Be a Robot! Robot Navigation Patterns in a Path Crossing Scenario

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***Abstract*—In this paper we address the question how a human would expect a robot to move when a human is crossing its way. In particular we consider the problem that physical capabilities of robots differ from humans. In order to find out how humans expect a robot, with non humanlike capabilities, to move we designed and conducted a study were the participants steer the robot. We identified four motion patterns and our results show that driving straight towards the goal and stoping when a human might collide with the robot is the favored motion pattern.**

I. Introduction

Social robots will increasingly become part of the natural habitats and work spaces of humans. For the purpose of this coexistence acceptance of the robot plays an important role. A prerequisite for the acceptance of robots in everyday situations is that they move naturally and predictably and that humans feel safe. Several approaches have been proposed to make robot navigation socially acceptable [1]–[3] and Lichtenthäler et al. [4] showed in their experiments that the legibility and perceived safety of common navigation methods are rather low. However, there is currently no understanding of what humans expect from the navigation capabilities of a robot, in particular how it should behave in dynamic situations when the paths of humans and robots cross. Kruse et al [2] made the assumption that a robot is acceptable if it shows similar behavior to humans. However, physical capabilities of robots differ very much from humans (in particular those of wheeled robots). Therefore, the comparison to human behavior becomes difficult. In addition, it is not known humans expect robots to move in a different manner to humans. The question which comes up is how can we find out what kind of motion patterns humans expect from a robot with non humanlike physical capabilities. Our idea was to let naive participants steer the robot to find out how they would want the robot to react when a human is crossing its path. With the identified motion patterns we can develop a navigation strategy which mirrors human expectations.

II. Study Design

The study was designed to identify robot motion patterns in a dynamic situation and answer the question of how a human would expect a robot to move when a human is crossing its way.

A. Participants

We recruited 46 participants with an average age of 28 years - thereof 26 women and 20 men. Furthermore, 89% of the participants had rarely or no contact to robots and 11% had regular contact to robots.

B. Technical Setup

1) Robot: The platform used in this study was the BIRON (BIelefeld Robotic CompaniON) robot BIRON has an overall size of approximately 0.5m (w) x 0.6m (d) x 1.3m (h). Besides two wheels, BIRON has two rear casters for balance and is constructed with a differential drive (2 degrees of freedom: translation and rotation).

2) Robot Remote-Control: To steer the robot we used a wireless keyboard. The commands of how to steer the robot were marked on the keyboard with arrows. Five keys corresponded to the five ways of moving the robot: straight forward, rotate around its own axis in a clockwise direction, in an anti-clockwise direction, drive and turn left or right in an arc. The robot only moved by holding down the particular key and the robot stopped by releasing the key. There was no possibility to accelerate the robot as it was driving at its full speed of 0.7m/s.

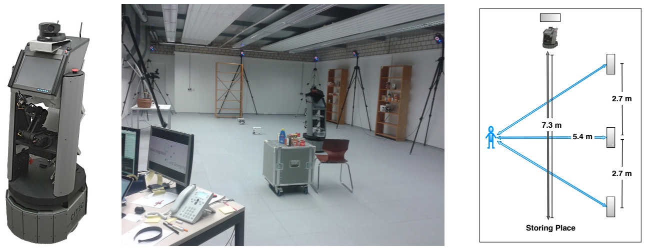
3) Motion Capturing System: To capture the movements of the robot and the interacting person we used a VICON motion capturing system (www.vicon.com) and a HD camera to record additional video data.

C. Study Setup

1) Cover Story: In order to make the scenario realistic the participants were told the same cover story about a grocery store that uses a robot (BIRON) to transport goods from the storing place to the shelves (see Fig. 1). The participants were asked to navigate the robot from the storing place to a shelf by steering the robot with the wireless keybord (see Fig. 1(a)). Furthermore, they were told that the robot might encounter customers in the store.

2) Setup: According to the grocery store cover story we built up a store scenario with four shelves and a storing place (see Fig. 1(b)) in a laboratory. Three shelves were placed at the wall on the right side of the storing place with a distance of 2.7 m between them (see Fig. 1). One shelve was placed 7.3 m opposite to the storing place. The shelves and the storing place were filled with typical grocery store products.

The robot, steered by a participant, had the task to bring items from the storing place to the opposite shelve (see Fig. 1). One experimenter took the role of a *customer*. The *customer*



(a) BIRON (b) Laboratory (c) Study Setup

Fig. 1. Used robot and design of the study

had the task to walk from a fixed point (see Fig. 1(c)) randomly to one of the three shelves at the wall and put an item into his/her basket. In addition to the three randomized aims the *customer* walked randomly in three different walking velocities slow (0.6 to 0.8m/s), normal (1.2 to 1.5m/s), and fast (1.9 to 2.1m/s). The customer had to go straight and maintain the velocity even if the robot would crash into them. Due to the arrangement of the shelves the robot and the customer coincidentally met each other in 45° and 90° angles (see Fig. 1(c)). Hence, we had nine different crossing conditions in random order. Thus the setup was designed to create completely random and unforeseeable crossing events. To avoid eye contact with the participant the *customers* wore sunglasses. Two other experimenters helped the robot to sort and to put away the good.

D. Procedure

In order to familiarize the participant with the setup and with steering the robot BIRON the participants received an introduction to the robot BIRON and an extensive practice of how to steer the robot via the wireless keyboard. The participant were told to carry 15 items (only one item per time) from the storing place to the opposite shelve (see Fig. 1) and then go back to the storing place. Therefore the robot moves 30 times (two times per item) straight through the room (see Fig. 1(c)). The customer crosses the robots path randomly as described in section II-C. The movements of the robot and the *customer* are captured by the VICON motion capture system. After the study was finished, participants were verbally debriefed.

III. Results and Discussion

In the 1380 robot path trajectories (30 x 46) we identified 1218 crossing situations in our data, whereby a crossing situation is defined as a situation where 1) the paths of both, BIRON and the *customer*, will cross and 2) both are located before reaching the crossing point. By analyzing the video and motion capturing data of the crossing situations we identified four navigation patterns:

1) stopping or stuttering (76.7%)
2) driving on and passing behind or in front of the *customer* (18%)
3) driving a curve (3.7%)
4) collision with the *customer* (1.6%)

The first motion pattern, which the participants performed the most (76.7%), was driving straight towards the goal (shelve or storage place) and stopping (or stuttering) when the *customer* came close to the crossing point. In 75% of these situations the distance of the *customer* to the crossing point was between 0.58m and 1.8m (median: 1.13m) and BIRON stopped within a distance between 1.14m and 2.13m (median: 1.55m) to the crossing point. 44 of 46 (95.6%) participants performed this pattern. The second motion pattern we identified was to drive along, passing the *customers* path far before or behind (18%). There is no risk of a collision in these crossing situations. This pattern was shown by all participants. The third identified motion pattern was to drive a curve in order to avoid a collision with the *customer* (3.7%). Similar to the first motion pattern BIRON was driving straight towards the goal and when the *customer* came close to the crossing point they started to drive a curve. 21 participants showed this behavior. The motion pattern "collision with the *customer*" (1.6%) was only shown by two participants. The participants were driving straight towards the goal without considering the *customer*.

Almost all participants, except the two who crashed BIRON into the *customer*, showed a defensive behavior. Two of the motion patterns (1 and 3) try to avoid a collision by reaction somehow, the second pattern shows that the participants anticipates a collision is foreseeable. Therefore we can conclude that a defensive navigation strategy is the most expected strategy and furthermore that the strategy with the least effort, a combination of 1 and 2 (towards the goal and stopping/stuttering when necessary) is the most preferred strategy.

IV. Conclusion

To sum up, we conducted a study to identify motion patterns in a human robot path crossing scenario. The overall navigation strategy we can conclude from the identified patterns is to drive straight towards the goal and only react (stopping, stuttering or drive a curve) to a crossing human when a collision is foreseeable, otherwise drive on towards the goal. With further analysis of the data we want to identify concrete rules for reaction when a human is crossing a robots path in order to develop a navigation method.

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