Mission-adaptive Crowd Navigation for Mobile Robots (Extended Abstract)

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ABSTRACT

Recent developments in mobile robotics made feasible the near future scenario of mobile robots assisting individual persons. Such robots must maintain a sufficient distance from their human owners to be able to offer assistance, but otherwise they need to be inconspicuous and observe the prevailing social and cultural norms. We are considering a scenario of mobile robots assisting a peacekeeper soldier patrolling a market with a dense crowd. The robot must balance the costs related to its mission (the danger of loosing contact with its owner) and the social cost of violating the crowd members' personal space. We develop a technique through which we predict the mission cost of different decisions, and use it to adapt the robot's strategies for resolving the micro-conflicts encountered in crowd navigation. We show that this adaptive strategy outperforms strategies of consistent politeness / assertiveness over a variety of scenarios.

Categories and Subject Descriptors

I.2.11 [**Computing Methodologies**]: Artificial Intelligence—*Multiagent systems*

General Terms

Intelligent Agents, Robot Learning, Predictive Models

Keywords

human-robot/agent interaction; social models; simulation

1. INTRODUCTION

For a mobile robot assisting humans in public, if the human user moves, the robot must follow the user at a distance sufficiently close that it can offer assistance if needed, but sufficiently far away that the human user should not need to adjust his behavior for the presence of the robot. In this paper we study the type of behavior required from a mobile robot to achieve this goal. Our working scenario involves a logistics assistance robot following a peacekeeper soldier on a patrol in a busy Middle Eastern market. The objective of the robot is to maintain a reasonable distance from the soldier. At the same time, the robot must minimize the impact on the civilians forming the crowd; it must conform, as much as possible, to the social and cultural patterns of the environment.

We say that moving in crowds proceeds through a series of *micro-conflicts* [1, 2], in which the participants must determine which one would give way. If the robot tries to avoid any violation of the social norms related to personal space, he will often be delayed by giving way to passersby, risking to lose contact with the owner. The robot must continuously balance between the *mission costs* (loosing contact with the soldier) and the *social costs* (violating social norms related to personal space and cutting off people's movement).

As the agents move on the map, they interact with each other and may violate the other agent's personal space resulting in micro-conflicts. Micro-conflicts are solved as a series of 2x2 games. For each micro-conflict, we maintain the accumulated mission and social costs suffered by that robot and the human.

The robot's behavior must depend on the soldier's behavior. We describe a technique through which the robot can predict the mission cost based on the current state of the scenario and the predicted movement of the soldier. Based on this predicted cost, we develop an adaptive strategy which it can use to play the games corresponding to the micro-conflict. For instance, if a soldier is moving quickly towards a destination, the robot must be more assertive and violate more social norms in order to keep up with him. On the other hand, if the soldier moves slowly, or even stops, the robot can afford to be polite and rigorously observe all social norms.

This work can be seen in the larger context of the study of crowd dynamics in the presence of a mobile robot. There are two new dynamics to consider. One of them is how the presence of the crowd influences movement of the robot – for instance, there is a possibility that a cautious robot will freeze up in a dense crowd [4]. Another aspect, possibly highly relevant in the future is how the presence of the robot modifies the behavior of the crowd, and whether this impact can be exploited for crowd control [3].

2. GAMEPLAY AND COSTS VECTOR

For modeling the payoffs of a micro-conflict, we consider a *vector of costs*, each of them being tied to a well-defined social norm, physical measurement or satisfaction level of a mission. These values are often traded off against each other, but they cannot, in general, be converted into each other in an arbitrary and linear way. We consider the following costs:

Appears in: *Alessio Lomuscio, Paul Scerri, Ana Bazzan, and Michael Huhns (eds.), Proceedings of the 13th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2014), May 5-9, 2014, Paris, France.*

Social cost: depends on the social norms governing the environment and the participants. We have modeled each agent as having several geometrical zones (physical zone, personal zone and movement cone) and these zones move with the agent in the environment. For each of these zones, the agent's physical location is the point of reference, and they may not necessarily be circular (movement cone). Whenever an agent enters in one of these zones of another agent, it incurs a social cost which is greatest for zones closest to the agent's location. The costs associated with these zones are justified by psychological models of human perception, and they must be calibrated for the individuals as well as for the culture. Our model uses an additive approach for social cost calculations. This means that if an agent violates multiple agents' space, the total social cost will be the sum of all individual costs incurred. However, for each micro-conflict we only retain the maximum social cost.

Mission cost: depends on the specific goals of the agent. Each agent in our model has its own mission with certain urgency and a planned path. In the case of human agents, we assume that they have non-urgent missions, for example visiting a shop; whereas the mission of the robot and soldier are of urgent nature. In spite of having non-urgent missions for each human, the delays as a result of micro-conflicts end in increasing mission cost. But since these are non-urgent, the mission can still be completed at a later time - thus the mission cost is proportional with the delay. For urgent missions, the delay reduces the probability of mission success, thus the cost of the delay escalates in time. For the robot, we model this cost by the amount of distance it falls behind the soldier at any time.

The gameplay: For our current work, we have modeled the micro-conflicts as series of 2x2 games. Each player has two available actions: move C (collaborate) under which the player stops and move D (defect) with which the player continues to move forward on the planned path. The payoffs of the game are given by the total costs incurred by the players for the various combinations of moves. The games are not, in general, symmetric, as the cost functions differ from agent to agent. As a note, for these games it is more convenient to speak in terms of cost minimization rather than payoff maximization. Rigorously, the payoffs are the costs with a negative sign.

The PMC-Adaptive strategy: For micro-conflict games, the robot plays stochastic strategies with a certain bias to what move will the opponent choose. During each game in a micro-conflict, the robot predicts the future mission cost as predicted mission cost (PMC) $\sum w_i f_i$. The weights w_i are associated with robot location specific functions f_i like distance between the robot and soldier, crowd density, the robot's average speed and current speed of the soldier.

The robot compares the PMC calculated in the most recent game to the one in the previous game. An increase in PMC values between successive games shows the robot that it is falling behind the soldier. The robot adjusts its stochastic strategy to have more bias that the opponent might play C (cooperate). This results in a higher probability that the robot will play D (defect) and try to catch up with the soldier thus reducing the mission cost. However, playing D in a micro-conflict might result in a higher social cost (violation of any of the opponent's zones). If the PMC decreases, this signifies that the robot is doing well in terms of mission cost, so it can now give more consideration to the surrounding crowd resulting in a decrease in social cost. This is done by adjusting the bias to have a higher probability to play C (cooperate).

3. EXPERIMENTAL RESULTS

We created a setup to perform a comparison between different strategies played by the robot against the PMC adaptive strategy. For comparative analysis we have used the following strategies for the mobile robot:

Polite: The mobile robot tries to minimize the social costs by cooperating (playing C) for all games unless the predicted costs are very low, hence giving minimal consideration to the mission cost.
Bully/Assertive: The mobile robot tries to minimize its mission cost while ignoring almost all associated social costs.
PMC-Adaptive: The mobile robot makes the decisions during the micro-conflict using the PMC adaptive strategy.

The strategies were tested for different scenarios. The speed of the soldier was varied for each scenario while all other external environment properties remained the same. All experiments were run for a sufficiently large amount of time to achieve stable results. We found that the PMC-Adaptive strategy gives an overall better performance compared to the consistent strategies by allowing us to find a more favorable balance between mission and social cost.

Acknowledgements. The research reported in this document/presentation was performed in connection with Contract Number W911NF-10-2-0016 with the U.S. Army Research Laboratory. The views and conclusions contained in this document/presentation are those of the authors and should not be interpreted as presenting the official policies or position, either expressed or implied, of the U.S. Army Research Laboratory, or the U.S. Government unless so designated by other authorized documents. Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation heron.

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