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Multi-Robot Cooperative Navigation

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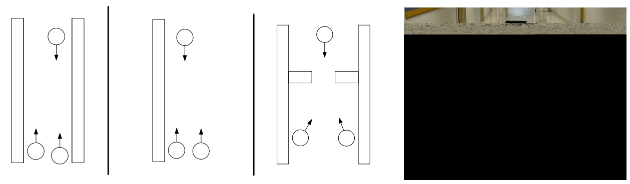
***Abstract*— In crowded multi-agent navigation environments, agents constrain each other's motions, which can lead to inefficient global motions. Recent approaches encourage implicit cooperation by having agents explicitly account for how their motions influence their neighbors. In this work, we experimentally demonstrate cooperation-based navigation for multiple non-holonomic robots in various situations.**

Navigation in crowded environments occurs in many domains, such as swarm robotics, traffic engineering, and crowd simulation. Conflicting constraints induced by the moving agents makes it difficult for everyone to reach their goals without collisions. In the popular ORCA framework [1], agents operate in a sense-plan-act loop to choose velocities which balance between heading to their goals and avoiding collisions with neighbors. However, in crowded environments, velocities that are locally optimal for one agent are not necessarily optimal for the entire group of agents. This can result in long travel times and deadlocks.

Recently, we proposed *ALAN* [2] and *C-Nav* [3], two distributed approaches that aim at increasing the navigation efficiency of the agents using only local information. In *ALAN*, we showed that agents could reach their goals faster by considering goal progress and interaction with other agents when choosing their goal velocity. In *C-Nav*, agents could better account for their neighbors' motion by also broadcasting their intended goal velocities; this leaded to more time-efficient motion compared to ORCA and *ALAN*.

Here, we explore if *C-Nav*'s advantages can be observed in real robots with kinematic constraints. In particular, we extended *C-Nav* to the non-holonomic version of ORCA known as NH-ORCA [4], as implemented in [5] for ROS. We tested our approach on three Turtlebots in different real world environments (see Fig. 1) where the objective for the robots was to reach their goals as soon as possible. A number of experiments were performed comparing *C-Nav* to NH-ORCA, measuring the arrival time of the last robot. We discuss some preliminary results below.

Results and Future Work. In the CORRIDOR scenario (Fig. 1), robots using *C-Nav* were all able to reach their goals, whereas using NH-ORCA one of the robots got stuck.



Method	CORRIDOR	2VS1	INTERSECTION
NH-ORCA	N/A	25	21
C-Nav	21	17	22

Fig. 1. Scenarios: (a) CORRIDOR. (b) 2VS1 (c) INTERSECTION. (d) Robots in the 2VS1 scenario. The table shows the travel time (in seconds) of the last robot to reach its goal.

In the 2VS1 scenario, one of the NH-ORCA robots had difficulties finding a suitable goal path. On the other hand, the same robot could easily reach its goal using *C-Nav* leading to shorter travel times. Finally, in the INTERSECTION scenario, using NH-ORCA, the single robot moving south is forced to wait on one side of the doorway while the other two robots move to their goals. In contrast, using *C-Nav*, the two robots moving north realize the constraints they impose on the motion of the robot moving south and decide to make way for it before going through the doorway. This polite behavior resulted in a slight increase in travel time, as can be seen in the table above, indicating that the relation between cooperative behavior and time-efficiency is not completely linear. As future work, we will further investigate at what point cooperative behavior translates into time-efficient motion.

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