How should home companion robots behave when encountering a human while performing independent tasks?

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Abstract -- While collision avoidance is an integral part of path planning, it is important to define robot behavior when suddenly encountering a social agent in its path. This article proposes an exploratory study to determine acceptable social behavior for home companion robots when suddenly encountering a human in its path. The proposed study is a 3x3 mixed factorial, exploring the effects of anthropomorphism and robot response with encounter behavior; participants view videos depicting different robot actions upon encountering a social agent, where the robot either avoids the human, waits for the human or interacts with the human.

Keywords -- human robot interaction, human aware motion planning, collision behavior, social robot, home companion robot, robot butler

I. INTRODUCTION

Human-robot interaction is a growing area of research, with a focus on ensuring robots are safe, comprehensible and enjoyable to the social agents sharing spaces with them. Mobile robots navigate using localization and path planning algorithms to define a trajectory in physical environments. Such algorithms identify an optimized path while avoiding obstacles; however, it is important to define robot navigation and behavior in a *social space* occupied by social agents, such as humans, which optimize more socially acceptable paths (Fig. 1). Such trajectories are defined using *human aware navigation* algorithms. While trajectories can be optimized for social navigation, it is crucial to define optimal robot *behavior* when navigating in social spaces.

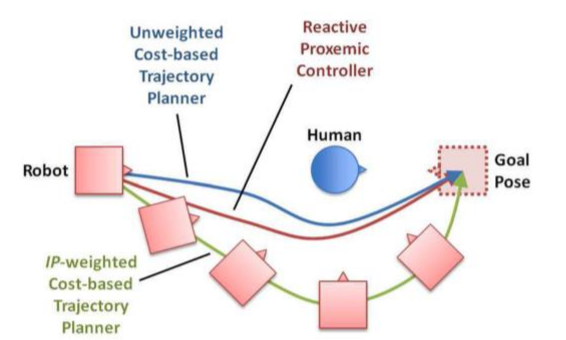

Fig 1: Various robot trajectories, including costs for proxemics and *interaction potential (IP)* with humans [1].

While human safety is the priority, defined by *collision avoidance* [2], researchers also study robot behavior that is socially acceptable, such as the use of non-verbal communication and gestures like gaze [3]. Robots must also behave in a way to make social agents feel safe and comfortable. Additionally, socially acceptable robot communication and behavior is essential to mitigate the effects of the *uncanny valley* by designing robots that not only look realistic, but also behave naturally.

Home companions, such as butler robots, is a popular use case of mobile robots [4]. Home companions can work independently or with other social agents in a home environment to complete tasks. In such environments, the robot traverses through an indoor space that can be unoccupied or occupied with social agents. Thus, it is important to define robot behavior in dynamic indoor environments. This article proposes an exploratory study to determine acceptable robot behavior upon encountering social agents while the robot is performing independent tasks in a dynamic environment.

II. RELATED WORKS

A. Collision Avoidance with Social Agents

Motion planning algorithms account for social agents and define safe robot trajectories that handle static and dynamic environments. Chen et al. define path planning algorithms that handle collision avoidance in densely populated environments [5]; Nishitana et al. define path planning algorithms that handle dynamic environments by predicting social agents' trajectories and updating the robot's path [6]. Volkhart et al. show that in home environments, Kalman Filters can be applied to each person to predict the pose (sitting, upright) of multiple agents [7], while Hashimoto et al. show that path planning algorithms can account for specific instances of collision avoidance, such as entering corners with humans [8]. While algorithms can model human navigation without explicit definition of their motion models [9] [10] [11], some consider that humans also attempt to modify their trajectory to avoid collisions, and propose algorithms that collaborate with humans [12], or observe humans' gaze patterns to predict changes in human motion [13].

B. Human Aware Social Navigation

In this subset of motion planning, humans are considered special objects [14]. Robots acknowledge social agents while navigating, and navigation models optimize person-acceptable paths using a social cost map [15] [16]. Mead and Mataric [1] and Torta et al. [17] incorporate proxemics into navigation algorithms, defining appropriate robot paths that minimize any intersection with humans' personal space. An extension to proxemics is culturally aware navigation, where Truong et al. integrate extended personal and social spaces into robot motion planning [18].

C. Nonverbal Communication

While algorithms attempt to predict human trajectories [19], robot gestures assist humans with predicting robot trajectories by attempting to inform the surrounding social agents with the robot's intentions. Gielniak et al. propose human-like motion for robots, allowing social partners to recognize the robot's motion intent [20]. Khambaita et al. propose head-body gestures, such as gazing at the path and the human, to communicate the robot's intentions while acknowledging the encounter with the social agent [3]. Fernandez et al. use hardware such as LED lights as turn signals to communicate the robot's intended path [21].

D. Home Companions

Research on home companions spans social perception, robot navigation and robot intelligence, among others. Dautenhahn et al. present perceptions of home companions, specifically how robot companions should be human-like in their communication, with their roles as assistants or servants in the home, rather than as friends [22]. Lee et al. present path planning algorithms for butler robots with 3D object detection and manipulation to fetch objects [23]. Luo et al. develop a Convolutional Neural Network to enhance household chore classification for home companions [24].

E. Approaching Social Agents

Ruijten and Cuijpers explore the stopping distance for a robot approaching a multiparty conversation by mapping shared interaction spaces to the robot's trajectory [25] [26]. Dautenhahn et al. present a study on robots handing over an item while approaching seated participants from different directions, determining the comfortable approach direction [27].

F. Anthropomorphism

Mobile robots are designed with varying degrees of anthropomorphism according to their intended use. Salem et al. present how non-verbal gestures enhance anthropomorphism and social perception of robots [28], while Kwon et al. present how a robot's physical appearance affects the social expectations of the robot [29].

III. RESEARCH QUESTIONS

The study proposed in this article acknowledges the advances in technology and research related to human aware social navigation, interaction, and collision avoidance for mobile robots; the study seeks to explore the social perception of anthropomorphism and robot actions when encountering a social agent in its path while performing an independent task.

For related works that discuss methods of robot interaction with social agents, the interaction is *intentional* and initiated by the robot. This study seeks to explore sudden, unintentional encounters and examine the effect of the robot's behaviors, determining which, if any, are socially acceptable. Additionally, for related works that discuss human aware navigation, the studies present findings on spatial effects, such as proxemics and minimizing interaction with personal space; whereas, this study seeks to explore the effects of robot *behavior* while satisfying the findings on spatial effects in an interaction. Thus, the exploratory study defines two Research Questions.

RQ1: Do anthropomorphic robots have different social norms upon encountering a social agent, compared to non-anthropomorphic robots?

RQ1-H1: Anthropomorphic robots are expected to follow social norms similar to humans

RQ2: How does the robot's response to a sudden social encounter influence the social perception of the robot?

It is notable that **RQ1** has a hypothesis, **RQ1-H1**, as existing literature finds that the social perception of a robot is influenced by the robot's physical appearance [29]. The second research question, **RQ2**, does not have a hypothesis, as it reflects the exploratory nature of the study.

IV. METHOD

A. Overall Design

The experiment design consists of a 3x3 mixed factorial study, varying two independent variables: the anthropomorphism (Humanoid, Non-Humanoid, control=Human) and the robot response to the encounter (Avoid, Wait, Interact). Thus, nine conditions are defined, where three are control conditions and six are experimental conditions, as indicated in Table 1. The study design is between-participant for the anthropomorphism and within-participant for the robot response to encounter. The control conditions are defined by C01, C02 and C03, where a human actor is used rather than a robot. As this study explores an application of robots that may replace a human's role (ex: home companion, butler) it is important to define a control group with a human

Table 1: Study Conditions (Control and Experimental)

Condition	**Anthropomorphism**	**Robot response to encounter**
C01	Human (control)	Avoid
C02	Human (control)	Wait
C03	Human (control)	Interact
C11	Humanoid	Avoid
C12	Humanoid	Wait
C13	Humanoid	Interact
C21	Non-humanoid	Avoid
C22	Non-humanoid	Wait
C23	Non-humanoid	Interact

actor to examine any differences in social impressions of a robot performing the same actions as a human.

For the experiment, video recordings are taken in a home-environment. It is proposed to modify the lab space to a home setting. The robot moves between two points placing cups from one point to another for a party setting. For each robot (or human, for the control case), a 20 second video is recorded to familiarize the participants with the robot and setting. Additionally, each condition is recorded as a separate 20 second video. Five volunteer human actors play social agents in the dynamic home environment that walk and stand in the robot's path. For the control conditions, a sixth actor is needed to play the role of the robot. The videos are post-processed to ensure the parameters of interest are visible and highlighted to the viewer. Captions are inserted to the video to guide the viewer. It is important to use the same camera and camera position for each video to avoid differences in quality and information presented to the participants.

The three possible robot responses are Avoid, Wait, and Interact. When the robot *avoids* a social agent, the robot updates its trajectory, moving around the social agent; when the robot *waits* for the social agent, the robot stops its motion until the social agent has moved, waiting for 10 seconds until proceeding with a new trajectory; when the robot *interacts* with a social agent, the robot says, "excuse me" while using gaze to look at its intended path and the social agent. As the non-humanoid robot does not have eyes, it turns its body. After the interaction, the robot waits 10 seconds for the social agent to move, before proceeding with a new path. The three possible robot responses are depicted in Fig 2.

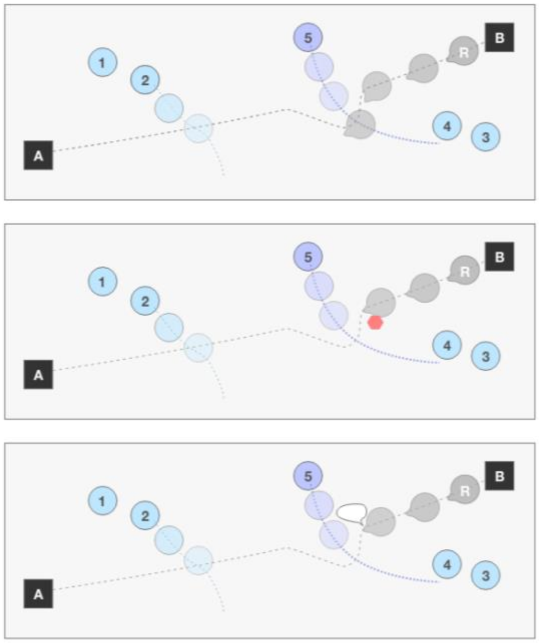

Fig 2: Illustrative layout of the experimental space; three robot responses to a sudden encounter with a social agent, (a) avoid, (b) wait and (c) interact; the robot moves from Point B to Point A where social agents dynamically move into the robot's trajectory. Social agent 5 and 2 move into the robot's path.

B. Participants

A total of 90 participants are needed for this experiment, where 30 participants are used for the control group and 60 participants are used for the experimental group. For generalized findings, it is important to ensure diverse participants. Diversity refers to diversity in age, gender and knowledge of technology and robots. As this study seeks to report findings on social perceptions of robots in a wide application area (home companions), it is important to diversify the sample population. When reporting the findings, the participant breakdown (#female, #male, average age and standard deviation) will be presented for each condition, as seen in Table 2.

The Amazon MTurk Marketplace [30] will be used to host the experiment, as it ensures participants cannot skip forward in videos, increasing the likeliness that the participant watches the entire video. With the study design, each participant receives one introductory video and three experimental videos. Participants will be selected through university channels via flyers and emails as well as web-based recruiting tools, as there

Table 2: Participant Demographics

	C01	C02	C03	C11	C12	C13	C21	C22	C23	Total
#F										
#M										
Avg. age										
STD age										

is no geographical restriction for the study, as it is hosted online. Additionally, it is important to note that there may be technical issues affecting some participants' ability to complete the study. Thus, not all 90 participants may be valid sessions. To mitigate the risk of losing sessions, an option is overshooting the number of participants to 120 (60 for control; 90 for experimental) which may lead to 90 valid sessions (30 for control; 60 for experimental).

C. Artefacts

The study seeks to examine the effect of anthropomorphism on the social expectations of the robot. Thus, two robots are used to vary the degree of anthropomorphism in the conditions. The non-humanoid robot used is the TurtleBot [31], and the humanoid robot is SoftBank Robotics' Pepper robot [32], where both robots are illustrated in Fig 3.

As the study is carried out via video recordings of the robot interacting with actors, it is not necessary to program advanced intelligence for the robots. When recording the videos, the robots can be controlled via Wizard of Oz or hardcoded behaviors. Hardcoding the behaviors is the ideal method, as the location of path intersection between the robot and social agent (actor) is explicitly defined in the experiment. By hardcoding the robot behaviors, it is important to mark the locations and time where the actors must encounter the robot to ensure the encounter seems natural.

D. Procedures and Measures

The procedure is concerned with addressing **RQ2**, while the overall results of the study seek to answer **RQ1**. During the experiment, the participant will answer questions that address **RQ2**; at the end of the experiment, by analyzing the difference between experimental groups' responses, we seek to answer **RQ1**. The experimental procedure is described.

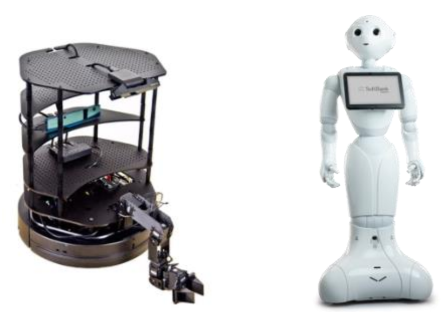

Fig 3: Robots with varying anthropomorphism; (a) TurtleBot [31] and (b) Pepper [32]

Fig 4 depicts the sequence of events that occur for each participant. Before commencing the experiment, the study must be approved by the ethics board. The experiment is split into three parts: (1) Introduction, (2) Experiment, and (3) Data Collection. The Introduction section begins with a consent form for the participant and an initial survey to determine demographics and initial perceptions and knowledge of robots and technology. The participant then becomes familiar with the robot and environment of interest by watching a video of the robot performing independent tasks. This video is recorded along with the experimental and control conditions; however, its purpose is to familiarize the participant with the setting before injecting the sudden encounter with a social agent. In this video, there are no social agents in the robot's path. The robot moves from point A to B with no disruption in its path. After watching the introductory video, participants are asked to fill out a quick form to ensure they were paying attention: (1) briefly describe the setting, (2) briefly describe the robot, (3) briefly describe the task.

In the Experiment section, participants are sequentially shown the three videos where the robot suddenly encounters a social agent in its path. The order of videos is counterbalanced across participants to ensure ordering effects do not influence the results. For example, for participants that observe Condition 1, the ordering of C11, C12 and C13 is counterbalanced. After watching each video, the participant is asked to briefly describe the action the robot performed.

For the Data Collection portion, self-reports are used to assess the social perception of the robot. The participants are asked to complete a survey to gather their opinions' on the robot's actions. **The Robotic Social Attribute Scale (RoSAS**) is used to evaluate the social attributes of the robot in each video, revealing attitudes on the robot's warmth, competence and discomfort. For each of the 18 adjectives, participants are provided a 9-point Likert Scale. In addition to the RoSAS measure, an **8-point Likert Scale** (strongly disagree; strongly agree) is used to evaluate the robot's behavior when interacting with the social agents as well as when it avoids the social agents, as seen in Table 3. Participants can review the videos of the robot's actions if needed. The even-numbered Likert Scale forces participants to select a non-neutral response.

At the end of the Data Collection portion, participants are thanked for their time and told that they will receive a 1-page summary of the research upon completion.

E. Coding and Reliability

The study does not have any audio interviews; therefore, there is no extensive coding needed to

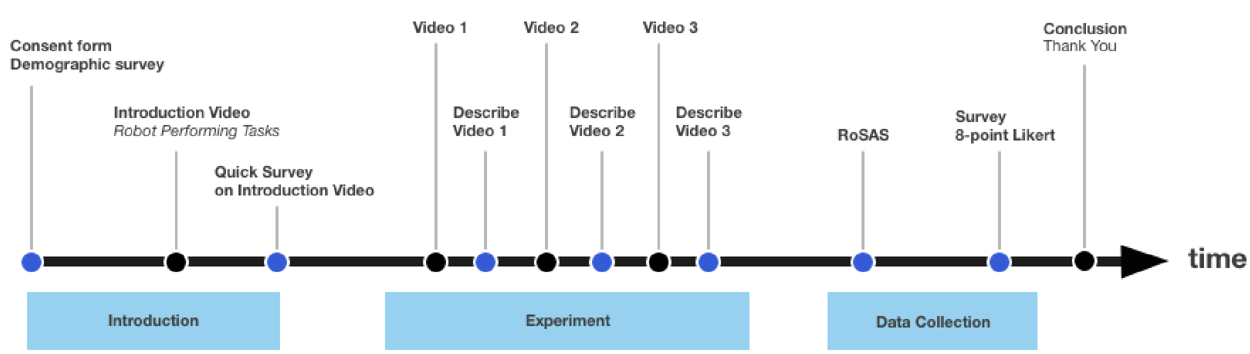

Fig 4: Sequence of events for study, spanning Introduction, Experiment and Data Collection

Table 3: Likert Scale questions

Robot behavior

- The service robot behaved in an acceptable way, when encountering humans
- The service robot behaved politely to the humans
- The service robot disrupted the humans with its behavior

Robot path planning (avoiding humans)

- The service robot should avoid crossing paths with humans whenever possible
- It is acceptable for the robot to cross paths with humans as long as there is no collision

transcribe participants' responses. The short text answers from the participants are analyzed with Natural Language Processing and simple text cleaning and analysis methods to present the frequency distribution of common descriptors for the robots and scenarios.

V. RESULTS

As this article presents a proposed study, there are no results to present. When presenting the results, the mean result and standard deviation need to be presented. The RoSAS score would be summed across each factor. The results would be analyzed to decide whether to accept or reject hypothesis **RQ1-H1** using a 95% confidence interval.

VI. DISCUSSION

As this article presents a proposed study, there are no results to discuss; however, it is possible to discuss some of the limitations with the study design.

A. Limitations

As the proposed study is executed online by showing videos to participants, the results are limited. The participants are viewing a scene rather than experiencing it in first-person; thus, their responses are limited. Had the study been carried out in person, the participants could evaluate the effect of the robots actions *towards* them rather than evaluating the effect of the robots actions towards another social agent via video.

It is important to consider the effect of the video camera positioning on the results. There may be optimal angles that capture the anthropomorphism of the robots as well as the interaction. It may be worthwhile to present various angles to the participant.

Additionally, several variations in the robots actions exist. The study presents only three actions taken by the robot upon encountering a social agent in its path. It's possible to define other actions or variations of the three actions, such as adding more complex gestures when interacting with the social agent or using other phrases rather than "excuse me." Such actions would be perceived differently depending on the cultural context of the robot and the participants' background.

Technical difficulties that can occur during the experiment include hardware issues with the robots or the camera. A mitigation plan is using a software simulation rather than live-video footage. The remainder of the experiment is unaffected by this difficulty. Such a difficulty would include a delay in the study, as time must be factored to create the simulations.

VII. CONCLUSION

As this article presents a proposed study, it is not possible to discuss the results or what was learned from the experiment.

This study would be beneficial to researchers who study human aware navigation for social robots or behaviors of robots in social settings. The study does not discuss path planning or alternate trajectories, but rather socially acceptable behavior for robots when encountering a human in their path.

VIII. FUTURE WORK

Future comprehensive studies should explore the variations in robot actions. For example, future studies can explore the effect of wait time before proceeding (10 seconds in this study) or the effect of different interactions when encountering a social agent. Additionally, it may be useful to study the effect of space on the reception of robot interaction; *is robot interaction unwanted in large spaces where the interaction can be avoided?* For home companions, future work can study the effect of the task executed by the robot on the acceptance of robot behavior upon encounter. *Are there some tasks where robot interaction is more acceptable?*

This study focuses on the human blocking the robot's path in the sudden encounter; however, a related research area would is exploring socially acceptable robot behaviors when the robot is blocking the human's path.

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