Mechanical Systems and Signal Processing 116 (2019) 347–369

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Review

Current development on using Rotary Inverted Pendulum as a benchmark for testing linear and nonlinear control algorithms

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ARTICLE INFO

Article history:
Received 31 October 2017
Received in revised form 24 June 2018
Accepted 27 June 2018

Keywords:
Rotary Inverted Pendulum
Swing up control
Stabilization control
Trajectory tracking control
Mathematical modelling

ABSTRACT

Rotary Inverted Pendulum (RIP) is an under-actuated mechanical system which is inherently nonlinear and unstable. For decades, it has been widely used as an experimental setup to explain and test different kinds of control algorithms. The main control objectives of RIP are: Swing-up control, stabilization control, switching control and trajectory tracking control. All these control objectives are described in this study. State-of-the art works proposed for each control objective have also been reviewed. These comprise the linear, nonlinear time invariant, self-learning and adaptive nonlinear controllers. Moreover, different kinds of nonlinear dynamic models of the RIP together with the developed linear models in the literature have been analyzed. This is because most of the proposed controllers applied on RIP are found to be model dependent since they are mainly based on integral and/or invariant motion. Other types of RIP are also reported along with their advantages. Future research opportunities and challenges of the previous approaches in this area of research are presented. We believe that expert researchers can use this paper as starting point for further advancement while graduate scholars can use it as an initial point.

Contents

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https://doi.org/10.1016/j.ymssp.2018.06.054
0888-3270/

1. Introduction

The initial motivation of studies of inverted pendulum (IP) arose based on the need to design balance controllers for rockets during vertical take-off. The rocket is highly unstable at the instant of launching. Thus, there is a need for a continuous alteration mechanism to stay at upright position in the open loop configuration [1]. IP is an important member of nonlinear unstable under-actuated mechanical systems. It is a suitable benchmark system that can be used for training and experimental validation of new control strategies in robotics and control theory. The most common types of IP are the single arm Rotary Inverted Pendulum (RIP), the cart IP and the double IP. The less familiar versions of IP are the two-link RIP, the triple IP, the parallel type dual IP, the 3D or spherical pendulum and the quadruple IP. RIP is one of the most available versions of IP that can be found in most control laboratories. This paper focuses on the RIP which inherits under-actuated, unstable, nonlinear and non-minimum phase system dynamics [2]. RIP was proposed in 1992 [3], and since then it has been investigated by many researchers [4–6]. The experimental setup of the RIP produced by Quanser is shown in Fig. 1(a) and (b). Other companies that are producing IP or RIP include Aimil, sisgeo. This setup consists of two optical encoders for measuring the angles of the pendulum and arm, respectively. It also comprises the data acquisition device for collecting the information from the encoders and feeding it to the computer. The data acquisition device receives the control signal from the computer and gives it to the power amplifier for amplification before feeding it to the motor.

The RIP systems perform in an extensive range of real life applications, such as aerospace systems, robotics, marine systems, mobile systems, flexible systems, pointing control, and locomotive systems [7]. In addition, the study of dynamic model and control algorithms in controlling the RIP plays an important role in controlling spacecraft and rockets, maintaining the equilibrium state for two legs robots and skyscraping buildings [8]. Moreover, when the pendulum of RIP is at hanging position, it represents real model of the simplified industry crane application [9].

The control objectives of the RIP can be categorized into four [10]: 1) Controlling the pendulum from downward stable position to upward unstable position, i.e., swing-up control [11]; 2) Regulating the pendulum to remain at the unstable position, i.e., stabilization control [12]; 3) Switching between swing-up control and stabilization control, i.e., switching control [13]; and 4) Controlling the RIP in such a way that the arm tracks a desired time varying trajectory while the pendulum

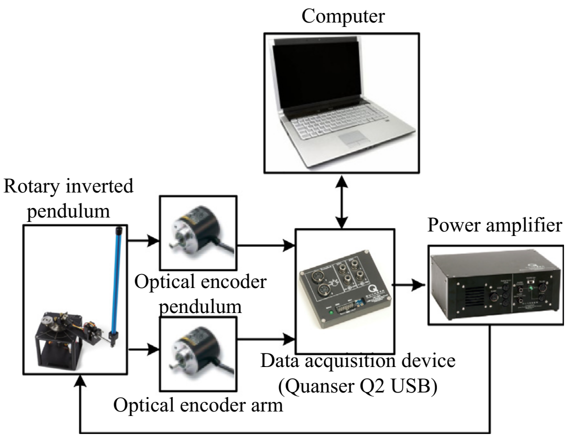

Fig. 1. Schematic diagram of the experimental setup of the RIP.