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An Analysis Of Human-Robot Social Interaction For Use In Crowd Simulation

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FOR USE IN CROWD SIMULATION

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ABSTRACT

The simulation of crowd dynamics is an important tool for a number of applications, including architectural design, pedestrian transport and escape planning. The use of robots has been recently proposed as a mechanism to improve the efficiency of pedestrian transport by modifying the large-scale dynamics of crowds. However, in order to simulate the effect of introducing robots into a crowd, one must have a model of how individuals will react to the form and behavior of the robots that are introduced. To this end, this paper provides an overview of the existing work on human-robot interaction in the field of social robotics and illustrates how this information can be integrated into crowd dynamics simulations.

KEYWORDS: Crowd and Pedestrian Simulations, Crowd Dynamics, Social Robotics, Human-Robot Interaction

1. INTRODUCTION

The study of crowd dynamics, or the large-scale motion of people, has an impact on a wide range of applications including architecture, pedestrian transportation, escape planning, stampedes, event organization, and crowd control. The use of autonomous robots is a possible mechanism for improving pedestrian flow and modifying undesirable crowd behaviors [1]. For example, in crowd control the robots could defuse dangerous situations in a socially acceptable manner that would minimize collateral damage and loss of life. However, it is very difficult to experimentally evaluate the effect of robots on crowds in such situations, so one must rely on crowd simulation software. Simulations of human pedestrian flow using the social force model [2, 3] are reasonably accurate at mimicking the behavior of human crowds; however, models for human-robot interaction are not as fully developed. Thus the focus of this paper is to present an overview of the existing work in human-robot interaction in the field of social robotics in order to develop a model that can be incorporated into existing human crowd dynamics simulations.

The remainder of this paper is organized as follows. The next section presents a brief review of the social force model used by Helbing [2, 3] to simulate crowd dynamics. This model is then augmented to illustrate how the introduction of robots into the environment can be simulated. The augmented model requires knowledge of parameters associated with how human's will react to robots in their midst. Section 3 discusses previous work in the field of social robotics that provides some information regarding the range of reasonable values for these parameters. In particular, factors such as size, gestures, social space, and physical contact that impact a human's response are considered. Finally, some concluding remarks are presented in the last section.

2. OVERVIEW OF THE SOCIAL FORCE MODEL

The social force model was first introduced by Helbing and Molnár [2] and has been expanded to include physical contact forces (with similarities to granular flows) for panic situations [3, 4]. The social force model used to describe pedestrian flow has its origins in gas-kinetic models [5]. It consists of self-driven particles, i.e., people, who interact through social rules. For a crowd consisting of N individuals, the force acting on the ith person is denoted by f_i and is given by

$$\boldsymbol{f}_i^{Person} = \boldsymbol{f}_i^{Self-Driven} + \sum_{\substack{j=1 \\ i \neq j}}^{N} \boldsymbol{f}_{ij}^{Person-Person} + \sum_{k=1}^{W} \boldsymbol{f}_{ik}^{Person-Wall} + \sum_{l=1}^{M} \boldsymbol{f}_{il}^{Person-Robot} \qquad (1)$$

where $\boldsymbol{f}_i^{Self-Driven}$ denotes the self-driven force that drives an individual towards their desired velocity, $\boldsymbol{f}_{ij}^{Person-Person}$ denotes the interaction force on individual i due to individual j, $\boldsymbol{f}_{ik}^{Person-Wall}$ denotes the wall avoidance force of individual i due to the kth wall (where W is the total number of wall surfaces), and $\boldsymbol{f}_{il}^{Person-Robot}$ denotes the interaction force on individual i due to robot l (where M is the total number of robots).

The self-driven force is based on a simple error correction term consisting of the difference between an individual's desired velocity and their actual velocity. The person-to-person interaction force consists of two major components, a social interaction and a physical interaction component. The first, the social interaction term, is used to represent an individual's inherent desire to maintain a certain amount of personal space relative to other people. The second term, the physical interaction term, consists of two forces, a body compression force and a sliding frictional force. The interaction term between a person and a wall is analogous to the social interactions between people. The final component of the model is a term representing the interaction between a person and a robot.

The governing equation for a robot's behavior is analogous to the model of an individual's behavior. The equation is composed of a self-driven term along with robot-wall, robot-person, and robot-robot interaction terms. The specific terms are analogous to the interaction terms in the equation governing an individual's behavior, but the parameters associated with them represent the programming of the robot's behavior.

Person-to-person and person-to-wall interactions are somewhat understood and the parameters affecting these interactions have been estimated in previous work [3]. However, little experimental data exists for determining the parameter values for the interactions between people and robots. Some of the various factors that should be considered to determine these parameters are discussed in the next section.

3. FEATURES AFFECTING HUMAN RESPONSE

3.1 Social Robot Size

Robot size is clearly a design aspect that would need to be considered in a crowd dynamic simulation environment because it will affect how people perceive and react to the robot. Figure 1 compares the height of a list of social robots grouped by their purpose; note that this contains only mobile robots because stationary robot designs would be less relevant. As an example of how social robot designers use size to influence human response, the creators of Robovie (see Figure 2) made the robot small (120 cm tall and 40 cm in diameter), i.e., about the same size as a grade-school child, to give people a more positive impression of the robot [6]. A small robot is perceived as less threatening and therefore more approachable than a larger, more imposing robot. Similarly, the creators of Cero, a small office assistant robot, believe that a smaller robot would appear less intelligent and its errors might therefore be more tolerable [7].
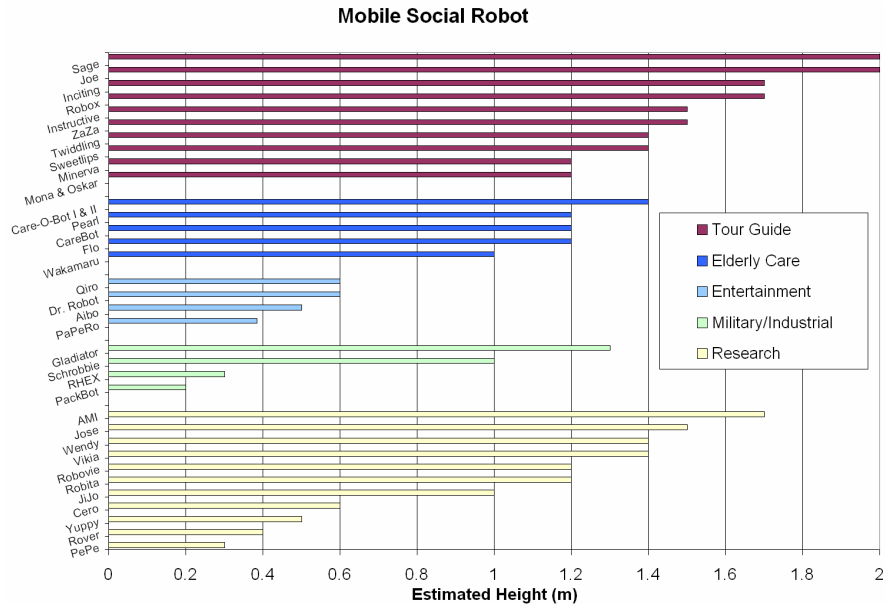
Mobile Social Robot

Figure 1: A comparison of size for mobile social robots is shown in this figure. Tour guide robots tend to be the largest, which achieves their task. Elderly-care robots tend to be smaller than tour guide robots but are more consistent in size. The entertainment robots tend to be small, probably to keep the robot more practical and affordable. The research robots tend to have a wider variety of sizes; this is expected since this category covers wide ranges of motivation and implementation. (Many of the sizes are estimates obtained from images.)

In some cases, functionality dictates a robot's size. For example, tour guide robots tend to be the tallest of the social robots studied because these robots need an unobstructed view of their environment, and they should also be visible to the visitors. In addition to these practical reasons, a tall robot would probably have an influence on how people socially perceive the robot. A tour guide robot would be in a position of authority, controlling (or at least suggesting) which exhibits people explore; furthermore, the robot would speak as an authority on the topic of the exhibit. A tall (and perhaps also a robot larger in girth) may enhance this impression. It is likely that size would also influence how people responded to instructions from the robot. (Studies with Pearl, an elderly assistant robot, have demonstrated that different robot personalities can affect a person's compliance [8, 9].)

3.2 Gestures
Robovie (see Figure 2) was used in experiments to examine how gestures affect human-robot communication [6, 10]. The robot interacted briefly with human subjects by giving directions to an unknown location in the building using one of six communication strategies. These strategies used different combinations of robot orientation relative to the subjects, gestures, and gaze. The most successful strategy was one where the robot faced the same direction as the subject and reinforced its instructions with both gestures and gaze.

This experiment may indicate how the robot's gestures and orientation relative to the subjects may help the spatial comprehension of navigational instructions. However, the ability to map another person's body onto one's own body appears to be a fundamental social skill [11]. This skill allows people to understand another person's perspective and interpret another's behavior. In this light, Robovie may also be exploiting this social skill by appearing more human-like through gestures and gaze, which helps further reinforce the social awareness of another person's perspective (and therefore helps clarify instructions).

3.3 Human-Robot Social Space

When a robot moves near a person, they may perceive the robot as violating their personal space. The speed and size/shape influence how much the robot affects a person's comfort level and their resulting response. In general, robots that move faster, are larger, and move closer using jerky trajectories were found to decrease the comfort level of humans [12]. Though these results are not surprising, they do provide guidelines for determining parameter values for crowd simulations.

Although not aimed at human-robot interaction, the Robot Sheepdog Project [13, 14] addressed the analogous problem of modeling the spatial relationships between a robot and a herd of flocking animals (ducks were used as a proxy for sheep). The ducks' behavior was first modeled in a computer simulation using a model similar to the social force model but using velocities instead of forces. The ducks were programmed to have an attractive velocity to other ducks (to model flocking behavior) and a repulsive velocity to the robot (called "Rover," see Figure 2). Due to the ducks natural tendency to maintain a certain "social space" from the robot, the researchers were able to identify a movement strategy that allowed the robot to direct the ducks to a desired location (both in simulation and in physical experiments).

One additional aspect that should be considered in the modeling of spatial relationships between robots and humans is the phenomenon of "social amplification." This was clearly illustrated by Kismet, a stationary head robot developed at MIT [15] (see Figure 2). Because the robot is not mobile, Kismet must encourage people to interact at an appropriate distance. When a person moves too close to the robot, Kismet cranes its head back; while it can only move a few inches, the person reads this social cue as an invasion of the robot's personal space and in turn will amplify the distance by backing up. By using social amplification the robot can leverage the surrounding environment beyond its physical capabilities [15].
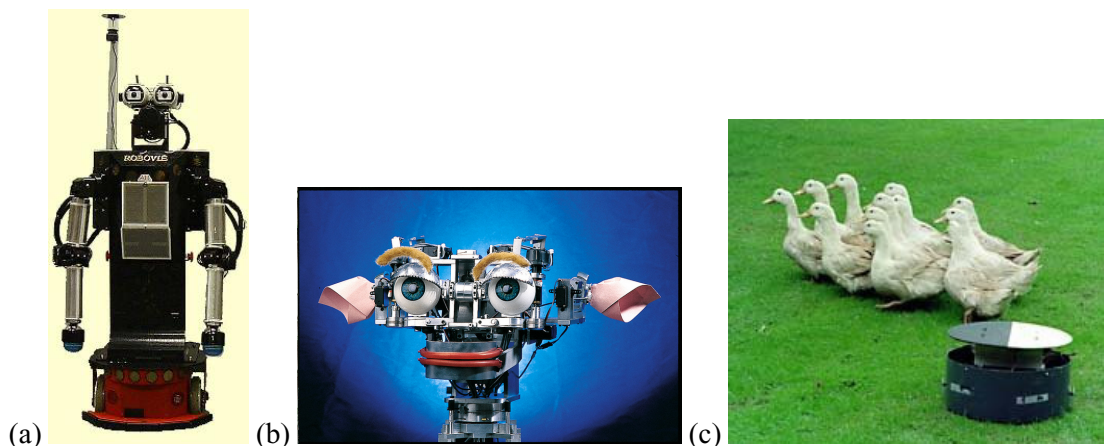

(a)   (b)   (c)

Figure 2: (a) Robovie, an interactive robot, has been used to study how people would respond to a robot in natural social situations. (Image obtained from http://www.irc.atr.co.jp/~m-shiomi/Robovie/ courtesy of ATR Laboratories). (b) Kismet, built at MIT, is a very famous social robot designed to interact with people through a wide variety of social channels (Image ©2000 Peter Menzel/Robo sapiens/www.menzelphoto.com.) (c) Rover, part of the Robot Sheepdog Project, was a robot used to influence the behavior of domestic ducks through social interactions. (Image obtained from http://www.sri.bbsrc.ac.uk/news/autumn98/rover.htm courtesy of Richard Vaughan.)

3.4 Physical Contact

Physical contact is another robot-human social interaction that must be considered to determine an appropriate value for the human-robot force term in Eq. (1). Robovie was used in an experiment where physical contact with the robot was required and measured [10]. Experimental results using Robovie show that when given an option, people choose the option that is consistent with perceiving the robot as anthropomorphic. (Although the locations of preferences for physical contact may have a strong cultural dependence.)

Interestingly, many tour guide robots were equipped with buttons or touch screens for people to choose various tours or request additional information. Many of these input devices were placed on the bodies of the robots; however, this is where human subjects were least comfortable with touching Robovie. The placement of input devices on the body may be motivated by reasons of practicality, accessibility, aesthetics, or visibility, but an arguably preferable approach would be to have the robot hold the device in its hand. Not only were people found to be more comfortable with touching Robovie's hand, but the very act of extending the device would be interpreted as a request for input.

4. SUMMARY AND CONCLUSIONS

The ability to include autonomous robots into crowd simulations allows researchers to explore how changes in small-scale interactions affect large-scale crowd dynamics, with the ultimate goal of steering the dynamics to desirable outcomes. While the social force model of crowd dynamics can be easily augmented to include robots, its implementation requires the specification of a large number of (currently) unknown parameters. The growing field of human-robot interaction, especially in the area of social robotics, provides some insight into how one can experimentally determine some of the relevant model parameters. This paper has discussed several aspects of human-robot interaction (such as size, gestures, social space, and physical contact) and how they are applicable to the simulation of crowds that include robots. However, despite determining some constraints, many of these interactive parameters remain elusive. Additional experiments with physical robots would be helpful to further narrow and quantify the precise values required to model human responses. Some questions that still remain unanswered include:

- What expectations or abilities does one want the crowd to attribute to the robot?
- To what degree does appearance influence expectations of the robot's abilities?
- To what extent should emotional expression be used to influence a crowd?
- What kind of face, if any, will be needed to convey the most appropriate expectations of the robot's abilities to crowd members?
- Matching the robot's personality to the instructed task can increase compliance. Does robot appearance also contribute to how people may comply with instructions?
- Is it preferable to use physical three-dimensional features or to render these features on two-dimensional displays?
- If using actuated cameras, will they need to be placed on a head? Will people be confused by two robot gazes, i. e., one from the head and one from the cameras?
- Will the robot need to initiate any physical contact? Will physical contact be necessary or useful to enhance the effectiveness of instructions? How does one model malicious attempts by individuals to thwart a robot's intentions (as in the case of Sage [16])?

Clearly, there is still much more work that needs to be done.

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