Robotics and Autonomous Systems 60 (2012) 1221–1230

Contents lists available at SciVerse ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot

Multi-robot collision-free navigation based on reciprocal orientation

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ARTICLE INFO

Article history:
Received 2 January 2012
Received in revised form
26 June 2012
Accepted 6 July 2012
Available online 20 July 2012

Keywords:
Collision avoidance
Multi-robots
Motion planning
Navigation

ABSTRACT

In this paper, a new method for robot navigation in dynamic environments, called the reciprocal orientation algorithm, is introduced. This algorithm deals with the case in which each robot moves without direct communication with the other robots. The algorithm suggested in this paper uses the concept of reciprocal orientation which guarantees both smooth and collision-free robot trajectories. The algorithm is implemented in several simulation scenarios, some of them involving tens of robots. The deadlock problem, which occurs between two robots, has been solved by using an adequate deadlock resolution algorithm.
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1. Introduction

In this paper, the problem of collision avoidance in multi-robot systems in dynamic environments is faced. This problem requires a real-time solution to path planning, so it is more difficult than the static case [1]. Differential-drive robots are used in this study. These robots consist of two driven wheels connected through a common axis, as shown in Fig. 1. Each wheel can be separately driven in both forward and reverse directions. The robot movement is chosen to be slow such that the side force applied on the robot's tires does not go over the maximum static friction between the tires and the ground. Differential-drive robots are extensively used in real-world applications for several tasks such as vacuum cleaning [2] and warehousing [3]. Groups of differential-drive robots may be used for search, environmental monitoring, and rescue applications [4]. So, it is important to use methods for navigation and coordination amongst multiple robots. In such cases it is required to build up techniques to compute collision-free paths for each of these robots [5,6].

In this paper we assume that the robots do not perform any particular task, but just wander in a two-dimensional space. The approach presented is general and works under different hypotheses, such as robots performing specific tasks, since the approach only deals with the high-priority task of collision avoidance without interfering with other lower-priority tasks. Particular attention has been paid to guarantee smooth robot movements, since this is an important property for many practical applications where the physical limits of robot actuators must be taken into account, although often existing approaches are limited to the control of a single robot moving amongst dynamic obstacles [7]. In general, there is a large amount of works on motion control of multiple robots, based on centralized approaches and local methods for computing collision-free paths [8,9]. However, most of these works do not take into account kinematic constraints, nor do they guarantee the smoothness of the trajectory.

The problem of collision-free navigation of a robot in dynamic environments with moving obstacles is discussed in many works [10–12]. In fact, collision avoidance is commonly studied in robotics, for example for independent robots, and robot swarms [13]. Most approaches prevent robots from collisions with moving obstacles by knowing the current velocities of these obstacles and predicting the future locations of them. The approach is also applied to avoid collisions with other robots, by introducing the concept of a *velocity obstacle*. This represents the set of all velocities of a robot resulting at some time in a collision with another robot, under the hypothesis that the velocity of the other robot is kept constant to its actual values [14]. Thus, according to this approach, each robot generates a velocity obstacle that the other robots should avoid, by selecting velocities outside this set of velocities. However, such an approach is not adequate when the robot is in front of other robots, because treating the other robots as moving obstacles [9,14] may lead to oscillations between the robot motions [15]: in fact, in this case reciprocal actions should be taken into account.

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doi:10.1016/j.robot.2012.07.006