Experimental Investigation of Mutual Avoidance Behavior for Multiple Autonomous Robots

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1. Introduction

Real-time multi-agent systems are required to carry out tasks that can be done more efficiently and effectively with team of agents such as in assembly, mining, search and rescue, etc. One of the central problems in such systems is to be able to have a real-time collision-free motion planning for all agents while they navigate independently without explicit communication between themselves.

A collision avoidance method in a dynamic environment that treats passive agents (agents with no collision avoidance mechanism) has been a focal point of study for the last couple of decades and as a result an extensive study has been made. Such kind of dynamic environment setting is rather ideal and unrealistic in nature.

In a multi-robot shared environment, agents are active elements, i.e. they are dynamic (change position over time) and also reactive (have avoidance behavior). Along this line, the prominent collision avoidance method used is Velocity Obstacles (VO) [1], though in practice it was shown to be prone to oscillation issue. To address the oscillation issue, an extension of VO by Jur van den Berg et al., the Reciprocal Velocity Obstacle (RVO) [2], was devised. Even though RVO can effectively avoid collision for active agents, implicitly each robot is made to take half of the responsibility for avoiding collision which is rather a simple approach to the complicated problem.

In our study, we intend to realize a collision avoidance method for active agents by investigating the mutual avoidance behavior experimentally. In this approach, first a collision avoidance method [3], which is able to plan the most feasible collision-free path geometrically, is selected, refined and modified recursively until the mutual interaction between the agents is collision-free.

2. Mutual collision avoidance behavior

2.1. Problem formulation and our strategy

Let Ra, Rb,... Rn be Robot A, Robot B ... Robot N in a dynamic environment with their designated Goals Ga, Gb,... Gn as Goal of Robot A, Goal of Robot B, .. Goal of Robot n and each robot having their own avoidance algorithm, realizing collision free mutual interaction is the central problem addressed by this study.

The approach taken by this study is summarized as a flow chart in Figure 1. First a collision avoidance method, iterated forecast and planning [3], is selected and implemented. The implemented collision avoidance method is then tested experimentally using static and moving obstacle to verify its viability and the robot could successfully arrive its goal without collision. Next, as in step 3 and 4, an experimental setup of "N" robots all having the implemented method is prepared and experiments are conducted to examine the mutual avoidance behavior. Studying the behavior, modification is introduced to the collision avoidance method until collision-free mutual interaction is observed. The whole process of Experimentation-Investigation-Modification is a recursive approach.

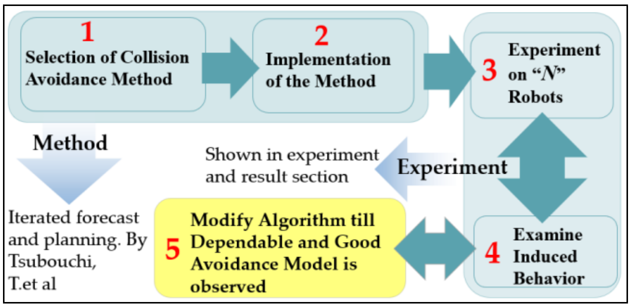

Figure 1 Flow chart of our research strategy

2.2. Collision avoidance method

The collision avoidance method, iterated forecast and planning [3], is a recursive forecasting and planning approach that aims at finding the fastest path for a robot to reach its desired goal without any collision. The path planning problem is treated in three-dimensional space-time that is formed by two-dimensional XY workspace and time, under the assumption that (1) all obstacles have a constant velocity, (2) obstacles are circular in shape, resulting cylindrical in shape in space-time and (3) robot is represented as a point and can move omnidirectionally, resulting in conical shape in space-time. The method applies a heuristic approach to the path planning problem as follows. It connects the start point with the Goal point by straight line as a candidate path. If the path doesn't cross any obstacle in space-time the straight line will be the solution. But, if it does, it generates a new path (its via-point being the intersection of the cone and the cylinder) so that the robot can escape from the obstacle.

3. Experiments

3.1. Implementation and hardware

The collision avoidance algorithm is implemented using C++ and for obstacle's velocity and position estimation, Kalman Filtering is used. The implemented algorithm is tested in a mobile robot equipped with a laser sensor as shown in the Figure 2.

3.2. Results and discussions

In the experiment two Robots, Robot A and Robot B, are used. They have the same avoidance algorithm installed and they intend to reach their goals. Initially they are six meters far apart each other and their goal is ten meters straight ahead, as shown in Figure 2.

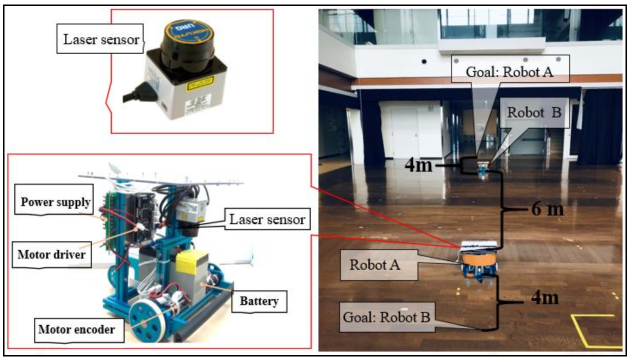

Figure 2 Hardware(left) and experimental setup(right)

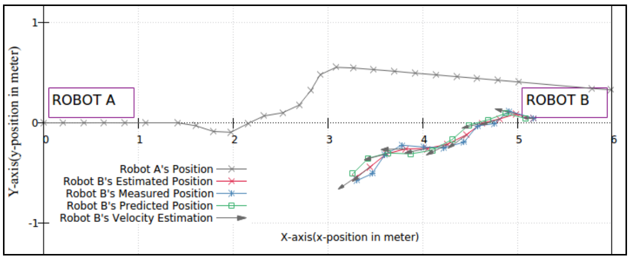

Figure 3 Experimental result 1: viewed by Robot A

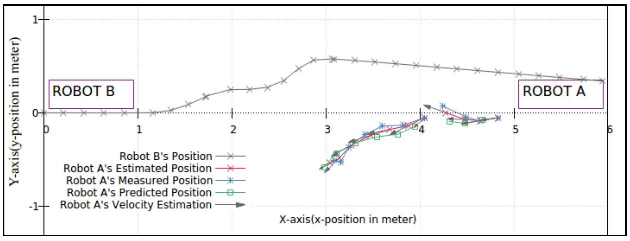

Figure 4 Experimental result 1: viewed by Robot B

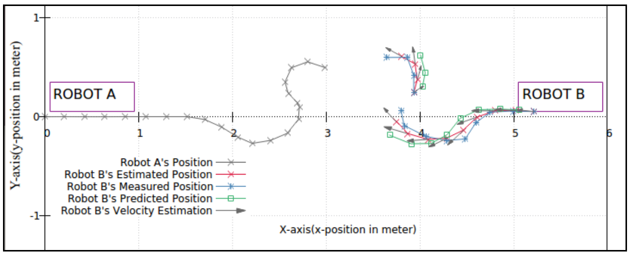

Figure 5 Experimental result 2: viewed by Robot A

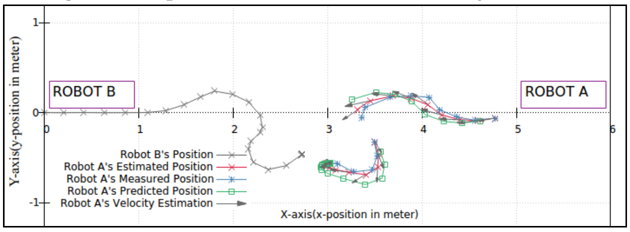

Figure 6 Experimental result 2: viewed by Robot B

According to the experimental setup, experiments are conducted by starting the robots manually at the same time. A total of five experiments are done and four of them have a result equivalent to experimental result 1, as shown in Figure 3 and 4 and one exceptional result as shown in Figure 5 and 6(experimental result 2).

Even if both experimental results are done under the same condition, they are completely different. In experimental result 1, robots could avoid collision successfully where as in experimental result 2 both robots entered into a deadlock oscillation and finally collided.

4. Future work

First, we'll work out a feasible solution for the deadlock oscillation and in parallel, we'll consider a number of different experimental setups and conduct multiple experiments for each experimental setup to investigate at a deep level the mutual collision avoidance behavior the robots show.

REFERENCES

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