

# Robust Control of Inverted Pendulum using Fuzzy Logic Controller

Sandeep Kr. Tripathi Himanshu Pandey and Prema Gaur

**Abstract**—Robust Control has been used in various applications to improve the performance of the system. The inverted pendulum (also called “Cart-Pole” system) is a classical example of nonlinear and unstable control system. In This paper we present different design techniques of controller for stabilizing the inverted pendulum (cart system) problem and there comparative analysis of performance and reliability which is done through simulation on MATLAB-Simulink. Robust control (H<sub>∞</sub>) in association with fuzzy produce better response as compared to fuzzy controller.

**Index Terms**—Inverted Pendulum, H<sub>∞</sub>, Fuzzy Logic, Robust Control

## I. INTRODUCTION

A two dimensional inverted Pendulum consists of a freely hinged rod over a dynamic platform that can be driven by either belt-motor system or by cart system. It has inherently two states i.e. stable and the unstable. The stable state is undesirable state and the pendulum is downward oriented. In unstable state pendulum orient strictly upward and hence, requires a counter force to stay align to this position because disturbance will shifts the rod away from equilibrium. This problem has been addressed by testing and implementation of under-actuated mechatronical system and controlling of inherently open loop unstable with highly non-linear dynamics like robotics [1-3] and space rocket guidance systems.

Process model is that component of control system which manipulates the inputs to get the desired output, however due to unexpected disturbances, its output deviates. So, in order to sense and rectify these random deviations dynamically feedback with controller to make it a close-loop system has been proposed.

Initially upright position of the pendulum has been assumed due to disturbance un-compensated model of the system has tendency to move downward towards the stability. Our proposed Controller will try to compensate this disturbance and maintain its upward state. Numerous controlling techniques are available, ranging from conventional controller, artificial intelligence controllers [4]-[6] to recent robust controllers [7]-[13].

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In our design, Matlab/Simulink platform used for observing such compensating controller. The inverted pendulum problem is the classical problem of the control system. It is a highly non linear system. Such type of control problem needs very precise and robust control. The overshoot and the error, both play crucial role in the stability of Inverted

Pendulum (IP). The objective of the present work is to get the optimized and robust performance of a nonlinear system with the help of Robust (H<sub>∞</sub>) controller using Fuzzy Logic Algorithm.

## II. MATHEMATICAL ANALYSIS

In order to analyses the control system, mathematical model is established to predict the behavior before utilizing it into a real system. In this process, we rationalize differential and algebraic equations obtained from conservation laws and its characteristics to obtain transfer function of the process.

We have taken mathematical model of [1] for our work. The separate Free Body Diagram of the cart and pendulum as shown in figure 2.1 is used to obtain its mathematical model.

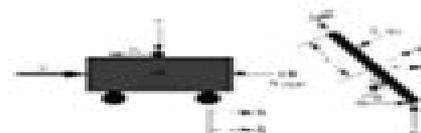


Figure 2.1 Free Body Diagram of the System

By applying Newton's 2nd law of motion to the cart system and assuming the (nonlinear) coulomb friction applied to the linear cart is assumed to be neglected. The force on the linear cart due to the pendulum's action has also been neglected in the presently developed model, the following dynamic equation in horizontal and vertical direction are:

*a) Horizontal direction:* Summing the forces in the Free Body Diagram of the cart in the horizontal direction, we get the following equation of motion:

$$M\ddot{x} = F - b\dot{x} - N \quad \text{-----(2.1)}$$

The force exerted in the horizontal direction due to the moment on the pendulum is determined as follows:

$$N = m \frac{d^2}{dt^2} (x + l \sin \theta) \quad \text{-----(2.2)}$$

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Proceedings of the International Conference on Intelligent Systems and Networks Thi Dieu Linh Nguyen, Maurice Dawson, Le Anh Ngoc, Kwok Yan Lam, 2024-08-31 This book presents Proceedings of the International Conference on Intelligent Systems and Networks Hanoi Vietnam a collection of peer reviewed articles accepted by ICISN 2024 It includes current research outcomes and results of cutting edge work reported by the authors The articles included here are very useful for researchers and industry practitioners The scope of the proceedings include but not limited to Foundations of Computer Science Computational Intelligence Language and speech processing Software Engineering and software development methods Wireless Communications Signal Processing for Communications Next generation mobile networks Internet of Things and Sensor Systems etc In all this proceedings is of great value as reference in these emerging areas of research

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Advanced Control Design with Application to Electromechanical Systems Magdi S. Mahmoud, 2018-04-12 Advanced Control Design with Application to Electromechanical Systems represents the continuing effort in the pursuit of analytic theory and rigorous design for robust control methods The book provides an overview of the feedback control systems and their associated definitions with discussions on finite dimension vector spaces mappings and convex analysis In addition a comprehensive treatment of continuous control system design is presented along with an introduction to control design topics pertaining to discrete time systems Other sections introduces linear H1 and H2 theory dissipativity analysis and synthesis and a wide spectrum of models pertaining to electromechanical systems Finally the book examines the theory and mathematical analysis of multiagent systems Researchers on robust control theory and electromechanical systems and graduate students working on robust control will benefit greatly from this book Introduces a coherent and unified framework for studying robust control theory Provides the control theoretic background required to read and contribute to the research literature Presents the main ideas and demonstrations of the major results of robust control theory Includes MATLAB codes to implement during research

The ... IEEE International Conference on Fuzzy Systems Proceedings, 1998 **Robust Control Theory Based Performance Investigation Of An Inverted Pendulum System Using Simulink** Mustefa Jibril, 2020-08-21 Academic Paper from the year 2020 in the subject Computer Science Software language English abstract In

this paper the performance of inverted pendulum have been Investigated using robust control theory The robust controllers used in this paper are H Loop Shaping Design Using Glover McFarlane Method and mixed H Loop Shaping Controllers The mathematical model of Inverted Pendulum a DC motor Cart and Cart driving mechanism have been done successfully Comparison of an inverted pendulum with H Loop Shaping Design Using Glover McFarlane Method and H Loop Shaping Controllers for a control target deviation of an angle from vertical of the inverted pendulum using two input signals step and impulse The simulation result shows that the inverted pendulum with mixed H Loop Shaping Controller to have a small rise time settling time and percentage overshoot in the step response and having a good response in the impulse response too Finally the inverted pendulum with mixed H Loop Shaping Controller shows the best performance in the overall simulation result

**Intelligent Equipment, Robots, and Vehicles** Qinglong Han, Sean McLoone, Chen Peng, Baolin Zhang, 2021-10-22 The three volume set CCIS 1467 CCIS 1468 and CCIS 1469 constitutes the thoroughly refereed proceedings of the 7th International Conference on Life System Modeling and Simulation LSMS 2021 and of the 7th International Conference on Intelligent Computing for Sustainable Energy and Environment ICSEE 2021 held in Hangzhou China in October 2021 The 159 revised papers presented were carefully reviewed and selected from over 430 submissions The papers of this volume are organized in topical sections on Medical Imaging and Analysis Using Intelligence Computing Biomedical signal processing imaging visualization and surgical robotics Computational method in taxonomy study and neural dynamics Intelligent medical apparatus clinical applications and intelligent design of biochips Power and Energy Systems Computational Intelligence in Utilization of Clean and Renewable Energy Resources and Intelligent Modelling Control and Supervision for Energy Saving and Pollution Reduction Intelligent Methods in Developing Electric Vehicles Engines and Equipment Intelligent Control Methods in Energy Infrastructure Development and Distributed Power Generation Systems Intelligent Modeling Simulation and Control of Power Electronics and Power Networks Intelligent Techniques for Sustainable Energy and Green Built Environment Water Treatment and Waste Management Intelligent Robot and Simulation Intelligent Data Processing Analysis and Control in Complex Systems Advanced Neural Network Theory and Algorithms Advanced Computational Methods and Applications Fuzzy Neural and Fuzzy neuro Hybrids Intelligent Modelling Monitoring and Control of Complex Nonlinear Systems Intelligent manufacturing autonomous systems intelligent robotic systems Computational Intelligence and Applications Proceedings of the International Conference on Applied Science and Technology on Engineering Science 2023 (iCAST-ES 2023) M. Udin Harun Al Rasyid, Mohammad Robihul Mufid, 2024-02-15 This is an open access book International Conference on Applied Science and Technology on Engineering Science 2023 iCAST ES 2023 is the fourth international conference organized by Indonesian Society of Applied Science iCAST ES 2023 is part of iCAST 2023 that focus on Engineering Science Topics of Interest iCAST ES 2023 Artificial Intelligence AI Internet of Things IoT Augmented Reality AR Virtual Reality VR Advanced Robotics 3D Printing New materials and technologies for

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## **Table of Contents Robust Control Of Inverted Pendulum Using Fuzzy Sliding**

1. Understanding the eBook Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - The Rise of Digital Reading Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Advantages of eBooks Over Traditional Books
2. Identifying Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - User-Friendly Interface
4. Exploring eBook Recommendations from Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Personalized Recommendations
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding User Reviews and Ratings

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---

- Robust Control Of Inverted Pendulum Using Fuzzy Sliding and Bestseller Lists
- 5. Accessing Robust Control Of Inverted Pendulum Using Fuzzy Sliding Free and Paid eBooks
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding Public Domain eBooks
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding eBook Subscription Services
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding Budget-Friendly Options
- 6. Navigating Robust Control Of Inverted Pendulum Using Fuzzy Sliding eBook Formats
  - ePub, PDF, MOBI, and More
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding Compatibility with Devices
  - Robust Control Of Inverted Pendulum Using Fuzzy Sliding Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Highlighting and Note-Taking Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Interactive Elements Robust Control Of Inverted Pendulum Using Fuzzy Sliding
- 8. Staying Engaged with Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Robust Control Of Inverted Pendulum Using Fuzzy Sliding
- 9. Balancing eBooks and Physical Books Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Robust Control Of Inverted Pendulum Using Fuzzy Sliding
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Setting Reading Goals Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Fact-Checking eBook Content of Robust Control Of Inverted Pendulum Using Fuzzy Sliding
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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