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The *CyCa*b: a car-like robot navigating autonomously and safely among pedestrians

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Abstract

The recent development of a new kind of public transportation system relies on a particular double-steering kinematic structure enhancing manoeuvrability in cluttered environments such as downtown areas. We call *bi-steerable car* a vehicle showing this kind of kinematics. Endowed with autonomy capacities, the bi-steerable car ought to combine suitably and safely a set of abilities: simultaneous localisation and environment modelling, motion planning and motion execution amidst moderately dynamic obstacles. In this paper we address the integration of these four essential autonomy abilities into a single application. Specifically, we aim at reactive execution of planned motion. We address the fusion of controls issued from the control law and the obstacle avoidance module using probabilistic techniques.

Keywords: Car-like robot; Navigation; Path planning; Obstacle avoidance; Autonomous navigation

1. Introduction

The development of new intelligent transportation systems (ITS), more practical, safe and accounting for environmental concerns, is a technological issue of highly urbanised societies today [18]. One of the long run objectives is to reduce the use of the private automobile in downtown areas, by offering new modern and convenient public transportation systems. Examples of these are the CyCab robot—designed at INRIA and currently traded by the Robosoft company (see http://www.robosoft.fr/)—and the pi-Car prototype of IEF (Institut d'Electronique Fondamentale, Université Paris-Sud).

The kinematic structure of these robots differs from that of a car-like vehicle in that it allows the steering of

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both the front axle and the rear one. We call a vehicle showing this feature a bi-steerable car (or BiS-car for short).

Endowed with autonomy capacities, the bi-steerable car ought to combine suitably and safely a set of abilities that eventually could come to the relief of the end-user in complex tasks (e.g. parking the vehicle). Part of these abilities have been tackled separately in previous work: simultaneous localisation and environment modelling, motion planning execution amidst static obstacles and obstacle avoidance in a moderately dynamic environment without accounting for a planned motion.

In this paper we address the integration of these four essential autonomy abilities into a single application. Specifically, we aim at reactive execution of planned motion. We address the fusion of controls issued from the control law and the obstacle avoidance module using probabilistic techniques. We are convinced that these results represent a step further towards the motion autonomy of this kind of transportation system. The structure of the paper is as follows.

In Section 2, we sketch the environment reconstruction and localisation methods we used and we recall how the central issue regarding the motion planning and execution problem for the general BiS-car was solved. Section 3 explains how our obstacle avoidance system was designed and Section 4 explains how it was adapted to the trajectory tracking system. In Section 5 we present the experimental settings showing the fusion of these essential autonomy capacities in our bisteerable platform the CyCab robot. We close the paper with some concluding remarks and guidelines on future work in Section 6.

2. Localisation, environment modelling, motion planning and execution

In the design of an autonomous car-like robot, we are convinced that localisation, modelling of the environment, path planning and trajectory tracking are of fundamental importance.

2.1. Map-building and localisation

The CyCab robot is the size of a golf-cab capable of attaining up to 30 km/h. Its “natural” environment is the car-park area of the INRIA Rhône-Alpes (about 10,000 m^2). For localisation purposes, we did not want to focus on the detection of natural features in the environment, since such detection is often subject to failure and not very accurate. So, in order to ensure reliability, we decided to install artificial landmarks in the environment. These landmarks had to be detected easily and accurately, and they should be identified with a reasonable computation effort. Figs. 1 and 2 show our robot, its sensor and the landmarks: cylinder covered with reflector sheets, specially designed for our Sick laser range finder.

Moreover, in order to keep flexibility, we wanted to be able to equip the environment with non-permanent beacons. For this reason, we could not rely on a definitive landmark map, and we had to build a system able to learn the current state of the car-park area. This led us to use SLAM[1] methods. The method which was the best suited to our needs was the geometric projection filter (see [21] for reference, and [24] for implementation details). It consists in building a map of features uncorrelated with the robot state. Such features are, for instance, the distance between landmarks or angles between three of them.

Owing to the accuracy of the laser range finder, to the good choice of our landmarks, and to the strength of the SLAM methods we use, we evaluate the worst case accuracy of our localisation system to the following value: about 10 cm in position and 2° in orientation. We refer the reader to [24] for more details about the way we evaluate these values.

2.2. The obstacle map

The previous method localises the robot and builds a landmark map. But, we still miss a map of observed obstacles in order to plan safe paths. To achieve this goal, we build a kind of simplified occupancy grid [8] on the environment. This structure gives us informations correlated with the probability that a given place is the boundary of an obstacle.

Both maps are built online, in real-time, by the robot during the construction phase. Fig. 1 shows how the obstacle map evolves while we are exploring the environment. This map is made of small patches which are added according to the need of the application. In

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[1] Simultaneous Localisation And Mapping.