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Backstepping Approach for Underactuated Systems

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Abstract - Control of underactuated systems usually required nonlinear technique because it cannot be stabilize with usual smooth, time-invariant and state feedback controller. Thus, backstepping approach is considered for stabilize underactuated systems, which the system is stabilized according to Lyapunov stability theory. This paper reviews the backstepping control method toward underactuated system.

Keywords - Underactuated systems, Backstepping, nonlinear control.

1. Introduction

Underactuated systems refer to those systems with less number of control or inputs than numbers of degrees of freedom (DOFs). The “underactuation" property of underactuated systems is due to the following reasons; dynamics of the system, by design for reduction of the cost or some practical purposes, actuator failure, and imposed artificially to create complex low-order nonlinear systems for the purpose of gaining insight in control of high-order underactuated [1].

Underactuation arises out of the need to reduce cost and saving fuel by fewer actuators is used. The lighter and compact structure of system also gives an advantage in positioning and save space. It also increase the reliability of the system in case of failure; if one actuators fails, other actuator can still achieve the objective of the system [2].

Application of underactuated systems are plenteous in our life, for example in robotics and vehicles (e.g. Wheeled Mobile Robot (WMR), walking robots, the Acrobot, the Pendubot, Wheeled Inverted Pendulum (WIP), Unmanned Air Vehicle (UAV), Vertical Take-Off and Landing (VTOL), helicopters, Autonomous Underwater Vehicle (AUV) and surface vessel).

Controlling underactuated systems has been in active research because it concern fundamentally nonlinear control problems which requires novel ideas and technique. The dynamics of underactuated systems may contain feedforward nonlinearities, non-minimum phase zero dynamics, nonholonomic constraints, and other properties that place this systems in nonlinear control research [3]. Nonlinear control is the area of control theory which deals with systems that are nonlinear, time-variant or both and backstepping method is one of the nonlinear control techniques that can be used to control underactuated systems.

2. Control Problem for Underactuated Systems

Control inputs of underactuated systems are less than the number of the states to be controlled and arise often in nonholonomics systems with nonintegrable constrains. There are two types of nonholonomic constraints: one is the first-order classical nonholonomic constraints and the other is the second-order nonholonomic constraints. The first-order nonholonomic constraints are defined as constraints on the generalized coordinates and velocities. The second-order nonholonomic constraints are defined as those on the generalized coordinates, velocities, and accelerations [3]. Nonholonomic constraints arise in two kinds of situations: one is bodies in contact with each other which roll without slipping and the other is conservation of angular momentum in a multibody system [4]. The problem of stabilizing this systems is a big issue, as it has been proved by Brockett [5] that the nonholonomic control systems with restricted mobility cannot be stabilized to a desired configuration (equilibrium) using a smooth time-invariant state feedback law. Nonholonomic constraints arise in a number of ways and in various underactuated systems and applications such as WMR, Space robots, underwater vehicles and aerospace vehicles. Therefore, for underactuated nonholonomics system, nonlinear control method such as backstepping is used because the nonholonomic constrains are inherently nonlinear.

3. Backstepping Method

3.1 Backstepping

In the beginning of 1990s, a new approach called “backstepping” was developed by Krstic, Kokotovic and Kanellakopoulos [6] for stabilizing controls for a special class of nonlinear dynamical systems. Backstepping is a recursive Lyapunov-based scheme for the class of “strict-feedback” systems. In fact, when the controlled plant belongs to the class of systems transformable into the parametric strict-feedback form, this approach guarantees global or regional regulation and tracking properties. An important advantage of backstepping is that it has the flexibility to avoid cancellations of useful nonlinearities and achieve stabilization and tracking. Another advantage of the backstepping design method is that it provides a systematic procedure to design stabilizing controllers, following a step by step algorithm.

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