Chapter 4
Path Planning and Path Tracking of Industrial Mobile Robots

Sašo Blažič
University of Ljubljana, Slovenia

El-Hadi Guechi
University of Valenciennes and Hainaut-Cambrésis, France

Jimmy Lauber
University of Valenciennes and Hainaut-Cambrésis, France

Michel Dambrine
University of Valenciennes and Hainaut-Cambrésis, France

Gregor Klančar
University of Ljubljana, Slovenia

ABSTRACT

The purpose of this chapter is to give a quick state of the art and to propose some new approaches in the area of path planning and path tracking for the differentially driven wheeled mobile robots. The main part of the chapter is devoted to the methods that ensure stable tracking of the prescribed reference trajectories. Of particular importance are the approaches that result in global stability of the tracking, e.g. Lyapunov-based control and parallel distributed Takagi-Sugeno fuzzy control. The effects of discrete measurements and delay on the control performance are also analysed. The second part of the chapter is devoted to path planning or trajectory design. Here, physical limitations of the robot and obstacle avoidance are treated.

INTRODUCTION

Intelligent transportation systems are a growing domain and have been a subject of extensive research in the mobile robotics field and in intelligent vehicles. Mobile, autonomous robots are about to become an important element of the "factory of the future" (Ting, Lei, & Jar, 2002). Their flexibility and their

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ability to react in different situations open up totally new applications, leaving no limit to the imagination. In order to achieve high performance of mobile robots in industrial environments there are several important aspects that have to be taken into account. These include path planning considering physical limitations, path following, and obstacle avoidance. It is also important to limit this study to a certain subset of mobile robots. The most often studied mobile robots in the scientific literature are mobile robots with differential drive which cannot move in the direction lateral to the wheels. There also exist other types of mobile robots with similar properties and the results shown here can be extended with some modifications to these types, e.g. four-wheel mobile robots.

To drive the mobile robot from its initial point to the target point, the robot must follow a previously planned path. A well-planned path with respect to robot capabilities ensures desired efficiency of the robot. The path could be optimized considering different aspects such as minimum time, minimum fuel, minimum length and others (Lepetić, Klančar, Škrjanc, Matko, & Potočnik, 2003; Desaulniers, 1996; Marchese, 2002; Velenis & Tsiotras, 2008; Martin, Sun, & Egerstedt, 2001). High-performance path tracking is also essential. Efficiency is higher when the robot can drive faster and at the same time stays more accurately on the planned path. Our approach will focus on path planning where acceleration limitations are taken into account.

The control of a mobile robot with nonholonomic constraints on a reference path is an important task in mobile robotics. Nonholonomic systems have motion limitations emerging from their kinematics (Kolmanovsky & McClamroch, 1995; De Luca & Oriolo, 1995; Sarkar, Yun, & Kumar, 1994). Therefore some directions of motion are not possible. This chapter deals with a mobile robot with differential drive which cannot move in the direction lateral to the wheels. The control of this robot is designed by considering its first order kinematics model. The obtained motion can later be upgraded to include the dynamics properties also (inertia and mass) where the robot control problem is transferred to a control of a second order kinematics model. The control of mobile robots considering only first order kinematics is very common in the literature as well as in practice. This is mainly because the control problem is easier to solve, the system dynamics can usually be neglected (fast and strong motors), especially at moderate speeds and because the robot design sometimes does not allow torque or acceleration to be forced at robot input (only the reference speed). The basic control of a mobile robot in obstacle-free environment can be solved by point-to-point control with classic control where the intermediate course of the states between start and end state is not important. The other possibility is to control the robot to follow the reference path from the start to the end position. When controlling nonholonomic systems, it is usually more appropriate to control the system to follow the reference path. When controlling the robot to the end point (classic control), the control law has to be discontinuous or time varying. Further on, the robot has to consider nonholonomic constraints so its path cannot be arbitrary. The robot usually moves in an environment including obstacles, limitations and other demands which all somehow defines desired robot path. All these facts give advantage to control on a reference path which should follow all kinematic constraints.

The main focus of the chapter will be the combination of flatness based control and an optional feedback. Such approach ensures that all the kinematics constraints are implicitly considered by trajectory design. The use of the open-loop (flatness based) control only is not suitable when the initial system states are poorly known and other disturbances occur during operation. Closed loop is therefore added. The above mentioned combination is intuitive and suitable for most nonholonomic mechanical systems.

In our approach the nonlinear error model between robot velocities (linear and angular) and tracking error is modelled by Takagi-Sugeno fuzzy model. Then, a classical parallel distributed compensation

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