A Human-Robot Cooperative Navigation Planner

Harmish Khambhaita, Rachid Alami

A Human-Robot Cooperative Navigation Planner

Harmish Khambhaita
LAAS-CNRS, Université de Toulouse, CNRS,
Toulouse, France
harmish.khambhaita@laas.fr

Rachid Alami
LAAS-CNRS, Université de Toulouse, CNRS,
Toulouse, France
rachid.alami@laas.fr

ABSTRACT

Navigation in human environments is a cooperative task and needs to be treated as it is. Humans concurrently assist and comply with each other. To achieve comparable efficiency, a robot needs to predict human trajectories and plan its own trajectory accordingly. We present a navigation planner that is able to plan such cooperative trajectories simultaneously respecting the robot's kinematic constraints and avoiding other non-human dynamic obstacles. Besides adapting the robot trajectory, the planner is also able to proactively propose co-navigation solutions especially in confined spaces.

1. INTRODUCTION

Standard practice in human-aware navigation planners is to add proxemics costs around humans [3]. Path planning algorithms use the cost information to generate paths that keep a safe distance from humans to maximize human comfort [8]. Since humans are regarded as static obstacles for these cost calculations, to cope up with dynamic situation a continuous re-planning scheme is used. More recent approaches include a prediction of future human positions to better cope with human motion [1].

State-of-the-art path planning algorithms, however, do not take into consideration the fact that humans do see the robot and will also try to avoid colliding with the robot by modifying their own trajectories. Therefore the resulting robot behavior is often over-reactive, or the planner fails to find any solution when a human is blocking the path (fig. 1).

In this paper, we propose a cooperative navigation planner that predicts a plausible trajectory for the humans and accordingly plans for a robot trajectory that satisfies a set of social constraints. It generates both robot and human trajectories, thus facilitating both agents to avoid any other static or dynamic obstacle present in the shared space. Generation of the trajectories is represented as solitary multiconstrained problem and solved using a graph-based optimal solver. We not only use proxemics, but also apply *time-to-collision* and *directional* constraints during optimization. Our approach aims to balance and tune the efforts between the human and the robot to solve a co-navigation task, in its spirit similar to the previously proposed approaches for geometric [9] and symbolic [7] planning systems.

2. METHODOLOGY

It is clear that robot navigation among humans requires minimizing multiple cost-functions using some optimization framework. We argue that it is imperative to also include
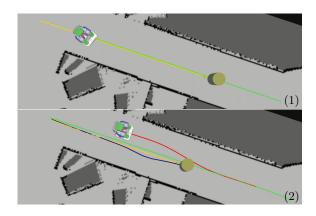

Figure 1: (1) Robot fails to find a path using standard planner when predicted human path (yellow) is blocking the way. (2) With our planner, robot is able to calculate its own trajectory (red) and proposes a trajectory for the human (blue).

prediction of plausible human trajectories within the same optimization framework. Our scheme combines in one step the *robot-plans*, *human-plans* and *robot-reacts* process.

Trajectory Optimization: Elastic band is a well-studied approach for obstacle avoidance that only locally modifies the robot path to keep a safe distance from previously unknown obstacles [5]. However, the modified path often does not satisfy the kinodynamic constraints of the robot. Recent proposal of *timed elastic band* evades this problem by explicitly considering temporal information [6]. It deforms local trajectory instead of a purely geometric path. *Timed elastic band* makes it easy to take kinodynamic and nonholonomic constraints into account, formalizing the optimization problems as non-linear least-squares problem. Consequently, it uses a general optimization framework g^2o [4] which requires mapping of the least-squares problem into a hyper-graph representation. Each node in the hyper-graph represents a pose along the trajectory and edges that connect two nodes represent constraints, as shown in fig. 2. Result of the optimization adjusts the position and orientation of the nodes in the hyper-graph such that the whole trajectory minimizes the imposed constraints.

We have selected this solver because it enables us to introduce the social constraints and rules. The key aspect of proposed framework is to predict optimized human trajectories by the same hyper-graph. Thus, we have multiple *timed elastic bands*, one for the robot and one for each of the
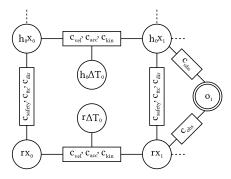
Figure 2: Hyper-graph structure. The bottom row has consecutive nodes for robot trajectory (rx_0, rx_1, ...) that are connected by edges enforcing velocity, acceleration, and kinodynamic constraints. Penalty imposed by these edges depends on time difference between consecutive nodes, they are attached to the *time-diff* node $r\Delta T_0$. Pose and *time-diff* nodes are subject to change by the optimization process. Similarly, the top row represents trajectory for human 0. Position of obstacle nodes (o_1) cannot be changed, and c_{obs} represents constraint for keeping safe distance from the obstacles. Nodes of the robot and a human that belong to the same time-step of their trajectories are connected by three edges (c_{safety}, c_{ttc}, c_{dir}) that impose social constraints.

humans, that are optimized simultaneously. We inherit the kinodynamic and nonholonomic constraints from [6]. By adjusting weights on the constraints for human and robot separately, we can tune the "tightness" of the elastic band which enables sharing the effort between the humans and the robot. Full hyper-graph is depicted in fig. 2.

Social Constraints: Since we have the whole trajectories of human and robot at our disposal, we have adedd social constraints between human and robot nodes in the hyper-graph that correspond to same time-step during their trajectories. The *safety* constraints simply require minimum safety distance between corresponding human and robot poses. A novel social constraint used in the proposed scheme is *time-to-collision*. It is shown that pedestrian interaction across wide variety of situation is governed by *time-to-collision* between self and other [2]. With this constraint our robot is able to proactively propose, a co-navigation solution well ahead of time compared to other state-of-the-art approaches. To improve legibility of the robot motions, we have added the *directional* constraint [3]. With these social constraints we have tested the proposed planner in simulation and on a real robotic platform.

3. RESULTS AND CONCLUSIONS

With proposed cooperative planning scheme, our robot does not remain purely reactive but now it can also propose a path for the human assuming human will consider the proposed solution benefits both agents (fig. 1, fig. 3). This is crucial especially in confined spaces, such as corridors where two agents can navigate only in side-by-side configuration. If the human decides to move on other path (e.g. choosing to pass by another side of the robot), because of continuous on-line planning, the robot will quickly adapt its trajectory. In
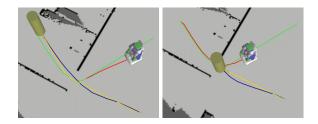

Figure 3: Robot stops not because of a planning failure but because it has planned a cooperative strategy where it waits until the human passes through.

situation where robot has enough space to move well advance in time, the robot will proactively choose a path that is both legible and comfortable for the human counterpart.

4. ACKNOWLEDGMENTS

5. REFERENCES

[1] G. Ferrer and A. Sanfeliu. Multi-Objective Cost-to-Go Functions on Robot Navigation in Dynamic Environments. In *IROS*, 2015.

[2] I. Karamouzas, B. Skinner, and S. J. Guy. Universal Power Law Governing Pedestrian Interactions. *Phys. Rev. Lett.*, 113(23), 2014.

[3] T. Kruse, A. K. Pandey, R. Alami, and A. Kirsch. Human-aware robot navigation: A survey. *Robotics and Autonomous Systems*, 61(12), 2013.

[4] R. Kümmerle, G. Grisetti, H. Strasdat, K. Konolige, and W. Burgard. g2o: A General Framework for Graph Optimization. In *ICRA*, 2011.

[5] S. Quinlan and O. Khatib. Elastic Bands: Connecting Path Planning and Control. In *ICRA*, 1993.

[6] C. Rösmann, W. Feiten, T. Wösch, F. Hoffmann, and T. Bertram. Efficient Trajectory Optimization using a Sparse Model. In *ECMR*, 2013.

[7] J. A. Shah, J. Wiken, B. C. Williams, and C. Breazeal. Improved Human-Robot Team Performance Using Chaski, A Human-Inspired Plan Execution System. In *HRI*, 2011.

[8] E. A. Sisbot, L. F. Marin-Urias, R. Alami, and T. Siméon. A Human Aware Mobile Robot Motion Planner. *IEEE Transactions on Robotics*, 23(5), 2007.

[9] J. Waldhart, M. Gharbi, and R. Alami. Planning handovers involving humans and robots in constrained environment. In *IROS*, 2015.