perceived appropriateness. Participants are mostly young adults (27 aged 18-34, and the other 4 aged 35-54) from the Netherlands, most of whom have slight encounters with robots in real life.

Analysis of the dataset showed that emotion and attention contribute most to the detection accuracy of perceived appropriateness (78.5%) compared with solely social cues (68.0%). Besides, detected emotion and attention from social cues still contribute to the detection of perceived appropriateness (73.4%). Considering rich research already in human emotion and attention detection, we expect that higher detection performance of perceived appropriateness can be further achieved in the future.

2.4 Effects of Perceived Appropriateness Information on Improving People's Trust and Acceptance of Faulty Robots

To investigate how the information of perceived appropriateness can be utilized properly, we plan to carry out a study, where participants and the robot controlled by trained operators make several encounters with each other. With participants' self-reported perceived appropriateness, human operators will adapt robot behavior for a better human interaction experience. To understand the importance and effects of perceived appropriateness information on human-robot interactions, we will compare people's self-reported perception, acceptance, and trust of the robot [1] with cases of with and without information of perceived appropriateness. Human-robot interactions will also be recorded for analysis in more detail to understand how trained human operators adapt robot behavior to inspire robot behavior design.

3 CONCLUSIONS

We conducted a field study of conflicts and observed the importance of detecting and using perceived appropriateness for improving robot social acceptance in a range of human-robot interactions. Based on these observations and insights from the literature, we then conducted data collection of the perceived appropriateness of robot social navigation behavior and proved emotion and attention serve as important intermediates for detecting perceived appropriateness.

In the future, we plan to conduct a Wizard of Oz study to understand how information on perceived appropriateness can contribute to behaviors that improve people's trust and acceptance of erroneous robots and draw insights for robot behavior design from the flexibility and cognitive decision-making of operators.

Overall, our research contributes to understanding, detecting, and adapting to conflicting interactions for robot social navigation. This will enable robots to avoid making the same mistakes repeatedly and compensate for people's negative perceptions, thus increasing their social acceptance.

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