Chapter 15
Kinodynamic Motion Planning for an X4-Flyer

Kimiko Motonaka
Okayama University, Japan

Keigo Watanabe
Okayama University, Japan

Shoichi Maeyama
Okayama University, Japan

ABSTRACT

This chapter describes kinodynamic motion planning and its application. Kinodynamics is the discipline that tries to solve kinematic constraints and dynamical constraints simultaneously. By using kinodynamic motion planning, control inputs can be generated in a much simpler way, compared to the conventional motion planning that solves kinematics and dynamics separately. After briefly overviewing the kinodynamic motion planning, its application to a flying robot is described in detail.

INTRODUCTION

"Kinodynamics" consists of the words "kinematics" and "dynamics", and it means the research area that considers and solves the kinematics and dynamics simultaneously. In most of conventional motion planning, dynamical constraints are generally solved by designing control inputs according to the result of kinematic constraints, after first solving kinematic constraints by using path planning. However, kinodynamic motion planning is aimed at solving the kinematic constraints and dynamical constraints simultaneously to generate a control input by using the current states of the controlled object (Donald, Xavier, Canny, & Reif, 1993). Kinodynamic motion planning is useful for generating the control input more simply because it can define the control input in one step by considering the kinematics and dynamics simultaneously after the controller is designed. Therefore, many kinodynamic motion planning methods are proposed up to now. For example, "Randomized Kinodynamic Planning" was proposed by LaValle and Kuffner (1999), where the path toward an arbitrary target point is calculated by a random

DOI: 10.4018/978-1-4666-7387-8.ch015

search method considering the dynamics of a robot. In this method, the searched path is reasonable and a natural route, which can be tracked by the assumed robot, because the velocity and form of the robot are also considered in a state space. Moreover, a method for generating an avoidable and realistic trajectory for the cooperation of multi-robots is also proposed in Jufeng et al. (2005) by combining the kinodynamic motion planning and the optimal control.

A method of using "Harmonic potential field (HPF)" was proposed as one of kinodynamic motion planning. An HPF is a smooth potential field that has no stationary points. By using its gradient vector, it is guaranteed that a kinematic trajectory can reliably reach an arbitrary target point from anywhere in the potential field while avoiding obstacles. When using the gradient of an HPF for the kinodynamic motion planning, damping forces are required for preventing that the controlled object deviates from the gradient direction. Using the viscous damping forces as damping forces is the simplest method, but the method always keeps the controlled object be converged with a slow speed.

From the above point of view, Masoud (2010) introduced the "nonlinear anisotropic damping forces (NADFs)" as an alternative to viscous damping forces. The NADFs can consider the direction of the gradient vector and they decelerate the controlled object only when it deviates from the gradient vector. Masoud also proposed "clamping control" for suppressing an overshoot or oscillation, and it is confirmed that these methods are useful for the control of a point mass.

Motonaka, Watanabe, and Maeyama (2013c) apply the method developed in Masoud (2010) to an X4-Flyer as a more realistic controlled object. The X4-Flyer is a vertical takeoff and landing (VTOL) aerial robot with four rotors, and it has received attention in recent years as search and rescue robots because of its highly maneuverability and hovering ability. Actually, there are recently many studies on the autonomous locomotion for an X4-Flyer. For example, there exist several control results of UAVs in Wang, Boussaada, Cela, Mounier, and Niculescu (2012), Aguilar-Ibnez, Sira-Ramirez, Surez-Castan, Martnez-Navarro, and Moreno- Armendariz (2012), and Raffo, Ortega, and Rubio (2010). In these methods, the controllers are designed under the assumption that the UAVs follow the given trajectory. The control of UAVs is considered to be simpler, if the controller can generate the control input for moving toward the target point at a time, while avoiding obstacles, keeping its attitudes, and assuming that an operator just gives the target point only. Especially, the autonomous navigation of an X4-Flyer may become easier by extending the kinodynamic motion planning to the control of an X4-Flyer. Samir et al. (2004) already confirmed that the altitude and attitude of an X4-Flyer was able to be controlled by using nonholonomic control input. However, the method was not able to guide the X4-Flyer to an arbitrary target point, because the controller just controlled the altitude and attitude only. Therefore, Motonaka et al. (2013b) achieved the kinodynamic motion planning for an X4-Flyer by adding the control input based on an HPF to nonholonomic control input. Moreover, the cooperation of multiple UAVs is also researched by Rigatos (2008, 2011). In this chapter, it is not explicated about the cooperation of UAVs, but UAVs may follow a leader and move toward the target point while avoiding obstacles, if a general idea of virtual leader is used and then the kinodynamic motion planning is applied to the leader.

The following sections describe the structure of an HPF, the control of a point mass using kinodynamic motion planning with NADFs, and the control of an X4-Flyer using kinodynamic motion planning, with some examples.