LOCAL AND GLOBAL CONTROLLERS FOR DECENTRALIZED DISCRETE-TIME VARIABLE STRUCTURE CONTROL TECHNIQUE FOR LARGE-SCALE SYSTEMS

CHAI CHOONG HENG

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Universiti Teknologi Malaysia

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To my beloved family

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ABSTRACT

This thesis presents a research on new discrete-time integral variable structure controllers for large-scale systems in the presence of matched and unmatched uncertainties. It is found in the literatures that limited works have been done on variable structure control for discrete-time large-scale system. Current computer technology allows direct implementation of discrete-time controller to control a system with greater simplicity and cost saving. The controllers developed in this research are able to achieve system stability in terms of both global and local controls. A global controller makes use of feedback from all subsystems to achieve the quasi-sliding surface and remains on it, with better performance than local controller. A local controller is able to perform the controlling task with feedback solely from the local subsystem itself, with simpler design but is compromised in performance. New theorems with mathematical proof for both local and global controllers are presented and simulations are carried out using Matlab for three different types of large-scale systems to test the proposed controllers. The simulation results also showed that the global controller has better performance than the local controller. Discrete-time integral variable structure control lets the implementation of the controller for large-scale systems a much more straight forward approach with computer. Furthermore, the characteristic of robustness in variable structure control ensures systems fast convergence to the desired value and rejects uncertainties and disturbances, which makes it very practical to be applied to many large-scale systems in real world applications. These newly developed controllers are able to provide cost effective implementations of discrete-time variable structure controllers using current digital hardware for various large-scale plants such as petrochemical, traffic control, telecommunication and robotic system.

ABSTRAK

Tesis ini membentangkan satu penyelidikan berkenaan pengawal struktur berubah kamiran masa diskrit yang baharu bagi sistem berskala besar yang mengandungi ketidaktentuan yang terpadan dan tidak terpadan. Adalah didapati bahawa penyelidikan berkenaan kawalan struktur berubah masa diskrit bagi sistem berskala besar ini amat kurang dalam literatur. Teknologi komputer masa kini membenarkan pelaksanaan secara langsung pengawal diskrit bagi mengawal sesebuah sistem dengan cara yang lebih mudah dan jimat kos. Pengawal yang dibangunkan dalam penyelidikan ini dapat mencapai kestabilan kawalan secara global dan lokal. Pengawal global menggunakan suapbalik daripada semua sub-sistem untuk mencapai permukaan quasi-gelincir dan kekal di atasnya dengan hasil yang lebih baik daripada kawalan lokal. Pengawal lokal dapat menjalankan tugas pengawalan dengan menggunakan hanya suapbalik daripada sub-sistem lokal sahaja, dengan rekabentuk yang lebih ringkas tetapi kompromi dari segi prestasi kawalan. Teorem baru dengan pembuktian matematik telah dikemukakan dan simulasi telah dilakukan dengan menggunakan Matlab ke atas tiga jenis sistem berskala besar yang berbeza. Keputusan simulasi menunjukkan pengawal global mempunyai kawalan yang lebih baik berbanding pengawal lokal. Kawalan struktur berubah kamiran masa diskrit ini membolehkan pelaksanaannya pada sistem berskala besar menjadi lebih mudah dengan komputer. Di samping itu, ciri lasak pada kawalan struktur berubah menjamin penumpuan yang pantas kepada nilai yang dikehendaki dan akan menolak ketidaktentuan dan gangguan, yang menjadikannya amali digunakan dalam sistem berskala besar yang terdapat di dalam aplikasi dunia sebenar. Pengawal yang baharu yang dibangunkan ini membolehkan pelaksanaan efektif-kos kawalan struktur berubah masa diskrit ini menggunakan perkakasan digital terkini bagi pelbagai jenis loji berskala besar seperti sistem-sistem petrokimia, kawalan trafik, telekomunikasi dan sistem robotik.

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LIST OF SYMBOLS

A	-	Nominal system matrix
ΔA	-	Uncertainty of system matrix
B	-	Nominal input matrix
ΔB	-	Uncertainty of input matrix
b	-	Distance between the pendulum hinges
D, d, ξ	-	Disturbances / uncertainty
f_{mi}	-	Matched uncertainty
$\hat{f}_{mi}$	-	Last matched uncertainty value measurable from system
f_{ui}	-	Unmatched uncertainty
$\hat{f}_{ui}$	-	Last unmatched uncertainty value measurable from system
g	-	Gravitational acceleration
K_p	-	Gain of P-controller
K	-	Gain of controller
J	-	Moments of inertia
l	-	Natural length of spring
m	-	Mass
P_s	-	Projection operator
R	-	Real number
r	-	Height of pendulum
S,s, σ_i	-	Sliding Surface/switching function
T	-	Sampling period
u_{eq}	-	Equivalent control input
u_0	-	Ideal control input
$\overline{U}_l$	-	Lower bound of quasi-sliding mode
$\overline{U}_u$	-	Upper bound of quasi-sliding mode
V	-	Lyapunov function
v	-	Torque disturbance

z	-	Integral part of integral switching function
z_{ji}	-	Interconnection between subsystems
ψ	-	State-dependent gain
ρ	-	Negative scalar function

LIST OF ABBREVIATIONS

B.O.D	-	Biochemical Oxygen Demand
D.O.	-	Dissolved Oxygen
DP	-	Dynamic Programming
LMI	-	Linear Matrix Inequalities
MIMO	-	Multiple-input and Multiple-output
P	-	Proportional Controller
PID	-	Proportional, Integral and Derivative controller
SISO	-	Single Input and Single Output
VSC	-	Variable Structure Control

CHAPTER 1

INTRODUCTION

1.1 Brief Introduction to Variable Structure Control

Control theory for variable structure systems has been developed since 1960 in Soviet Union with the pioneering work by Emelyanov and Barbashin. The ideas started to be known to outside world after a book published by Itkis in 1976 and a survey paper published by Utkin in 1977 (Edwards, C. and Spurgeon, S. K.,1998). It stands the advantage of robustness in rejecting the uncertainty in system and disturbances. In contrast to the fixed state feedback of linear state regulator design, the structure of variable structure control is allowed to change, by switching at any instant from one to another member of a set of possible continuous functions of the state. The variable structure problem is then to select the parameters of each of the structures and to define the switching logic (Utkin, 1977).

The study in this control field has been quite substantial especially for the continuous time control with sliding mode in small scale single input single output variable structure systems. On the other hand, the study on large scale variable structure system still remains the focus of many researchers by incorporating new finding in control theory, especially by using the continuous time control methodology. However, the development of discrete-time control methodology for large-scale variable structure system is relatively limited in literatures. This is a rather unexpected phenomenon in the research world of variable structure control theory. In view of there are many large-scale systems in our daily life as well as in the industry, in conjunction with the advancement in computer technology, it is very important and practical to implement the discrete-time variable structure control theory.

Variable structure control method stands an advantage in control system design especially for nonlinear decentralized systems. This is because once the controller is in the sliding mode, it is very robust and invariant to the matched and unmatched uncertainty and disturbances in the system. Uncertainty arises due to imperfection in plant modeling and inaccuracy in sensor feedback requires the controller to be able to adjust to the variation to achieve good performance in controlling the plant. Variable structure control is also able to achieve order reduction to the system once in sliding mode that allows for more simplicity in the design and analysis of the system.

Discrete-time variable structure control theory allows the direct implementation of digital control formula by using computer or micro-processor based control system. This will save the time in design and development of the whole control system, and it will also eliminate the need to use analog to digital and digital to analog converter that add to complexity and cost to the control system project.

The control of a decentralized large-scale system will take the advantages of the discrete-time variable structure controller for its ability to reject the uncertainties and disturbances. As it is commonly known that decentralized large-scale system will have a lot of interconnections and others system parameters modeling error that is inherited in the system modeling process. Once the controller in this research has been developed, it can be applied to various applications such as the advanced technology automation and process control systems. The examples are robotic arms for industrial automation and oil refinery plant or food processing plants.

1.2 Problem Statement

The problems that become the focus of this research are lack of discrete-time variable structure controllers for large-scale system and problem of controlling the stability of a discrete-time large-scale system when feedbacks of other subsystems are not available.

Multiple subsystems in a discrete-time large-scale system is a very complicated system by itself that involve enormous control effort to handle the local subsystem as well as the interconnection of feedback to each other subsystem. The research of a robust control theory for discrete-time large-scale system by using variable structure control to solve the problem of stability and uncertainty as a whole and handle the feedback problem of interconnectivity is very crucial. The variable structure control theory must be able to ensure the system achieve quasi-sliding mode for a designed sliding surface, and at the same time impose the corrective control to the interaction among the subsystems by rejecting its effect that might render instability to the local subsystem.

When the size of the dynamical system increases, the implementation of centralized control will be either impossible or uneconomical. Research in decentralized control has been motivated by the inadequacy of conventional modern control theory to deal with certain issues in large-scale system, such as it is impossible to incorporate so many feedback loops into the centralized design. Decentralized control theory has risen in response to the difficulty that there are restrictions on information transfer between certain groups of sensors or actuators. The controller would be very much depends on the local control at the subsystem itself when feedbacks from other subsystems are not available.

The problem in the industry is also lack of discrete-time controllers that is robust and suitable for large-scale system. The key challenge would be to design a discrete-time variable structure controller that is able to control all the local subsystems in a large-scale system, and able to handle the influence of interconnection by other subsystems. This is getting more difficult especially for a large-scale system with a big quantity of subsystems in it. Nowadays, it is not easy to find a control system and hardware that is simple to implement and cost effective which is crucial for industry to stay competitive. As compare to analogue control system hardware that is more complicated to develop and tune, the computer technology makes the lower cost hardware easily available and enable faster development of discrete-time technology. Most of the design and tuning to the system has been taken over by software and the development of controller for direct implementation in discrete-time method is in great demand to solve the problems.

1.3 Research Objectives

The objectives of this research are to design a new decentralized integral variable structure controller to control a discrete-time large-scale system as follow:

I. To propose a new local controller in integral variable structure control for controlling a discrete-time large-scale system when only the feedback of local subsystem is available but feedbacks of other subsystems are not available.

II. To propose a new global controller in integral variable structure control for controlling a discrete-time large-scale system when feedbacks of all subsystems are available.

III. To propose a new integral variable structure controller that is able to handle matched and unmatched uncertainty of a discrete-time large-scale system.

The new controllers will ensure the system maintain in the quasi-sliding surface designed for each subsystems and achieve the overall stability of the whole system by eliminating the effect of interconnection and disturbances.

1.4 Scope of Research

The scope of this research covered the development of decentralized discrete-time large-scale system controller with integral variable structure controller. The controllers were designed for both local and global control. The controllers served as local controller to control a discrete-time large-scale system when only the feedback of local subsystem was available but feedbacks of other subsystems were not available. On the other hand, when the feedbacks of all subsystems in a discrete-time large-scale system were available, the global control strategy was applied. New theories and mathematical proofs were given for the local and global controllers in study based on the assumptions given.

The new discrete-time integral variable structure controllers were designed to control the large-scale systems with matched and unmatched uncertainty.

Simulation in Matlab was done to show the results of the controllers that are able to reach the quasi-sliding surface and ensure the stability of the systems. The simulations were carried out with a few examples of discrete-time large-scale systems for the tests on the controllers developed.

1.5 Research Contributions

In this research, new variable structure control theories are developed for the control of discrete-time large-scale system. The contribution of this research is very substantial to decentralized control as it adds on to the field of discrete-time variable structure control that is very limited for large-scale systems. This is because the new controllers are relatively easy to implement and cost effective by riding on the current technology advancement in digital hardware.

Two approaches have been taken for this research to demonstrate the advantages of the discrete-time variable structure control to large-scale systems. Firstly, it is the global control approaches that take the feedbacks from all subsystems to the controller to achieve the control objective. The second approach is focusing on the local controller method, which is a valid concern that sometimes feedback from certain subsystems are missing or difficult to obtain in a large-scale system. The new theorems developed for both global and local control will give a more complete picture on the capability of the new variable structure controllers that is able to ensure the achievement of quasi-sliding mode in discrete-time control, and the rejection of uncertainty and disturbances to the system.

This research outcome can be used in many large-scale systems such as petrochemical process control system, power transmission systems, telecommunication systems, traffic control system, robotic and many other large-scale systems that are available in our daily life. The theorems developed in discrete-time format is able to be implemented more straight forward by using digital computer or micro-controller based logic controllers, that can save the cycle time in developing such a system in practice.

1.6 Structure and Layout of the Thesis

Chapter 2 reviews the literatures and background of variable structure control, beginning from the basic theory in general to large-scale system. The different approaches of designing the sliding surface and controller are discussed. Both continuous-time and discrete-time variable structure control theories will be discussed in this chapter in separate sections.

Chapter 3 discusses the design of the discrete-time integral variable structure control as a local controller. The design of the sliding surface and controller is given in this chapter. The theory for the local control is developed with proof to demonstrate that the controller is able to achieve the quasi-sliding mode with only the feedback from the local subsystems themselves. The overall stability of the controller is also presented to show the system remain stable based on the new theory.

Chapter 4 discusses the design of a global controller for discrete-time integral variable structure control. The sliding surface design for the global controller is given and the mathematical formula is used to provide the proof for the new theorem. The overall stability of the system as a whole is ensured which is covered by the proof from the formula.

Chapter 5 presents the simulation results for the controllers developed. The simulation demonstrated the local control of discrete-time integral variable structure with a large-scale 3 subsystems plant and comparison is done with the P-controller. Then the simulation on global controllers was also done and compared with P-controller as well. Subsequently the comparison of performance between local and global controller was given.

It is followed by the simulation of global controller on large-scale system in 3-reach river pollution and double inverted pendulum. The simulations to demonstrate the effect of parameters in the controller were also done to evaluate the performance and to have better understanding for designing the controller.

Chapters 6 summarize the whole idea presented in this thesis with a conclusion and provide suggestions for future works.

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