Differential-drive Robot Navigation in Crowded Environments

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Abstract

AVOCADO is a highly effective algorithm for real-time collision avoidance in dynamic, multi-agent environments, but it cannot be directly applied to non-holonomic robots, whose kinematic constraints are not considered. This work addresses that limitation by approximating holonomic velocities with safe non-holonomic ones, ensuring the deviation remains within a bounded error.

Introduction and Objectives

Navigating in dynamic environments with multiple moving agents and unpredictable obstacles is one of the main challenges in robotics. Ensuring safe and efficient motion in such scenarios requires algorithms capable of adapting in real time. AVOCADO [1] is a low-cost algorithm that enables coordination among robots and is based on the principles of ORCA [2] to compute collision-free velocities in multi-agent scenarios with moving obstacles. Unlike standard ORCA, AVOCADO allows for adaptive cooperation levels, enabling navigation among non-cooperative and cooperative dynamic agents.

However, AVOCADO assumes holonomic motion, which limits its use in real robots like differential drive platforms that cannot move in arbitrary directions. While adaptations of ORCA for non-holonomic robots, NH-ORCA [3] exist, no such extensions has been developed for AVOCADO. This work addresses that limitation by adapting the planner to consider non-holonomics kinematic constraints, allowing it to generate safe and feasible trajectories while preserving the core design and efficiency of AVOCADO.

Methodology

The proposed method is based on translating holonomic velocities into non-holonomic ones. This translation is not perfect and invariably introduces an error, known as tracking error. To address this, we define a maximum error, ε, and then select only those velocities that remain within this bound. These velocities are safe for the robot to follow without exceeding its limitations.

Admissible Velocity Calculation

To achieve this, the tracking error resulting from applying holonomic trajectories to a robot with limited movement capabilities is analyzed, and an admissible set of velocities is determined based on its physical characteristics. First, the set of valid holonomic velocities is calculated based on the robot's physical limitations and the chosen ε value using the equations derived in NH-ORCA [3]. Then, this set is visualized as an error map, where each cell represents how much the robot would deviate when attempting to follow a specific velocity. To simplify implementation, a bounding box is fitted inside the admissible region (see Figure 1). These constraints are then introduced into the planner to influence real-time leading to feasible motions compatible with the kinematic and dynamic constraints.

Integration into the AVOCADO Planner

The next step is to implement these constraints in the AVOCADO planner. AVOCADO uses half-planes in the velocity space to define which velocities are safe. Inspired by this approach, we extract four lines from the sides of the bounding box, and use them to define new half-plane constraints that represent the robot's motion limitations. This allows the constraints to dynamically adapt to the robot's direction (see Figure 1). This strategy makes it possible to integrate constraints into AVOCADO without modifying its internal structure, preserving its efficiency while enhancing the realism of the motion planning.

Experimental Validation

Simulation results show that when AVOCADO does not account for the kinematic constraints of non-holonomic robots, a high number of collisions occur between agents. In contrast, by incorporating these constraints into the planner, the generated trajectories better match the robots real capabilities significantly reducing collisions. An example of multiple collisions caused by the lack of kinematic constraints is shown in Figure 2, while Figure 3 illustrates how agents move safely and avoid collisions using the adapted planner. To evaluate the method, two simulation experiments were conducted, each consisting of 4 scenarios repeated 25 times, with 20 agents per run, each one with an agent maximum linear velocity of 0.5 m/s. In both experiments, there are two maximal angular velocities, 5.96 rad/s and 0.5 rad/s. In the first experiment, all agents are cooperative, using the AVOCADO planner with non-holonomic constraints. In the second, only half of the agents are cooperative, while the others do not avoid collisions with the robots. These conditions are reflected in Table 1, where the number of collisions increases a lot in the scenarios without constraints.

Table 1: Collision rate observed in simulation experiment.The non-zero collision rate in constrained cases is due to motion limitations under challenging situations.

Simulation type	Exp. 1	Exp. 2
Constraints (ω_{msx}=5.96 rad/s)	0.0 %	6,4 %
Constraints (ω_{max}=0.5 rad/s)	0.0 %	23,2 %
Without Constraints (ω_{max}=5.96 rad/s)	47.2%	74 %
Without Constraints (ω_{min}=0.5 rad/s)	67.7 %	88 %

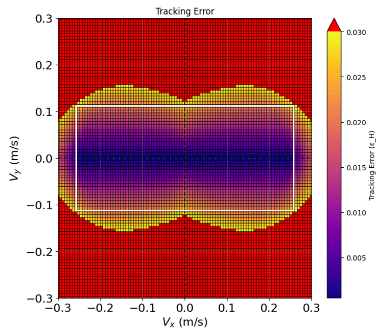

Figure 1. Admissible velocity region and fitted bounding box for a non-holonomic differential drive robot.

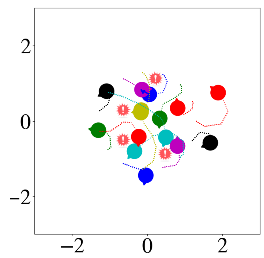

Figure 2.. Simulated trajectories without considering non-holonomic constraints. Several collisions are produced.

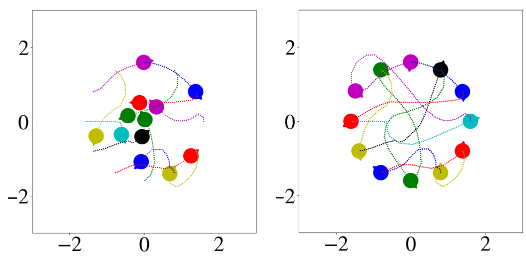

Figure 3. Simulated trajectories of the adapted AVOCADO planner with non-holonomic constraints, during the simulation (left) and after all agents have reached their goals (right).

Conclusions

This work successfully extends the AVOCADO planner to support non-holonomic differential drive robots by integrating their kinematic constraints into the planning process. The proposed method enables the generation of safe trajectories without altering AVOCADO's structure. Results confirm that this integration reduces collisions and provides a necessary foundation for future testing with physical in real-world scenarios.

References

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