Dynamic Generation and Execution of Human Aware Navigation Plans

(Extended Abstract)

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ABSTRACT

A robot moving in the presence of humans is highly constrained by the dynamic environment and the need to comply with human safety, preferences, cognition and actions. The dynamic nature of the environment should be taken into account at planning time and must be allowed for by flexible plan execution, to produce safe, efficient and legible robot behavior. Moreover, when the space in which humans and robots interact is small, additional measures must be taken to allow efficient robot movement. This paper extends an existing human-aware navigation planner with mechanisms to account for movement of humans and confined areas.

Categories and Subject Descriptors

I.2.8 [**Problem Solving, Control Methods, and Search**]: Plan execution, formation, and generation; I.2.9 [**Robotics**]: Kinematics and dynamics

General Terms

Algorithms, Performance, Human Factors

Keywords

Robot planning (including action and motion planning), Human-robot/agent interaction, Reactive vs deliberative approaches

1. MOTIVATION

In a household environment, companion robots may perform tasks to help humans in everyday activities. When robots act in the presence of humans, one challenge is to plan for motions of the robot without causing harm. As a prototype approach, this can be achieved by only planning paths which avoid humans, treating humans like obstacles.

We believe that a human-centric approach to navigation in human presence must treat humans not just as obstacles, but as cooperative agents. Taking humans into account for navigation means weighting costs for circumventing humans versus optimistically approaching humans such that they may cooperate.

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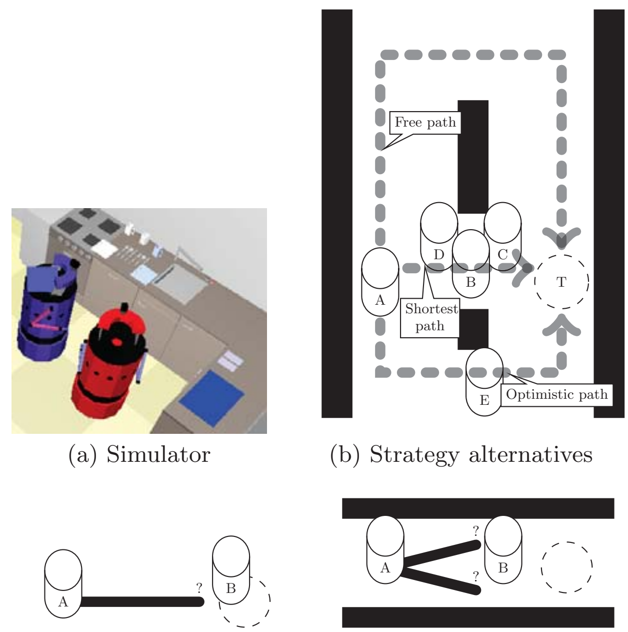


(a) Simulator (b) Strategy alternatives

(c) Endpoint blocked (d) Corridor middle conflict

Figure 1: (a) Experiments with 2 robots in Gazebo Simulator. (b) Strategy alternatives: Collision free path, shortest path ignoring humans, optimistic path balancing length vs. human comfort. (c) Conflict for goal location. (d) Conflict to find path to goal.

A robot taking much longer for tasks because it needlessly prefers long distance paths is annoying, as well as a robot which always tries to take the shortest path regardless of whether humans are discomforted by that or not.

In the situation shown in Figure 1(b), the direct way for robot A to the target location T is blocked by persons B, C and D. The alternative path using the free space is extremely long. With the assumption of the persons being cooperative, the robot would show a more natural behavior when trying to pass by making persons move, in that situation ideally by just disturbing one person, E.

In Figures 1(c) and (d) there is no safe solution to the planner, while the robot still could safely, as a human, proceed toward its goal and thus convey its intention. Such a natural path to a goal might intersect with the position of a human, thus a controller for a robot needs to follow such a path while ensuring the robot will stop and wait whenever a human is on the path.

Also when humans move, a path planned around them though free at planning time might become blocked in the future. Those are the challenges of current planners which we contribute to solve in this paper.

2. APPROACH

The existing Human Aware Navigation Planner (HANP) [1] generates a path for a robot to move in the presence of humans. Unlike other path planners, it considers additional human-centric constraints during motion planning to ensure comfort of the human rather than just safety. Motion plans generated by HANP are correct in that they will not lead to collision when followed. However, HANP cannot exploit space occupied by humans, which could be freed if the humans moved. In oder to adapt to social conventions, we changed HANP to allow the space occupied by humans to be available to the planner. As a consequence, plans are not strictly correct, but the behavior of the robot remains correct if the motion controller interrupts the plan and waits whenever a human is in the way. After waiting a certain time, the planner will plan a strictly correct plan. Costs were introduced such that the planner still has a preference for free space.

We also changed the costs for humans that move, to make it expensive to cross the space in front of a moving human. This may be called predictive planning, as we predict the human will occupy space in his direction of travel. We expected this heuristic to yield better results than to assign the same cost functions to static and moving humans. This takes into account the simple prediction that a moving human will soon occupy the space in front of him.

3. EVALUATION OF STRATEGIES

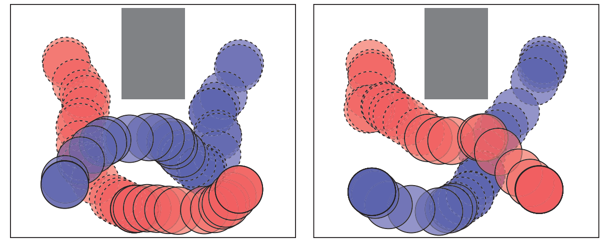
We analyzed the properties of our algorithms in a simulation with two robots, using a custom motion controller, HANP for the path planning, and Gazebo for a physical simulation of the 3D environment as shown in Figure 1a.

We were interested in whether the robot behavior would indeed be more legible and more efficient. As one experiment, we let two robots, one representing a human, one representing a household-robot, perform tasks in a kitchen environment. Their tasks were to bring dishes to a table, as if they were setting the table or preparing food. We varied the household-robot's planning algorithm between standard planning and optimistic planning. In all trials, there were situations in which the household robot's target location for picking up or placing items was occupied by the human.

In the case of standard planning, such a situation caused the robot to wait wherever it currently was, which did not convey its intention or what the conflict was. With optimistic planning, the robot would approach its desired target location up to a short distance to the human, where the robot would then wait. We believe this conveys better the presence of an intention that is in conflict.

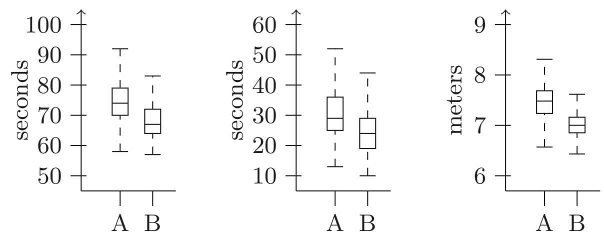
In experiment 2, we were interested in whether predictive planning improved efficiency. We evaluated a dynamic situation in which both robots moved to individual goals, with the shortest paths crossing each other. The environment we examined is illustrated in Figure 2.

An improvement due to optimistic planning can be observed from the motion in the shown example, as in b) the robots were able to remain closer to the ideal straight line towards their target. The robots did not behave symmetrically due to natural dithering in the simulation setup.



(a) Non-predictive planner (b) Predictive planner

Figure 2: Experiment 2: Behavior in a room with a table, seen from above. The robots had to go to opposed corners of the room. Predictive planning in (b) allowed the robots to solve the space conflict earlier.



(a) Time to goal (b) Stopped time (c) Path length

Figure 3: Results for Experiment 2. Values are the sums for both robots in each trial. Only trials in set B used preditive planning. 300 trials were made for each planning method.

Figure 3 shows the statistics for the curved room in experiment 2. It is noticeable that the all measures improved with the predictive planner.

4. CONCLUSION

Generating and executing navigation plans in the presence of humans imposes additional challenges on a robot controller with respect to social rules and legibility. Household tasks impose further constraints such as confined spaces and moving humans.

We extended a motion planner that works well for static humans and wide spaces to improve the robot behavior under these additional constraints. Optimistic planning exploits space in search space that is occupied by humans but could be freed if the human moved away, and predictive planning reduces conflicts caused by robots crossing a predicted path of humans.

The empirical evaluation using two robots that act independently — one in the role of the human, the other as the robot — shows an improvement of the robot behavior considering the legibility of its movement and indicates a possible efficiency gain. We expect the results to also show improvements when controlling a robot in the real world next to humans.

5. REFERENCES

[1] E. A. Sisbot, L. F. Marin-Urias, R. Alami, and T. Simeon. Human aware mobile robot motion planner. *IEEE Transactions on Robotics*, 23:874–883, 2007.