MuMMER

MULTIMODAL MALL ENTERTAINMENT ROBOT mummer-project.eu

Grant No. 688147. Project started 2016-03-01. Duration 48 months.

DELIVERABLE D5.1
INITIAL COMPONENTS OF HUMAN-AWARE MOTION PLANNER

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Beneficiaries:	**LAAS** (lead), SBRE
Workpackage:	**WP 5: Human-Aware interactive tasks and motion control**

Version:	Final
Nature:	OTHER (Software)
Dissemination level:	Public (PU)
Pages:	8
Date:	2017-2-22

This project has received funding from the European Union's Horizon 2020 research and innovation programme.

1 Executive Summary

This Deliverable reports on the availability of a software package that corresponds to a first simplified version of a human-aware navigation planner to be tested on the first project software integration.

The main components of this software implements a reactive planning scheme that allows the robot to navigate in a human environment and to adapt its path and speed to the human context, taking into account a set of “social constraints” that enforce safety, predictability, human comfort and pro-activity in proposing solutions in intricate situations.

The software has been fully implemented and integrated, for ease and generosity of use, in a well-established `move_base` scheme used by the navigation-stack in ROS.

Besides, SBRE has developed and delivered a Navigation module in NAOqi 2.5 as well as its associated ROS services providing human detection and safe motion.

The next two sections provide a brief description of both software components.

2 A Human-aware cooperative Navigation Planner

Navigation in human environments is a cooperative task and needs to be treated as such. Cooperation helps individuals to efficiently reach their own goals and respect the personal space of the others. To achieve comparable efficiency, a robot needs to predict human trajectories and plan its own trajectory accordingly in the same shared space. During the first year of the project, we have developed a navigation planner that is able to plan such cooperative trajectories simultaneously respecting the robot’s kinematic and nonholonomic constraints as well as avoiding other non-human dynamic obstacles. Besides adapting the robot trajectory, the planner is also able to pro-actively propose co-navigation solutions especially in confined spaces.

2.1 Main features

This scheme is based and compatible with our earlier contributions [1, 2, 3, 4] where we proposed a set of criteria and costs-based plan optimisation constraints in order to enforce acceptable robot behaviours. However, we have focused here on the design and implementation of a reactive planning scheme that not only integrates such constraints but also takes into account kinodynamic constraints.

Key aspects of the cooperative planning scheme are following:

- The planner uses multi-objective optimisation techniques that can generate cooperative, socially acceptable robot trajectories simultaneously respecting the robot’s kinematic and nonholonomic constraints thanks to a set of well chosen and tuned constraints that favor a human-aware navigation behaviour. At the moment we have implemented three social constraints:
  - *Safety* constraint requires minimum (user adjustable) distance between corresponding human and robot poses along the entire robot trajectory.
  - *Time-to-collision* constraint enables the robot to pro-actively propose a co-navigation solution well ahead of time in a path-crossing like situations.
  - *Directional* constraint penalizes robot motions in the direction towards human (often considered “threatening”), thus making robot slow down when passing near to humans, and consequently improving legibility of the robot motion.
- Prediction of plausible human trajectories and planning of robot trajectory is combined within the same optimisation framework.

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With this scheme we are able to solve the path planning problem in open as well as constrained situations. Furthermore our approach has the additional advantage to balance and tune the efforts between the human and the robot to solve a co-navigation task.

2.2 Integration in Robot Software Architecture

In the MuMMER project we have decided to use ROS[1] as a middle-ware. Consequently, we have developed navigation software components that adhere to the well-established `move_base` scheme used by the navigation-stack in ROS, originally proposed by [5]. See Fig. 1 for an overview of the full navigation system. The `move_base` framework uses a combination of a global path-planner and a local robot controller to achieve smooth real-time navigation planning in dynamic environments. Given a navigation goal, either by the user or higher-level decisional components, the global path-planner generates a path from the current location of the robot to the goal keeping a safe distance from people that are perceived as *static* in the robot environment. The local robot controller receives this global path and generates velocity commands for the mobile base respecting the robot's kinematic and nonholonomic constraints as well as avoiding any non-human obstacles and humans that are perceived as *moving*. Specifically, we have replaced the local-planner in the `move_base` scheme and enhanced the local-planning software with a human path prediction module.

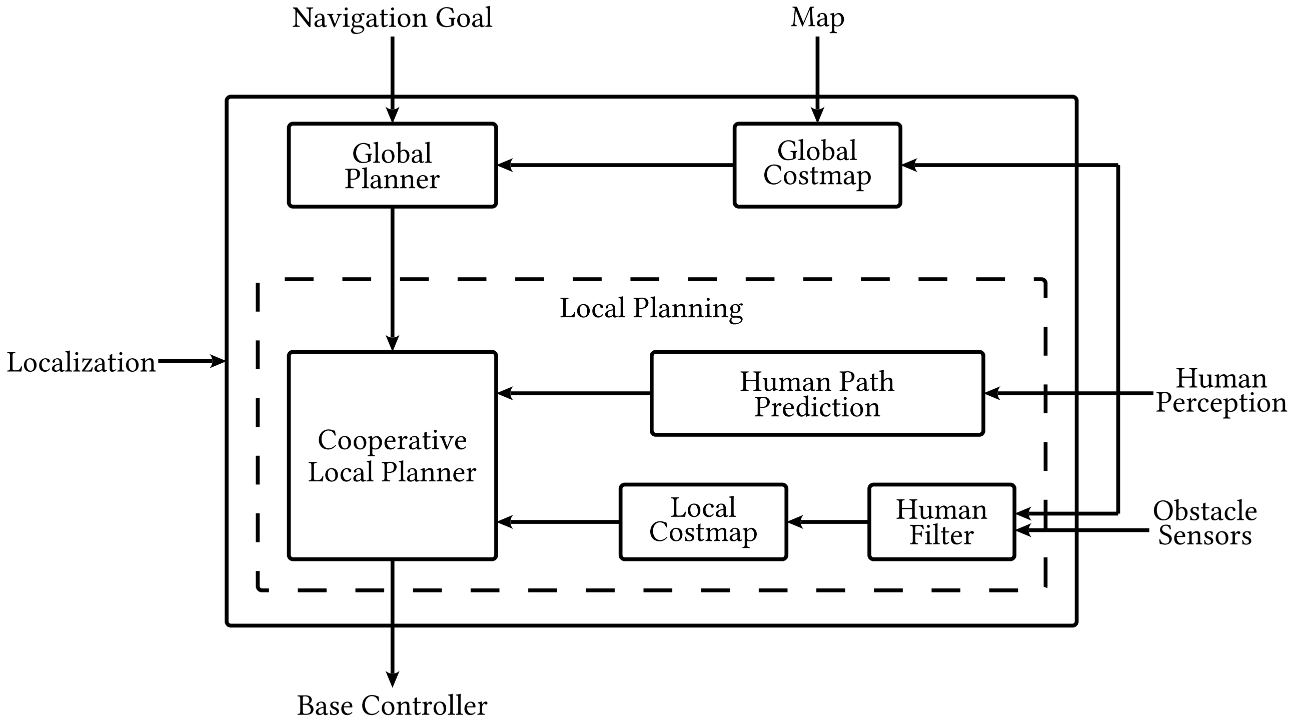

Figure 1: Overview of the navigation software architecture.

More technical details are given in the short paper attached:

- Khambhaita H., Alami R., A Human-Robot Cooperative Navigation Planner, ACM/IEEE International Conference on Human-Robot Interaction Late-Breaking Reports (HRI-LBR17), Vienna, Austria, 2017.

A longer and fully detailed paper is under submission.

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[1] `http://www.ros.org`

2.3 Results

We have already tested the planner in simulation as well as partially on the real robot system. The planner is able to generate robot trajectories at about 6-8 Hz.

Figure 2 shows the resulting robot behaviour in a corridor crossing situation when human and robot can only safely pass in a side-by-side configuration. It is important to note that in this example it is important for the human to adjust their path as well, otherwise she can completely block the robot path. Therefore, as shown in the figure, the robot is acting well in advance to initiate a change in the human behaviour, when human complies with the solution proposed by the robot, the robot continues on its path.

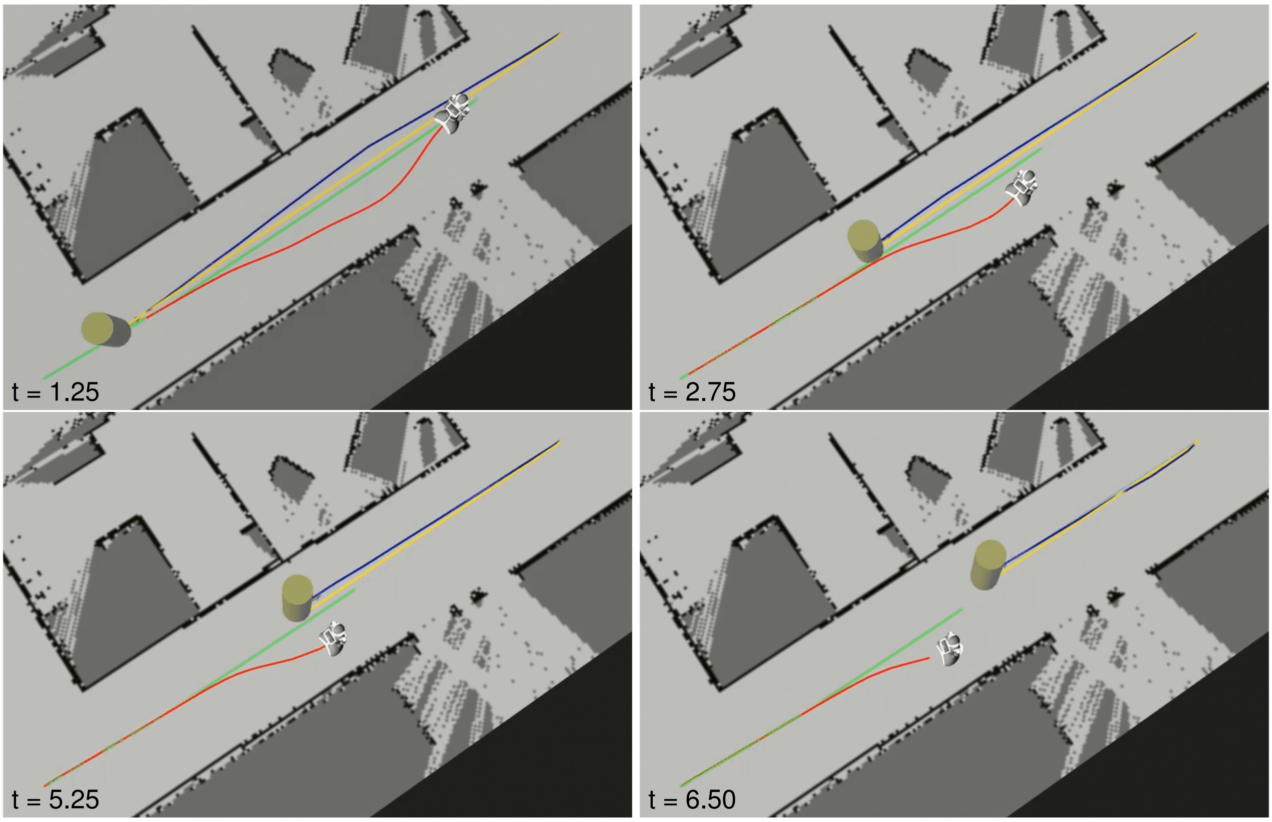


Figure 2: Human-robot corridor crossing scenario. With given robot global-path (green) and use of predicted human global-path (yellow). the robot plans its trajectory (red) as well as predicts a plausible human trajectory (blue) that can solve the co-navigation situation in socially acceptable way.

The proposed planning scheme is not limited to situations where robot needs to avoid colliding with humans while moving towards its goal, but it is also useful in other collaborative tasks like approaching a human for engaging in a verbal conversation. By augmenting the planning scheme with additional constraints of respecting approaching angle towards humans, we are able to generate an adaptive *social approach* behaviour in which the robot approaches a person while ensuring that it is in the field of view.

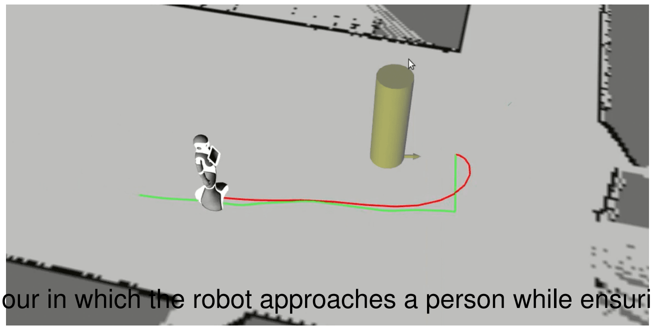
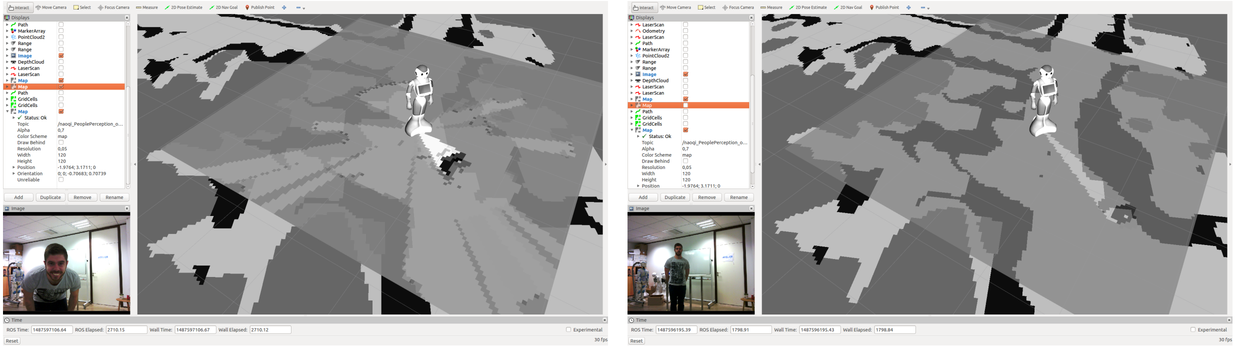


Figure 3: Social Approach behaviour. It is also implemented based on reactive human-aware scheme. Robot will adapt to human motion if it happens.

3 Basic components for human detection and safe motion in NAOqi

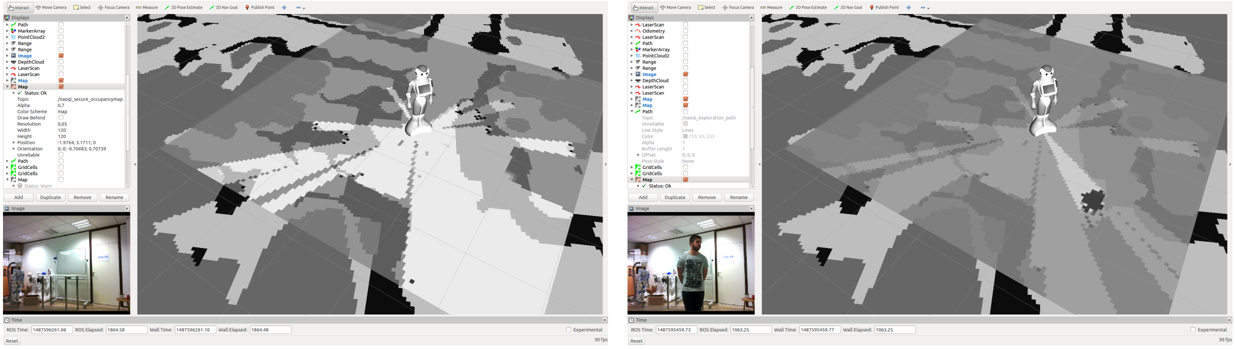
SBRE has been working on human detection and safe motion for Pepper. The initial software has been delivered in NAOqi 2.5 in the Navigation module described in this report. In addition to the NAOqi API, we have developed ROS services in NAOqi Navigation package allowing to execute Motion Planning from the ROS environment.

The Pepper robot is designed to work in a human environment as an assistant or a companion robot. Thus, it is important for us to ensure that Pepper can function and move safely in the close presence of humans. Pepper is equipped with a set of complementary embedded sensors such as sonar, IR and 3D sensors that are used to continuously detect obstacles nearby the robot including moving obstacles all around the robot. The 3D sensors together with a front RGB camera on Pepper are used for continuous human detection and tracking within the NAOqi `ALPeoplePerception` Module. Theses embedded sensors allow to detect and track people at a distance up to 2.5m according to our experiments. The information about detected people is integrated together with detected obstacles into a safety map (see Fig. 4) that is the basis for any movement of Pepper (including navigation, base movements and interactive gestures). Before executing any motion, the robot analyses its safety map and planes its motion in the available free space. Detected humans and obstacles are stored in the memory of the robot; close obstacles stay in the memory even if they are not visible for about 15 seconds.



(a) `PeoplePerception` occupancy map with a person detected at a closest possible distance about 0.5m

(b) `PeoplePerception` occupancy map with a person detected at the farthest possible distance 2.5m



(c) Safety map that integrates the data from all embedded sensors on the robot

(d) The Safety map combined with `PeoplePerception` occupancy map

Figure 4: Examples of `PeoplePerception` map and Safety map that are used for motion planning on Pepper; the combined map (d) is used to compute a free space that is used for planning safe motion and navigation.

The work is already integrated in the core of NAOqi running on the robot and also tested on the robot. It is delivered in NAOqi 2.5 [6]. The next step would be to provide a public API to access these data through the ROS NAOqi Navigation module described in the year 1 progress report (Task 5.4).

4 Conclusion

The human-aware reactive planner is fully implemented and has been tested intensively in simulation in various situations, including intricate situations where the human and the robot have to share the load in order to solve the problem. It has been also tested successfully on a PR2 platform in a laboratory experimental environment.

The next step is to run and test the planner on Pepper fully integrated with the navigation and perception of human functions.

The basic components for human detection and safe motion are are also fully integrated and available in NAOqi 2.5. The system was tested on a real robot in a human environment.

5 Outputs and Future Directions

We will seek to test intensively and improve the robot behaviour through the tuning of the set of available social constraints and perhaps the introduction of new ones based on users study.

We have already discussed the *social approach* task above. In the context of MuMMER project we plan to implement several such interactive navigation tasks with addition of rich human-aware constraints in our planning framework.

6 Deviations

No deviations.

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A Human-Robot Cooperative Navigation Planner

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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.

Keywords

Robot Navigation; Elastic Band; Optimization

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 multi-constrained 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.

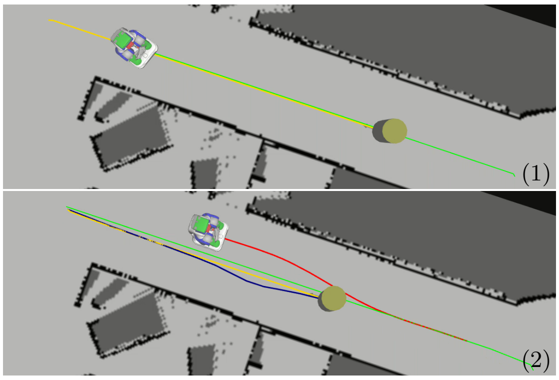

Figure 1: (1) Robot fails to find a path using standard planner when predicted human path (yellow) is blocking the way. (2) With our planner, robot is able to calculate its own trajectory (red) and proposes a trajectory for the human (blue).

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 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

HRI '17 Companion March 06-09, 2017, Vienna, Austria

ACM ISBN 978-1-4503-4885-0/17/03.
DOI: http://dx.doi.org/10.1145/3029798.3038374

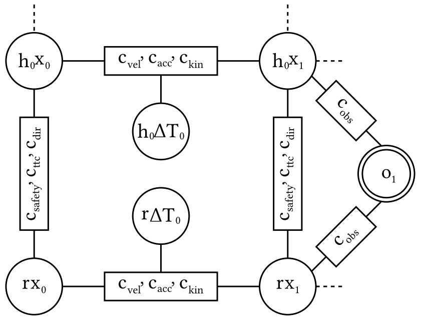

Figure 2: Hyper-graph structure. The bottom row has consecutive nodes for robot trajectory (rx_0, rx_1, . . .) that are connected by edges enforcing velocity, acceleration, and kinodynamic constraints. Penalty imposed by these edges depends on time difference between consecutive nodes, they are attached 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.

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 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.

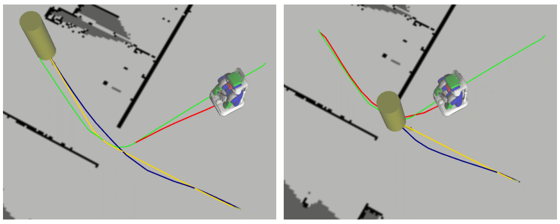

Figure 3: Robot stops not because of a planning failure but because it has planned a cooperative strategy where it waits until the human passes through.

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 online planning, the robot will quickly adapt its trajectory. In 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

This work is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 688147 (MuMMER project).

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