Robust Control of Inverted Pendulum using Fuzzy Logic Controller

Sandeep Kr. Tripathi Himanshu Pandeyand Prerna 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∞) in association with fuzzy produce better response as compared to fuzzy controller.**

***Index Terms*—Inverted Pendulum, H∞, 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 un-expected 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∞) 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 conservational 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.

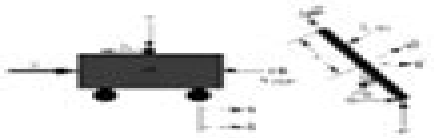

Figure 2.1 Free Body Diagram of the System

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:

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

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

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

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Robust Control Of Inverted Pendulum Using Fuzzy Sliding:

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 **Advances in Robust Control and Applications** Nabil Derbel,Ahmed Said Nouri,Quanmin Zhu,2023-09-12 The book presents recent applications and developments in the field of control of industrial systems covering a wide range of modeling and feedback control using various robust approaches such as fuzzy systems sliding mode control and H infinity This book provides insights into theory applications and perspectives relevant to the field of robotic systems exoskeletons power systems photovoltaic systems etc as well as general methodologies and paradigms around them Each chapter provides an enriched understanding of a research topic along with a balanced treatment of the relevant theories methods or applications It reports on the latest advances in the field This book is a good reference for graduate students researchers educators engineers and scientists and contains a total of 15 chapters divided into five parts as follows The first part of this book focuses on the application of fuzzy control to robotic systems and consists of three chapters The second part of this book proposes the control of lower and upper limb exoskeletons and includes two chapters The third part is dedicated to the control of power systems and comprises three chapters The fourth part deals with various approaches to the modeling and control of industrial processes and comprises four chapters The fifth and final part describes observers and fault tolerant control systems and comprises five chapters **Emerging Trends in Computing and Expert Technology** D. Jude Hemanth,V. D. Ambeth Kumar,S. Malathi,Oscar Castillo,Bogdan Patrut,2019-11-07 This book presents high quality research papers that demonstrate how emerging technologies in the field of intelligent systems can be used to effectively meet global needs The respective papers highlight a wealth of innovations and experimental results while also addressing proven IT governance standards and practices and new designs and tools that facilitate rapid information flows to the user The book is divided into five major sections namely Advances in High Performance Computing Advances in Machine and Deep Learning Advances in Networking and Communication Advances in Circuits and Systems in Computing and Advances in Control and Soft Computing Intelligent Systems Design and Applications Ajith Abraham,Aswani Kumar Cherukuri,Patricia Melin,Niketa Gandhi,2019-04-11 This book highlights recent research on Intelligent Systems and Nature Inspired Computing

It presents 212 selected papers from the 18th International Conference on Intelligent Systems Design and Applications ISDA 2018 and the 10th World Congress on Nature and Biologically Inspired Computing NaBIC which was held at VIT University India ISDA NaBIC 2018 was a premier conference in the field of Computational Intelligence and brought together researchers engineers and practitioners whose work involved intelligent systems and their applications in industry and the real world Including contributions by authors from over 40 countries the book offers a valuable reference guide for all researchers students and practitioners in the fields of Computer Science and Engineering **Sliding-Mode Fuzzy Controllers** Mojtaba Ahmadieh Khanesar,Okyay Kaynak,Erdal Kayacan,2021-07-21 This book addresses some of the challenges suffered by the well known and robust sliding mode control paradigm The authors show how the fusion of fuzzy systems with sliding mode controllers can alleviate some of these problems and promote applicability Fuzzy systems used as soft switches eliminate high frequency signal oscillations and can substantially lower the noise sensitivity of sliding mode controllers The amount of a priori knowledge required concerning the nominal structure and parameters of a nonlinear system is also shown to be much reduced by exploiting the general function approximation property of fuzzy systems so as to use them as identifiers The main features of this book include a review of various existing structures of sliding mode fuzzy control a guide to the fundamental mathematics of sliding mode fuzzy controllers and their stability analysis state of the art procedures for the design of a sliding mode fuzzy controller source codes including MATLAB and Simulink codes illustrating the simulation of these controllers particularly the adaptive controllers a short bibliography for each chapter for readers interested in learning more on a particular subject and illustrative examples and simulation results to support the main claims made in the text Academic researchers and graduate students interested in the control of nonlinear systems and particularly those working in sliding mode controller design will find this book a valuable source of comparative information on existing controllers and ideas for the development of new ones Soft Computing for Problem Solving Aruna Tiwari,Kapil Ahuja,Anupam Yadav,Jagdish Chand Bansal,Kusum Deep,Atulya K. Nagar,2021-10-13 This two volume book provides an insight into the 10th International Conference on Soft Computing for Problem Solving SocProS 2020 This international conference is a joint technical collaboration of Soft Computing Research Society and Indian Institute of Technology Indore The book presents the latest achievements and innovations in the interdisciplinary areas of soft computing It brings together the researchers engineers and practitioners to discuss thought provoking developments and challenges in order to select potential future directions It covers original research papers in the areas including but not limited to algorithms artificial immune system artificial neural network genetic algorithm genetic programming and particle swarm optimization and applications control systems data mining and clustering finance weather forecasting game theory business and forecasting applications The book will be beneficial for young as well as experienced researchers dealing across complex and intricate real world problems for which finding a solution by traditional methods is a difficult task *Digital Communication and Soft*

Computing Approaches Towards Sustainable Energy Developments Gayadhar Panda,Thaiyal Naayagi Ramasamy,Seifeddine Ben Elghali,Shaik Affijulla,2024-04-10 This book is a second volume and contains selected papers presented at Second International Symposium on Sustainable Energy and Technological Advancements ISSETA 2023 organized by the Department of Electrical Engineering NIT Meghalaya Shillong India during 24 25 February 2023 The topics covered in the book are the cutting edge research involved in sustainable energy technologies smart building technology integration and application of multiple energy sources advanced power converter topologies and their modulation techniques and information and communication technologies for smart microgrids *Advances in Electrical Control and Signal Systems* Gayadhar Pradhan,Stella Morris,Niranjan Nayak,2020-07-01 This book presents select proceedings of the International Conference on Advances in Electrical Control and Signal Systems AECSS 2019 The focus is on the current developments in control and signal systems in electrical engineering and covers various topics such as power systems energy systems micro grid smart grid networks fuzzy systems and their control The book also discusses various properties and performance of signal systems and their applications in different fields The contents of this book can be useful for students researchers as well as professionals working in power and energy systems and other related fields **Time-Varying Sliding Modes for Second and Third Order Systems** Andrzej Bartoszewicz,Aleksandra Nowacka-Leverton,2009-04-03 A principal objective of control engineering is to design control systems which are robust with respect to external disturbances and modelling uncertainty This objective may be well achieved using the sliding mode technique which is the main subject of this monograph More precisely Time Varying Sliding Modes for Second and Third Order Systems focuses on only one but very important aspect of the sliding mode system design i e the problem of the sliding plane selection In this self contained monograph the main notions and concepts used in the field of variable structure systems and sliding mode control are presented before in the main part the issue of the switching surface design is discussed This is done by considering two standard plants which are very often encountered in the control engineering practice the second and the third order nonlinear and possibly time varying systems **Mobile Robot: Motion Control and Path Planning** Ahmad Taher Azar,Ibraheem Kasim Ibraheem,Amjad Jaleel Humaidi,2023-06-30 This book presents the recent research advances in linear and nonlinear control techniques From both a theoretical and practical standpoint motion planning and related control challenges are key parts of robotics Indeed the literature on the planning of geometric paths and the generation of time based trajectories while accounting for the compatibility of such paths and trajectories with the kinematic and dynamic constraints of a manipulator or a mobile vehicle is extensive and rich in historical references Path planning is vital and critical for many different types of robotics including autonomous vehicles multiple robots and robot arms In the case of multiple robot route planning it is critical to produce a safe path that avoids colliding with objects or other robots When designing a safe path for an aerial or underwater robot the 3D environment must be considered As the number of degrees of

freedom on a robot arm increases so does the difficulty of path planning As a result safe pathways for high dimensional systems must be developed in a timely manner Nonetheless modern robotic applications particularly those requiring one or more robots to operate in a dynamic environment e g human robot collaboration and physical interaction surveillance or exploration of unknown spaces with mobile agents etc pose new and exciting challenges to researchers and practitioners For instance planning a robot s motion in a dynamic environment necessitates the real time and online execution of difficult computational operations The development of efficient solutions for such real time computations which could be offered by specially designed computational architectures optimized algorithms and other unique contributions is thus a critical step in the advancement of present and future oriented robotics *Variable Structure Systems: Towards the 21st Century* Xinghuo Yu,Jian-Xin Xu,2003-07-01 The book is a collection of contributions concerning the theories applications and perspectives of Variable Structure Systems VSS Variable Structure Systems have been a major control design methodology for many decades The term Variable Structure Systems was introduced in the late 1950 s and the fundamental concepts were developed for its main branch Sliding Mode Control by Russian researchers Emelyanov and Utkin The 20th Century has seen the formation and consolidation of VSS theory and its applications It has also seen an emerging trend of cross fertilization and integration of VSS with other control and non control techniques such as feedback linearization atness passivity based control adaptive and learning control system identi cation pulse width modulation H geometric and algebraic methods arti cial intelligence modeling and optimization neural networks fuzzy logic to name just a few This trend will continue and ourish in the new millennium To re ect these major developments in the 20th Century this book cludes 16 specially invited contributions from well known experts in VSS theory and applications covering a wide range of topics The rst chapter First Stage of VSS People and Events written by Vadim Utkin the founder of VSS oversees and documents the historical developments of VSS in the 20th Century including many interesting events not known to the West until now The second chapter An Integrated Learning Variable Structure Control Method written by Jian Xin Xu addresses an important issue regarding control integration between variable structure control and learning control 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 **Control Systems Design 2003 (CSD '03)** Stefan Kozak,Mikulas Huba,2004-04 The material presented in this volume represents current ideas knowledge experience and research results in various fields of control system design *Innovation in Electrical Power Engineering, Communication, and Computing Technology* Renu Sharma,Manohar Mishra,Janmenjoy Nayak,Bighnaraj Naik,Danilo Pelusi,2020-02-21 This book features selected high quality papers from the International Conference on Innovation in Electrical Power Engineering Communication and Computing Technology IEPCCT 2019 held at Siksha O Anusandhan Deemed to be University Bhubaneswar India on 13 14 December 2019 Presenting innovations in power communication and computing it covers topics such as mini micro smart and future power grids power system economics energy storage systems intelligent control power converters improving power quality signal processing sensors and actuators image video processing high performance data mining algorithms advances in deep learning and optimization methods Analysis and Synthesis of Fuzzy Control Systems Gang Feng,2018-09-03 Fuzzy logic control FLC has proven to be a popular control methodology for many complex systems in industry and is often used with great success as an alternative to conventional control techniques However because it is fundamentally model free conventional FLC suffers from a lack of tools for systematic stability analysis and controller design To address this problem many model based fuzzy control approaches have been developed with the fuzzy dynamic model or the Takagi and Sugeno T S fuzzy model based approaches receiving the greatest attention Analysis and Synthesis of Fuzzy Control Systems A Model Based Approach offers a unique reference devoted to the systematic analysis and synthesis of model based fuzzy control systems After giving a brief review of the varieties of FLC including the T S fuzzy model based control it fully explains the fundamental concepts of fuzzy sets fuzzy logic and fuzzy systems This enables the book to be self contained and provides a basis for later chapters which cover T S fuzzy modeling and identification via nonlinear models or data Stability analysis of T S fuzzy systems Stabilization controller synthesis as well as robust H and observer and output feedback controller synthesis Robust controller synthesis of uncertain T S fuzzy systems Time delay T S fuzzy systems Fuzzy model predictive control Robust fuzzy filtering Adaptive control of T S fuzzy systems A reference for scientists and engineers in systems and control the book also serves the needs of graduate students exploring fuzzy logic control It readily demonstrates that conventional control technology and fuzzy logic control can be elegantly combined and further developed so that disadvantages of conventional FLC can be avoided and the horizon of conventional control technology greatly extended Many chapters feature application simulation examples and practical numerical examples based on MATLAB

Smart Technologies for a Sustainable Future Michael E. Auer,Reinhard Langmann,Dominik May,Kim Roos,2024-05-31 This book includes the proceedings of the 21st International Conference on Smart Technologies Education STE2024 The

International Conference on Smart Technologies Education STE is an annual global meeting dedicated to the fundamentals applications and experiences in the field of Smart Technologies Online Remote and Virtual Engineering Virtual Instrumentation and other related new technologies Nowadays online and smart technologies are the core of most fields of engineering and the whole society Consequently the motto of this year s STE2024 was Smart Technologies for a Sustainable Future The STE conference is the successor of the long standing annual REV Conferences and the annual meeting of the International Association of Online Engineering IAOE together with the EduNet World Association EWA and the International Education Network EduNet In a globally connected world the interest in online collaboration teleworking remote services and other digital working environments is rapidly increasing In response to that the general objective of this conference is to contribute and discuss fundamentals applications and experiences in the field of Online and Remote Engineering Virtual Instrumentation and other related new technologies like Cross Reality Open Science and Big Data Internet of Things and Industrial Internet of Things Industry 4 0 Cyber Security and M2M and Smart Objects Another objective of the conference is to discuss guidelines and new concepts for engineering education in higher and vocational education institutions including emerging technologies in learning MOOCs and MOOLs and Open Resources This year STE2024 has been organized in Helsinki Finland as an onsite event supporting remote presentations from March 6 until March 8 2024 The co organizers of STE2024 were the Arcada University of Applied Sciences the International Association of Online Engineering IAOE together with the Global Online Laboratory Consortium GOLC the International Education Network EduNet and the EduNet World Association EWA STE2024 has attracted 140 scientists and industrial leaders from more than 40 countries *The ... IEEE International Conference on Fuzzy Systems Proceedings* ,1998 **Intelligent Control and Automation** De-Shuang Huang,George William Irwin,2006-09-08 Results of the International Conference on Intelligent Computing ICIC 2006 Lecture Notes in Computer Science LNCS Lecture Notes in Artificial Intelligence LNAI Lecture Notes in Bioinformatics LNBI Lecture Notes in Control and Information Sciences LNCIS 142 revised full papers are organized in topical sections Blind Source Separation Intelligent Sensor Networks Intelligent Control and Automation and Data Fusion Knowledge Discovery and Data Mining Includes a Special Session on Smart and Intelligent Home Technology **Fractional Order Control and Synchronization of Chaotic Systems** Ahmad Taher Azar,Sundarapandian Vaidyanathan,Adel Ouannas,2017-02-27 The book reports on the latest advances in and applications of fractional order control and synchronization of chaotic systems explaining the concepts involved in a clear matter of fact style It consists of 30 original contributions written by eminent scientists and active researchers in the field that address theories methods and applications in a number of research areas related to fractional order control and synchronization of chaotic systems such as fractional chaotic systems hyperchaotic systems complex systems fractional order discrete chaotic systems chaos control chaos synchronization jerk circuits fractional chaotic systems with hidden attractors neural network fuzzy logic controllers behavioral modeling robust and

adaptive control sliding mode control different types of synchronization circuit realization of chaotic systems etc In addition to providing readers extensive information on chaos fundamentals fractional calculus fractional differential equations fractional control and stability the book also discusses key applications of fractional order chaotic systems as well as multidisciplinary solutions developed via control modeling As such it offers the perfect reference guide for graduate students researchers and practitioners in the areas of fractional order control systems and fractional order chaotic systems **Fuzzy Information and Engineering 2010** Bing-Yuan Cao,Guojun Wang,Shuili Chen,Sicong Guo,2010-09-27 This book is the proceedings of the 5th Annual Conference on Fuzzy Information and Engineering ACFIE2010 from Sep 23 27 2010 in Huludao China This book contains 89 papers divided into five main parts In Section I we have 15 papers on the mathematical theory of fuzzy systems In Section II we have 15 papers on fuzzy logic systems and control In Section III we have 24 papers on fuzzy optimization and decision making In Section IV we have 17 papers on fuzzy information identification and clustering In Section V we have 18 papers on fuzzy engineering application and soft computing method

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