Can the Modeling of Pedestrian Movements Improve Robot Behaviors?

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Abstract. This position paper discusses the added value for service robots that can be obtained by modeling the movements of pedestrians. Two main fields of benefits can be identified here: improving the robot's capability to adapt to nearby humans and enabling the robot to guess imminent confusion due to actions it is going to perform. Here the robot would be able to take the initiative and initiate a clarifying communication with bystanders to explain its actions...

1 Introduction

Analyzing pedestrian's movements is not a new field of research. At the end of the 19th century several disasters motivated the research in this field. For example in December 1881 the theatre in Vienna burned down, killing hundreds of attendees and enforcing the research in pedestrian's dynamics [2]. The main focus was placed upon evacuations to be able to save human lives [3]. Today this is still an ongoing and relevant topic (e.g. [9]) thinking of even worse firetraps like tunnels or subway stations.

Beginning in midst of the 20th century researchers began modeling and simulating traffic, first focused on streams of cars, but later on of streams of pedestrians as well (e.g. [4]). The economical benefit was obvious: by simulating the traffic the design of crossroads or subway stations could be outfitted with the necessary capacity saving the cities and companies from expensive failures.

Up to today scientists have collected a huge amount of knowledge, tools and methods. What can robotic engineers learn from them? Some time ago robots were developed mainly for industrial applications or as research platforms to operate in labs, screened from the public. But today the robotic society pushes into public spaces and designs service robots for specific public applications like museum guides (Robox[10], Rhino[11]) or shopping assistants like InBOT [5][6] or Toomas [1]. Here the robots have to operate in the same space like people without confusing or disturbing them. The knowledge of human movements can be used either to enable the robot to guess the behavior of nearby people or to behave in a human-like manner itself. To make the knowledge applicable a model is needed. A popular model is briefly introduced in the following sections together with a discussion of possible impacts on service robots.

2 Hierarchical model of pedestrian's movements

The behavior of modeled pedestrian agents has been divided in three hierarchical Layers [7]. These are illustrated in Fig.1).

1. *Strategic behaviors*: The topmost layer represents the human route selection based on landmarks. It defines roughly the way that has to be taken to move from the starting point to the goal. A list of nodes containing landmarks or areas that have to be passed/crossed is generated here instead of a continuous path. In pedestrian movement simulation the set of possible nodes is defined by the scenario designer manually.
2. *Tactical behaviors*: The middle layer refines the given route based on the local environment and infrastructure like stairs, doors, walls or corners. Here again nodes are generated instead of a continuous path.
3. *Operative behaviors*: In the bottom part of the hierarchy the real movement behavior is generated. Here the agent moves from node to node until he reaches the target destination. While doing so he adjusts the path to local disturbances like obstacles or other agents.

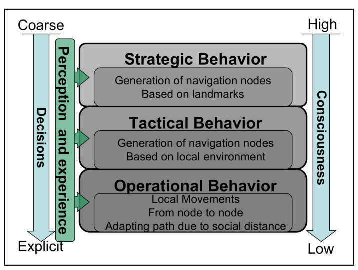

Fig. 1. Pedestrian Behavior Hierarchy

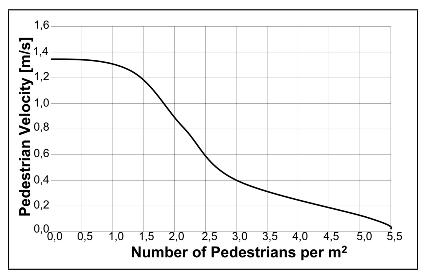

Fig. 2. Example: Fundamental Diagram

Route selection of pedestrians The decision of a pedestrians for a certain route depends on five criteria: *attractiveness, availability, infrastructure, safety, complexity and topography.* The exact order of priority of these criteria differs for each individual but in general people prefer short and fast routes (*topography*) and those which offer a varied environment (*attractiveness*) [8]. This knowledge is of special interest for guiding robots. They can take these criteria into account when generating a suitable route to a given target under the assumption that they can estimate their user's preference. Or the robot could at least be able to inform the user why it has taken a route the user would not expect.

Local movements of pedestrians After the pedestrian has - intuitively - decided for one route he starts moving along it node for node or landmark for landmark respectively. The local movements are influenced by two main factors: the desire to reach the next way-point and the reluctance to come too close to any objects, especially other people. Here the *social distance* was defined which individuals try to keep as good as possible. People generally dislike any violation of this distance so service robots should try to keep them as well. Keeping this in mind the robot would know how fast and how close it may approach people and that it must not move past them closely behind their back. If necessary the robot would at least know when to warn bystanders of its approach.

Movement velocity of pedestrians Additional to the actual path the velocity of the pedestrian's movement is a crucial characteristic. Therefor the fundamental diagram (Fig.2) is used [9]. It correlates the average velocity with the amount of people per square meter, or the other way around: the rate of free room along the path. A service robot, especially guiding robots, should adapt to this velocity. Else-way it would either scare or annoy people.

Perception of traffic jams A special case in the route decision are blockages of routes. If the way is totally blocked the case is obvious. A more interesting case is a traffic jam. Here the interpretation differs for each individual. Therefore a model was developed that calculates a characteristic code based on the number of people on the desired route. A fuzzy logic defines if it shall be interpreted as traffic jam or not. This model enables a guiding robot to estimate if the user would pass through a crowd or change to another route. This can be used to adapt the route to the (estimated) user's preference. The other way around it could be necessary for the robot to move around the crowd while the model indicates that the user would not interpret the situation as traffic jam. Here the robot would know that it has to explain the route change to the user.

3 Discussion

There are three major cases in which the modeling of human movements can be beneficial for the behavior of service robots. The knowledge that can be gained from the model can be used either to adapt the robot's movements accordingly or to take over the initiative and inform the robot's user or bystanders about the robot's actions resulting from occurring problems.

1. *Movement of the user:* Using a model of the estimated movement of the user, the robot is able to predict the users movement. If the robot is guiding the user the robot can estimate if the path it intends to take differs from the path the user would prefer. Here the robot can either adapt to the (probable) user preference or it can take the initiative and inform the user about the following unexpected movement.
2. *Movements of bystanders:* If the robot possesses a suitable model of human movements it can estimate their future movements. This can improve

the robots control by estimating the future movement of individual humans nearby enabling the robot to plan a path which will not penetrate the humans social distance. Furthermore the movements of whole groups of humans can be estimated which would enable the robot to avoid future crowded areas.

3. *Re-planning:* For the robot there is a fixed threshold which defines if the robot interprets a situation as traffic jam and therefore re-plans its path. But for humans the borderline is fuzzy. As result the robot might re-plan its path due to the traffic jam while the user does not recognize it at all. Here the robot needs to estimate if the user has detected the traffic jam himself. If this is not sure the robot has to inform the user about the reason for the re-planning.

So the final answer is: Yes, modeling of pedestrian movements can improve the behavior of service robots. It is for sure an important, interesting as well as challenging task to bring the experiences from both domains together. But it will result in a great benefit for robot engineers as well as the populace having more and more robots in their close vicinity.

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