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Collaborative Optimal Reciprocal Collision Avoidance for Mobile Robots

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Abstract

Avoiding collision is one of the major research fields in mobile robotics. Various researchers around the globe are working on static and dynamic collision avoidance algorithms. One such algorithm is the Optimal Reciprocal Collision Avoidance that deals with multiple robots moving in a joint space without causing collision, that also without communicating and without centralized processing. This algorithm is very effective in handling collision avoidance. However, the problem of deadlock often appears when the robots have to navigate through densely crowded environments in joint space. The aim is to move robots in a small joint space and achieve collision avoidance without facing deadlocks. For this purpose we have extended this protocol into Collaborative Optimal Reciprocal Collision Avoidance to solve the problem of deadlocks. The protocol is inspired from the traffic rules and solves the problem of deadlocks effectively. The protocol was tested upon Player-Stage based simulation where deadlocks were avoided successfully.

Keywords: *dynamic collision avoidance; mobile robotics; holonomic robots; ORCA; C-ORCA*

1. Introduction

A fundamental research oriented problem, majorly studied and researched upon in the fields of mobile robotics and artificial intelligence, is that of collision avoidance. Whenever an autonomous robot navigates in a dynamic surrounding, the problem of avoiding collision arises [1]. For this purpose the robot employs a continuous cycle of sensing and acting. It is during this cycle that the robot senses obstacles; calculates various parameters and decides a valid course of action that will lead to a collision free motion.

Collision avoidance is a part of the motion control of mobile robots but is not related to the path planning. The path planning module is used for planning path from start to end while the collision avoidance is used to make sure that robot does not collide with a static or dynamic obstacle. Thus path planning module acts on the information from the collision avoidance module.

Avoiding collision in time-varying configuration space has been the interest of research for many researchers over decades. The problem of collision avoidance for a single robot has been studied in most of the cases [2-4], and less research has been done for the reciprocal multiple robots avoiding collision, where collisions need to be avoided among numerous

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robots while each robot is independently controlled and avoids collision on its own without communication with the other robots or even knowing the state of the other robots.

The approach of avoiding collision is extended to multiple robots by combining path planning and navigation in [5]. In the same manner a method based on velocity based reasoning and scheduling to navigate several cars in a common environment has been presented in [6]. Thus multiple robotic collision avoidance is achieved but some of the robots have to stop and come to halt completely in order to avoid collision and let other robots move ahead freely. D.E. Chang et al in [7] have taken a different path and investigated potential fields as a solution to the multiple robots avoiding collision in dynamic environment, while D.M. Stipanovi'c et al in [8] have used cooperative control theory as an option for avoiding collision amongst a group of robots while they move towards their objectives.

The advantages of reciprocal collision avoidance are in the De-centralized control which helps to lower the cost of computation and adds robustness and flexibility to the multiple robotic system. The navigation among humans has also been studied where humans were considered as dynamic obstacles based on navigating car-like robots in dynamic scenarios in an area where there are pedestrians [9]. The use of dynamic window approach to solve the problem of dynamic collision avoidance has been successfully presented in [10].

The dynamic collision avoidance techniques differ from static in the manner of the obstacle under study. If the obstacle; from which avoiding collision is intended to be achieved, is moving the case is an example of dynamic collision avoidance. Otherwise if the obstacle is stationary the case comes under the study of static collision avoidance. The field of dynamic collision avoidance is much more complex than that of static collision avoidance due to the fact that the obstacle is continuously moving and thus capable of changing its position and trajectory which should be monitored continuously.

Our field of study of dynamic collision avoidance between holonomic robots on which this research is based upon builds on Optimal Reciprocal Collision Avoidance (ORCA) [11] for holonomic robots. In [12] ORCA is extended and applied to non-holonomic robots which have car-like kinematics by using a trajectory tracking control [13].

Holonomic robots are those that can completely rotate about its own axis without drift of its center of gravity from a single point. Non-holonomic robots are more like cars that need to displace their center of gravity in order to turn.

ORCA is a mutual collision avoidance method for avoiding collision among obstacles, where each robot makes individual but identical reasoning for avoiding collision and collision-free motion is ensured by the use of this method. ORCA can be further subdivided into position, velocity and acceleration based reasoning of Dynamic collision avoidance.

In case of ORCA a problem faced was that of deadlock. The problem of deadlock arises in extremely crowded situations and researchers suggested that further research was needed to solve this problem [12].

We have done work on position based ORCA and have extended it to form Collaborative Optimal Reciprocal Collision Avoidance (C-ORCA) which works upon solving the deadlock problem of the ORCA based collision avoidance in case of extremely crowded situations in small area.

This paper will discuss in detail the principle of ORCA and the use of ORCA for avoiding collision in dynamic environments. Also the problem of deadlock that arises with the use of ORCA is discussed. Furthermore the solution to the problem in the form of C-ORCA is discussed in detail. A complete C-ORCA algorithm model is explained in detail and the successful simulation results are presented. Also the comparison of the C-ORCA and ORCA is presented along with tabular information about the effectiveness of C-ORCA.

2. Optimal Reciprocal Collision Avoidance (ORCA)

ORCA is a simple algorithm that deals with many robots moving in a joint space. It is basically inspired from how humans avoid collision while moving in joint space. The ORCA algorithm makes sure that all the robots are moving in a collision free state. In position based ORCA this is achieved by sensing of the surroundings by the sensory network and keeping track of it continuously while it moves and reacts to its surroundings. The actions taken are individually computed for every robot on its own without communicating to other robots or central coordination. Yet ORCA makes sure that the robots are in motion without any collision [1].

The formulation "reciprocal collision avoidance" refers to the fact that each robot is computing its own actions and that each robot selects its own velocity and direction in order to ensure avoiding collision without centralized computation or communication amongst the robots. Each robot avoids collision on its own without the knowledge of the other robot's reasoning and actions. The only source of knowledge is the sensory network through which the each robot individually obtain the information of the surroundings.

Unlike other algorithms that requires communication or centralized control ORCA is a much more effective and practically viable algorithm to be used in practical applications because of its simplicity and less computational cost along with less hardware requirements.

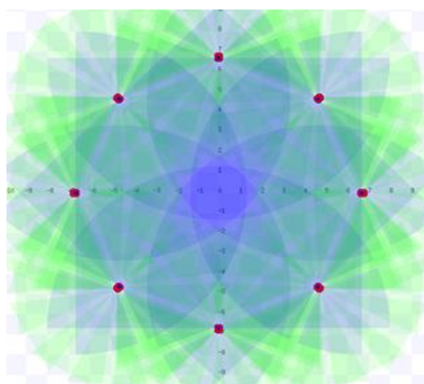

Figure 1. Robots with Overlapping PCS

To achieve the said task of collision avoidance in dynamic environment, the ORCA employs the notion of potential colliding set. A Potentially Colliding Set (PCS) of robots is computed which comprises either of robots having overlapping or close proximity of the zones of motions. If a robot is not a part of the PCS, it implies that the robot cannot collide with other robot in the PCS. Thus due to this property, the pairs of robots in close proximity are found which have chances of collision [14]. Other robots which are not part of the PCS can thus be considered collision free and can be checked less often while the computation can be focused on PCS. Thus it reduces the overall computation and this forms the basis of the optimality criterion in the ORCA.

In a single iteration of every robot the sonar sensor arrays provide the distances and based on these the PCS is formed. In this way the algorithm can compute if the path of two robots intersects or not. If it does intersect than the robots motion can be altered as to avoid collision. Otherwise the robots can keep moving on its own path without modification as it is not part of the PCS. Moreover, during a single cycle data is reassessed by each robot at its own level (to form the basis of the reciprocal concept) and PCS is updated. Based on this the motion of each robot can be altered if required.

Figure 1 shows the overlapping PCS with respect to each robot. The blue band is the potential collision zone of each robot. As one can see the more crowded the scenario is the more will be the number of members of the PCS.

3. Deadlocks and Solutions

We have discovered in our survey is that in all the previous approaches deadlocks are possible and often observed [12]. The deadlock is the problem that arises due to overcrowding and thus each PCS is very large. Due to large PCS each robots optimum decision is self-interest based and does not consider the optimality as a whole. This leads to deadlocks and also potential collisions in some cases. Figure 2 shows such a scenario.

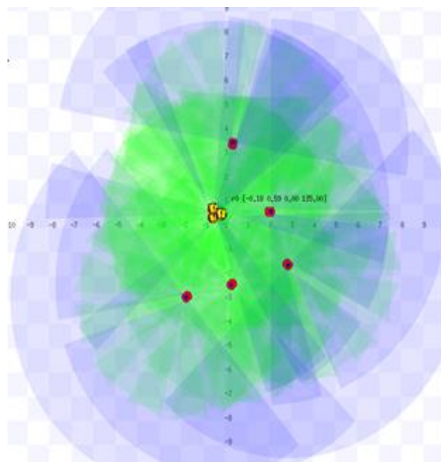

Figure 2. Robots during Deadlock Implementing ORCA

The deadlock does not mean that ORCA is not effective or is a failure. It is simply defining a limitation of ORCA. Deadlock situation also occurs between humans. When two approaching humans try to avoid collision, sometimes they turn towards the same side. This is exactly what deadlock is.

However humans are intelligent enough to give each other space to step out of the deadlock situation. Since the artificial intelligence has not yet evolved up to the human intelligence level an up-gradation to the ORCA algorithm is required to cope with the problem.

Therefore to avoid deadlock we introduce a collaborative protocol (CP) that will resolve the problem of the deadlock. The suggested CP may have two approaches. Either make suitable set of rules and make a general model out of it which can solve the problem for deadlock. Or use communication between the robots. Using communication will basically lay dead the whole idea of ORCA as it specifically suggests a decentralized approach for each robot. Thus the obvious solution is a set of rule based CP. The result is an extension of ORCA in the form of Collaborative Optimal Reciprocal Collision Avoidance (C-ORCA). Thus that is exactly what we have gone on to achieve.

By collaborative one should not confuse the concept that the robots are somehow communicating. It simply suggests that all the robots are using the same protocol with given set of rules that make sure that none of the robots will ever cause a deadlock situation.

4. Collaborative Optimal Reciprocal Collision Avoidance (C-ORCA)

This section formally introduces our proposed algorithm Collaborative Optimal Reciprocal Collision Avoidance (C-ORCA). C-ORCA is very simple and is inspired by the traffic regulations and everyday driving. According to C-ORCA whenever different robots are on a course of collision the robots take use of the rule set inspired by traffic laws rather than choosing the most effective and optimum path. Thus in addition to ORCA based reasoning based on the PCS concept, a traffic rule priority is used to select the path of action.

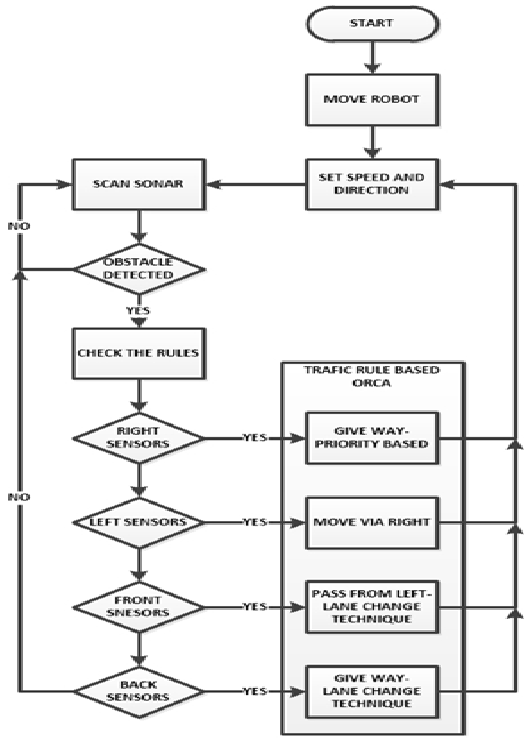

Figure 3. Flow Chart of C-Orca

Thus it can be stated that although the system is not optimized in theory and the C-ORCA algorithm is less efficient theoretically for avoiding collisions between robots but in crowded scenarios C-ORCA will provide successful collision avoidance without the deadlocks which is the basic aim of this research. The main features of traffic law (based on right hand drive) inspired rules are as under:

1. Robots coming from the right will be given priority.
2. Robots will stay on the left side of the path.
3. Change of lane technique.
(a) Over take by changing path slightly.
(b) Give way to overtaking robot if there is any.
4. Give preference to left side turn in collision avoidance.

These defined rules combined with simple position based ORCA which formulates the bases of C-ORCA makes sure that the deadlock does not occur. Figure 3 shows the overall C-ORCA algorithm in the form of a flow chart.

5. Experimental Results

This section demonstrates the experimental results of ORCA and C-ORCA done on a Dell Inspiron Laptop N-5110, 2.7 GHz core i3 Processor, 4 GB ram, 2 MB cache, running a Ubuntu 12.04 Operating System. The simulations are performed on open source Player-Stage software.

In each experiment eight Pioneer 3-AT (P3-AT) models which were controlled by a code based on our model generated from C- ORCA and used them to solve the problem of deadlock.

We set a known environment where they roamed around amongst various points and avoided collision with each other without the deadlock. The robots used their sonar in identifying an obstacle and avoiding it.

In the simulation the robots were placed facing each other and they were moved towards each other. C-ORCA and ORCA algorithms were tested separately and results were tabulated for both.

Table 1. Requirements for the Equations

S. NO.	Factors	ORCA Results	CORCA Results
1	Number of simulations	120	120
2	Time per simulation	3600 S	3600 S
3	Total time	432000 S	432000 S
4	Maximum velocity	0.7 M/S	0.7 M/S
5	Minimum velocity (other than halt)	0.2 M/S	0.2 M/S
6	Average velocity attained over total time	0.5 M/S	0.45 M/S
7	Number of times for which a single robot is halt (not a deadlock)	7936	8092
8	Number of times for which multiple single robots are halt (in different locations – non-overlapping pcs – not a deadlock)	774	786
9	Number of times for which multiple single robots are halt (in single locations – overlapping pcs – deadlock or collision)	252	0

Table 1 encompasses all the statistical data in a simple manner. It also gives the comparison between C-ORCA and ORCA. As seen from the table in case of C-ORCA the robots never exhibited deadlocks during the test simulations. It is interesting to notice that the number of deadlocks observed in C-OCA amount to zero which means that the robots implementing C-ORCA successfully exhibited no deadlocks while avoiding collision. Thus the results implicate that the C-ORCA successfully deals with the problem of deadlock.

6. Conclusions and Future Works

The Traffic laws inspired algorithm of C-ORCA has proved its effectiveness in our experiments in rendering a collision-free motion without deadlocks in a simulation of 8 robots in a defined space using player stage successfully.

Further work can be done in:

1. Implementation of path planning, navigation and tracking during motion using C-ORCA and verification of effectiveness of the model during these phases.
2. Using Lidars for better results and elimination of delays while collision avoidance.
3. Using C-ORCA for non-holonomic robot.
4. Test studies conducted with more number of robots will lead to further validation of the results.
5. Velocity and acceleration based algorithms of ORCA combined with our proposed protocol to form velocity based C-ORCA and acceleration based C-ORCA.

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