Motion Planning and Control for a Class of Underactuated Systems

白, 楊

https://hdl.handle.net/2324/2236225

出版情報：Kyushu University, 2018, 博士（工学）, 課程博士
バージョン：
権利関係：

（様式２）

氏　　名　：　白　楊

論 文 名　：　Motion Planning and Control for a Class of Underactuated Systems
（劣駆動システムの軌道計画と制御について研究）

区　　分　：　甲

論文内容の要旨

In recent years, there has been a growing interest to the motion planning and control of underactuated mechanical systems. These systems have fewer independent actuators than the number of degrees of freedom. The need for analysis and control of underactuated mechanical systems arises in many practical applications because they are superior to the fully-actuated systems in terms of energy saving, cost and weight reduction, and system flexibility.

Despite these merits, however, from the perspective of control theory, the limitation of the input for the underactuated systems leads to challenging planning and control problems. To deal with these challenging problems, a geometric phase based method and a function approximation technique (FAT) based control method are developed, respectively for the motion planning and control problems for a class of underactuated systems. A spherical rolling robot driven by a 2DOF pendulum (ball-pendulum system), is used as a testbed for the proposed planning and control algorithms.

In Chapter 2, the motion planning and control problems for the ball-pendulum system were introduced. For the motion planning problem of the ball-pendulum system, the dynamic realizability condition for the ball-pendulum system is firstly established. Then, assuming that the contact path is specified and the sphere moves in a pure rolling mode which is realizable, the full dynamic model was reduced by imposing corresponding virtual constraints. A timing control law was constructed, based on the geometric phase approach, for tracing the contact curves in rest-to-rest motion. For the dynamic control problem, the controller was designed under a backstepping framework: the system kinematics was first considered, and then, the dynamics were taken into account. Noting that both in the kinematic and dynamic stages, the systems are under actuated, A FAT based adaptive controllers for the kinematic and dynamic systems is proposed and tested them by simulations.

In Chapter 3, the motion planning problem for underactuated systems was studied. The underactuated portion of these systems forms a constraint in modeling between the system outputs. This constraint makes the motion planning problem challenging due to that the generated motion trajectory needs to respect the constraint. The motion planning techniques proposed in the literature are usually computationally expensive and thus, cannot be run in real-time on robots. A geometric phase based motion planning algorithm that provides near-optimal results but with less computational cost.

The proposed motion planning algorithm is applicable to a class of underactuated systems, which we call the base-free systems. This type of systems is partially differentially flat after partial feedback linearization. Based on this property, the motion planning algorithm has been constructed as follows. First, the derivative of Beta-function weighted by a constant parameter is selected as a candidate for the base variable due to that it is shown to be the optimal solution for the linearized system. Its feasibility is proved by showing that the corresponding fiber variable can satisfy the given boundary conditions. Finally, the parameter of the derivative of the Beta-function is adjusted such that a desired shift for the fiber variable can be obtained.

In Chapter 4, the dynamic control problem for underactuated systems was studied. In the literature, a great number of related works have been proposed, but they are usually applicable to systems with special features in their models. Instead of the model-based approach, A FAT-based method is proposed where it has almost no limitations on system models and thus works on a wide range of systems. Moreover, the little dependence on models enables the controller design process to be completed without much human interference. Based on these advantages, my method could be applied in solving an interesting problem: let robots design the controller for themselves.

The FAT based controller is applicable to a class of non-square systems (non-square systems include underactuated systems). By introducing an auxiliary input, the non-square system was restructured in the form of the combination of a square system and the variation from the original non-square system, which is treated as system uncertainties. The uncertainty term was then replaced by its approximation as a chosen basis function weighted by constant parameters to be determined. These unknown plant parameters are estimated at each instant, denoted by the adjustable control parameters using a defined update law. Thus the influence to the control process caused by the variation between the auxiliary square system and the original non-square system can be eliminated.

Finally, conclusions are drawn in **Chapter 5**.