Chapter 11

Fabrication and Stabilization of a Low-Cost Rotary-Inverted Pendulum Setup (STRIPS 1.0): Using Full-State Feedback Algorithm

Tufail Ahmad Bhat
https://orcid.org/0000-0002-6296-7140
Islamic University of Science and Technology, India

Majid Hameed Koul
Department of Mechanical Engineering, Islamic University of Science and Technology, India

ABSTRACT

This paper presents the fabrication and Stabilization of a low-cost in-house developed Rotary Inverted Pendulum Setup (STRIPS 1.0), commonly known as a Furuta Pendulum. The developed setup consists of a base frame on which an arm is mounted to allow rotary motion in the horizontal plane and a pendulum link subsequently mounted on the other end of the arm to allow rotation in the vertical plane. Essentially the setup possesses 2- DOF (Degrees of Freedom); however, since the actuation is provided at the arm axis only, the setup behaves as an under-actuated one. Owing to the inherently unstable nature of these under-actuated systems, full-state feedback and an LQR (Linear Quadratic Regulator) controller are designed and implemented, which maintain the pendulum link in the upright position even if disturbed about its linear region of control. In particular, a set of gains are chosen for a particular performance criterion and implemented using a MATLAB interface with the micro-controller on the developed setup, allowing a restricted arm movement.

DOI: 10.4018/978-1-6684-5887-7.ch011

INTRODUCTION

One of the primary, however fascinating, problems in the field of control theory is the inverted pendulum control. It is a challenge that can be readily envisioned since everyone at one time has attempted to balance a broomstick on their hand. While the broomstick is a relatively simplistic demonstration, it highlights the inherent instability of the inverted pendulum system. The problem of balancing a broomstick on the hand can be modeled as a rotary inverted pendulum in which the human arm is mimicked by a rotating arm, actuated by an electric motor, and the broomstick modeled as a pendulum connected to the arm using the revolute joint, with control torque given to the arm link in order to stabilize the pendulum in an upright position. Inverted pednulum has two equilibrium states: vertical downward stable equilibrium and vertical upright unstable equilibrium. The downward position is achieved by gravity; therefore, no feedback approach is required; but in order to achieve the unstable upright position, an external feedback approach is implemented; one such technique utilized in the system is LQR.

The inverted pendulum is inherently an under-actuated system with more degrees of freedom than the number of actuations. In this system, a single actuator at the arm indirectly impacts the motion of the pendulum also, owing to the multibody nature of the arm and pendulum. This indirect impact of the arm motion on the pendulum and the absence of an actuator at the pendulum axis makes the system intrinsically unstable at various operating points. A good control strategy would allow one to control the pendulum in the upright position without requiring an additional actuator. Such systems thereby widely find applications ranging from balancing humanoid robots, where the robot itself can be considered an inverted pendulum, to the Segway human transporter, where a vehicle moves in the direction that the rider leans.

However, because of the system's inherent instability and ability to operate in a non-linear range, the inverted pendulum problem is widely researched and considered a classical benchmark problem in control systems engineering. Figure 1 shows a commercial setup of a rotary inverted pendulum used to teach control systems and experiment with new strategies in the laboratories of UG (Undergraduate) and PG (Postgraduate) courses on Control Systems. Although the setup is highly optimized and useful, the primary reason for fabricating the in-house setup (STRIPS 1.0) was the affordability and that the commercial setups act as a black box to the learner. Several other solutions also exist; however, they are available only in the laboratories of various research institutions. In addition to our interest in fabrication, the primarily focused on the controller design, simulation, and implementation. Before the such attempt, the authors present a review of various inverted pendulum systems and associated control techniques that have been investigated in the past.

Related Content