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Simulation modeling of pedestrian behavior in the presence of unmanned mobile robots

John M. Usher[a,*], Ross McCool[b], Lesley Strawderman[a], Daniel W. Carruth[c], Cindy L. Bethel[d], David C. May[e]

[a] *Department of Industrial & Systems Engineering, Mississippi State University, Mississippi State, MS 39762 USA*
[b] *Department of Psychology, Mississippi State University, Mississippi State, MS 39762 USA*
[c] *Center for Advanced Vehicular Systems, Mississippi State University, Mississippi State, MS 39762 USA*
[d] *Department of Computer Science and Engineering, Mississippi State University, Mississippi State, MS 39762 USA*
[e] *Department of Sociology, Mississippi State University, Mississippi State, MS 39762 USA*

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ABSTRACT

Interactions between pedestrians and robots are becoming more commonplace. In public areas, for example, robots may be used for information dissemination, security, or patrol tasks. Based upon existing literature in the field of human-robot interaction, the ISAPT simulation system was revised to model individual pedestrian behavior in the presence of a mobile robot. Using an agent-based modeling approach, pedestrians are statistically assigned one of six reported behaviors when a robot is encountered: interact, watch, curious, ignore, cautious, and avoid. The modeling methods for incorporating these behaviors include modifying a pedestrian's existing agenda and/or their perception of the threat represented by the non-humanoid robot, while the pedestrian continues to make navigation decisions based on their overall utility function. This paper discusses the implementation of this capability and presents results on ISAPT's ability to reproduce the different behaviors reported in the literature. Data collected in a field study are used to further validate the system by comparing measures from observed behaviors to simulation output. Validation measures included lateral distance to robot and lateral path deviation. These results illustrate this approach is an effective means for adding this capability to microsimulation modeling systems.

1. Introduction

With the rising popularity of mobile robots for various applications, we are now beginning to see them appear in public settings involved in such tasks as information assistance, security, navigation aids, and personal assistants. One question that arises is how the presence of mobile non-humanoid robots impacts pedestrian traffic. This paper reports on efforts to model the reaction of pedestrians within a general public setting. These reactions are based on what has been reported from observational studies reported in the literature. The basis for this work is the extension of the capabilities of an existing microsimulation system, ISAPT, so as to incorporate these new modeling capabilities. The ISAPT (Intermodal Simulator for

* Corresponding author.
E-mail addresses: usher@ise.msstate.edu (J.M. Usher), ram287@msstate.edu (R. McCool), strawderman@ise.msstate.edu (L. Strawderman), dwc2@cavs.msstate.edu (D.W. Carruth), cbethel@cse.msstate.edu (C.L. Bethel), dmay@soc.msstate.edu (D.C. May).

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the Analysis of Pedestrian Traffic) system was originally developed for the purpose of modeling pedestrian traffic within intermodal facilities, so that designers may evaluate the impact of building design on the level of service provided [1–3]. The consideration of robots within pedestrian environments is a growing possibility that needs to be addressed. Understanding how to incorporate such behavior will allow such systems to model pedestrian traffic in a wider range of applications. This paper begins with a review of pedestrian simulation followed by a section discussing the results of the observation studies on human-robot interaction in public settings. The fourth section then presents the methodology used for modeling the pedestrian behavior of individuals followed in the fifth section with simulation examples of various significant scenarios. The last section provides a summary of the work and presents ideas for future research.

2. Background

2.1. Modeling pedestrian behavior

The modeling and simulation of pedestrian traffic and crowd behavior has been a popular area of research over the last decade. These microsimulation systems have been applied to such areas as transportation facility design [4], evacuation modeling [5], urban planning [6], and safety assessment [7]. Several common approaches that have been employed for pedestrian simulation include cellular automata models, social force models, and agent-based models.

The cellular automata approach defines the area to be simulated as a 2D grid of equal sized cells where each cell is in one of several states (e.g., empty, occupied by pedestrian, occupied by object type x, etc.). The state of each cell is updated at each discrete time step based on the states of surrounding cells and the evaluation of a set of rules. Cellular automata was already being applied in vehicular traffic flow, when Blue and Adler [8] began investigating its application to pedestrian flow modeling. Although cellular automata systems are not as commonly employed as other approaches, due to its computational simplicity this approach is favored by some for large scale systems comprised of large populations, such as the ship evacuation system developed by Roh and Ha [9].

Social force models define the movement of each pedestrian based on its response to a set of attractive and repulsive forces in its environment using a series of nonlinearly coupled Langevin equations. Attractive forces within the model would include a pedestrian's destination, other pedestrians identified as friends (e.g., walking together) or objects in the environment they want to be near (e.g., window displays). Repulsive forces include other pedestrians (to avoid collision) as well as statics objects (e.g., walls, furniture, etc.). The strength of these forces is defined by such factors as object type, distance, and location within the defined simulated area. This approach was first introduced by Helbing and Molnar [10] to illustrate its ability to reproduce the self-organizing behavior of pedestrian traffic. This approach is still commonly used for a variety of pedestrian simulation applications such as behavior analysis at signalized crosswalks [7] and service system queues [11].

The third common approach, agent-based modeling, uses virtual agents to represent each pedestrian which are each driven by a set of rules that governs the interaction between the agents of the system. Each pedestrian is a fully autonomous entity operating within an environment with other pedestrians, out of which arises collective behavioral patterns with an ability to replicate observed traffic patterns. Some recent examples of agent-based pedestrian simulation systems include the system developed by Wagner and Agrawal [12] for modeling concert venues to test and assess alternative disaster scenarios with respect to emergency evacuation of the facility, and the system of Pluchino, Garofalo [13] which models the Castello Ursino museum in Italy to assess facility capacity and visitor safety when faced with emergency evacuation. As well, a recent study by Wang, Lo [14] employed their CityFlow system to explore pedestrian behaviors in complex environments where they specifically model a metro station.

Köster, Treml [15] state that one of the biggest challenges in pedestrian simulation is model validation. That is, determining if the model accurately represents the real system in the context of the study. Klugl [16] presents the various issues associated with validation of agent-based systems, like ISAPT, covering such points as inability to capture individual behavior characteristics, dealing with transient dynamics, non-linearities, and difficulty of acquiring (or unavailability of) data with sufficient detail. These are supplemented by Frydenlund, Elzie [17] mention of the data-related issues of generalizability, collection ethics, and costs. Dridi [18] validate the pedestrian model by focusing on walking speeds, densities over time and space, and boundary conditions making use of video data as one primary data source. To validate our system, we will explore its capability to reproduce observed and published response behaviors of individual pedestrians under set conditions, and then make use of video data as a basis for measuring the system's ability to reproduce pedestrians' paths in response to specific encounters with a robot.

2.2. Studies of pedestrian–robot interaction

A review of the literature was conducted to identify existing studies related to the interaction between pedestrians and robots in public spaces in order to provide parameter data for the initial simulation model. The work of E.T. Hall addressed the spacing of people during communication, which he called proxemics [19,20]. Hall proposed classifying the distances between people into four categories: intimate (<0.5 m), personal (0.5–1.2 m), social (1.2–3.7 m), and public (3.7–7.6 m). Later research by Walters, Dautenhahn [21,22] shows that those classifications are applicable to human-robot interaction. These distances are helpful for defining how close pedestrians will get to the robot in the current simulation model.