CONTAINMENT CONTROL BASED ON STATE-FEEDBACK FOR MULTI-AGENTS SYSTEM WITH NON-LINEARITY ELEMENT

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DEDICATION

I dedicate this Final Year Project thesis to my parents, families, supervisor, and friends, who always understand and support me to finish this project and make this project possible. Thank you.

ABSTRACT

"Multi-agents system" is a term used to describe a group of agents connected to achieve specified control tasks over a communication network. These agents are required to reach an agreement upon certain conditions proposed to reach "containment". This study investigates the containment control problem of the leader-follower configuration in a multi-agents system with a type of non-linearity such as input time delay with respect to a continuous-time and directed spanning forest communication network topology. Control theory and the Laplacian network topology are applied to construct and propose a state feedback containment controller that employs the relative information of each agent. The design controller and containment problem has been achieved in this project where the system is designed with 4 different network topology; Directed, undirected, directed with strongly connected agents and not strongly connected agents. All agents successfully achieved containment through out the system despite the time delay inserted. The stability analysis is done based on Lyapunov stability theory. The goals for this project has been met as all agents able to reach containment and have a stable system. The simulation results of the proposed controllers were shown to prove their theoretical validity. Adding more non-linearities and leaders in one system and applying the current system into a real life project is recommended for future work to improve the system and so that the stability of the system can be proven better.

ABSTRAK

""Sistem berbilang ejen" ialah istilah yang digunakan untuk menggambarkan sekumpulan ejen yang disambungkan untuk mencapai tugas kawalan tertentu melalui rangkaian komunikasi. Ejen-ejen ini dikehendaki mencapai persetujuan atas syarat-syarat tertentu yang dicadangkan untuk mencapai "pembendungan". Kajian ini menyiasat masalah kawalan pembendungan konfigurasi pemimpin-pengikut dalam sistem berbilang ejen dengan jenis bukan lineariti seperti kelewatan masa input berkenaan dengan topologi rangkaian komunikasi hutan rentang masa berterusan dan terarah. Teori kawalan dan topologi rangkaian Laplacian digunakan untuk membina dan mencadangkan pengawal pembendungan maklum balas keadaan yang menggunakan maklumat relatif setiap ejen. Pengawal reka bentuk dan masalah pembendungan telah dicapai dalam projek ini di mana sistem direka bentuk dengan 4 topologi rangkaian yang berbeza; Diarahkan, tidak diarahkan, diarahkan dengan ejen yang berkait rapat dan ejen tidak berkait kuat. Semua ejen berjaya mencapai pembendungan melalui sistem walaupun kelewatan masa dimasukkan. Analisis kestabilan dibuat berdasarkan teori kestabilan Lyapunov. Matlamat untuk projek ini telah dicapai kerana semua ejen dapat mencapai pembendungan dan mempunyai sistem yang stabil. Keputusan simulasi pengawal yang dicadangkan ditunjukkan untuk membuktikan kesahihan teorinya. Menambah lebih banyak bukan lineariti dan peneraju dalam satu sistem dan menggunakan sistem semasa ke dalam projek kehidupan sebenar disyorkan untuk kerja masa depan untuk menambah baik sistem dan supaya kestabilan sistem dapat dibuktikan dengan lebih baik.

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MAS	Multi-agents System.

LIST OF SYMBOLS

$\mathscr{L}$	The Laplacian matrix.

CHAPTER 1

INTRODUCTION

1.1 Brief Overview

Cooperative Control of Multi-agents System (MAS) has become one of the most fascinating study fields in recent years. Due to its application in evaluating and creating coordinating behaviours among agents in multi-agent frameworks, consensus and containment control in multi-agent systems is becoming progressively popular among researchers. Cooperative control entails working with a group of agents to achieve collective group behaviour via local interaction.

Cooperative control of multi-agent systems has been studied and applied in a variety of settings. Multi-agents are used in a variety of areas, including formation control, flocking, coverage control, project and role assignment, and other cooperative activities. For example, in [1] assessments on flocking control method for UAV groups were explored,as were system uncertainties and unknown disturbance in [2].

According to [3], in a multi-agents system involving the systems and control community, the agents are generally dynamically disconnected from one another, implying the need for cooperation in terms of information sharing between the agents in order to achieve collective behaviour. In this case, each agent requires data from other agents via a direct sensing or communication network, which is often depicted as a graph with nodes.

Recently, much progress has been made on both leaderless and leader-following consensus problems (see [4–8] and references therein). Although the leader-following consensus problem for multi-agent systems with a single leader is intriguing, the leader-following problem for multi-agent systems with numerous leaders is sometimes more interesting. The goal of the containment problem is to guide all of the followers into the convex hull spanned by the leaders. Because of its vast applicability in swarm robotics, academics have given a lot of attention to the containment control problem in recent years. [9–12]. In [13], the containment control problem is investigated in both continuous-time and discrete-time domain.

Containment control evolved from consensus control, in which each member is referred to as an agent or subsystem, and the group is referred to as a multi-agent system. Consensus must first be obtained before containment can take place. When the group reaches a consensus, one single outcome is obtained, which is followed by all members or agents in the group. The state feedback containment controller that uses each agent's relative information is developed and proposed using control theory and the Laplacian network structure. According to the design of the controller, the leaders are responsible for creating the convex hull form, which is responsible for containing the followers. For containment to take place, there must be at least one leader who is able to maintain an open line of communication with the followers, whereas in consensus control, there must be no more than one leader at any given time. Following a study of the network structure, the Lyapunov stability theory is referred to in order to derive the stability conditions. The Laplacian matrix must only have a simple zero eigenvalue as one of the containment control's requirements.

1.2 Objectives

- To model the containment control system problem for multi-agents system
- To design state feedback containment controller for multi-agents system
- To analyze the stability of the system with and without the non-linearity elements

- To validate the performance of the controller for a multi-agent system using MATLAB and Simulink

1.3 Problem Statement

Each agent's ability to establish a consensus outcome is one of the issues associated with the multiagent system. The same holds true for containment control. Incorporating the non-linearity factor into the system exacerbates this issue, leading in a non-consensus and non-containment outcome. In recent years, the containment challenge for multi-agent systems has received increasing attention. The issue is met frequently in the real world, such as in distributed computation, flocking, formation flight, and traffic congestion control. A system where the leader is able to contain all the followers by introducing some virtual/actual leaders or containment control system to guide the agents to move about safe places is required to ensure that a group of autonomous agents or robots does not wander into a dangerous location that could result in a non-containment output.

1.4 Scope of Work

To meet the project's objectives, a particular scope must be specified. Modeling a linear multi-agents system using state-space approach is the first step. This model can be achieved by carefully examining the Laplacian matrix generated by the agents' network topology, in which each agent is connected via a directed graph. Before introducing non-linearity features, we conduct a simulation to ensure that the system is operational. Then, aspects of nonlinearity, such as time delay, are introduced into the system, rendering it unstable. A nonlinear containment controller is intended to maintain system stability. The controller's ability to stabilise the system will be validated by experimental simulations.

1.5 Project Outline

This research is divided into five chapters. Chapter 1 briefly describes the background of the study regarding the Nonlinear Containment Control for Multi-Agents System. This section includes the problem statement, project objectives, and scope of work.

Chapter 2 reviews the literature review discussing the mathematical preliminaries of consensus control, and it addresses the mathematical aspects and notations required for consensus control to function correctly. Some preliminaries introduced are graph theory, adjacency matrix, Laplacian matrix, Kronecker product, and the fundamental Lyapunov stability theorem. All these are pointed out in connection to help design the controller.

Chapter 3 is about the methodology. This chapter focuses on the project flow chart of the whole project flow. This chapter also will elaborate more on steps taken to achieve the project results.

Chapter 4 covers all the results that show the step-by-step for the system to reach containment. This chapter will show all the details of the mathematical calculation parts. This chapter also discusses the final results obtained from the previous chapter. The explanation of the results and findings of the project will be discussed in more detail.

Chapter 5 is the final chapter in the thesis, which summarizes all the results and findings from previous chapters. The achievement of this project will be highlighted based on the objectives. Future work will also be included so the improvement can be made for the further research plan.

CHAPTER 2

BACKGROUND STUDY

2.1 Introduction

This chapter discusses the analysis of past researchers' journals in order to improve the project's outcome. There have been a number of publications on this project's relevant topic. A shared variable of interest between agents is required to achieve consensus. In order for containment to be achieved, the system must first reach consensus control. For consensus control to work, it is necessary to understand the mathematical features of consensus. Prior scholars' ideas and publications greatly influenced the concepts of consensus control, the mathematical approach used, and control design. This data was gathered from theses, journals, papers, online books, and other internet sources.

2.2 Mathematical Preliminaries of Consensus Control

A journal on linear multi-agent systems under weighted- balanced and strongly connected digraphs to achieve an optimal point has been discussed in [14]. One of the essential keys in this thesis is to understand how the network topology relates with the controller, and the presence of non-linearities element relates to Lyapunov analysis's stability. The mathematical features of consensus must be explored and understood for consensus control to work thus containment can be reached. Because the mathematical idea of consensus is a well-known subject in the field of computer science, it's easy to see how it's used in consensus control.

Designing a consensus control system entails a number of processes. First of all, a number of agents need to be determined. Then, using Algebraic Graph Theory, the position of each agent is included in the derivation of the adjacency matrix from the graph. The graph is then utilized to generate the Laplacian matrix, which is the core of consensus control. Finally, the system will achieve a consensus output based on numerous definitions and conditions based on this matrix. As a result, this section will focus on Graph Theory and how it pertains to consensus control. However, compared to Computer Science, the amount of material available on this issue is not as large, yet it is sufficient for consensus control.

The first-order (single-integrator) mathematical notion of consensus is studied, followed by the second-order (double integrator) and higher-order (multi-integrator) mathematical concepts of consensus (more than double-integrator). Special algorithms that analyze and use relative state information represent all sorts of consensus. Finally, stability analysis is performed using this data to confirm that the controlled system is stable and that consensus is reached.

2.2.1 Graph Theory

In consensus control, algebraic graph theory is frequently employed to define the topology of agent networking. The graph is based on the topology of information transfer between agents and has a directed or indirect topology. This section explained graph theory's core concept. This also explains the layout of each agent in the group's graph topology to generate the adjacency matrix. The Laplacian matrix will then be produced from the matrix that will be utilised for consensus control.

A directed graph is considered to be strongly connected if there exists a path between every pair of different nodes. A directed graph has a directed spanning tree if there is a node named root (agent 0) such that there is a directed path from this node to every other node, as depicted in the picture 2.1. All work on consensus control of multi-agent systems presented in this study will be based on a directed spanning tree communication topology.

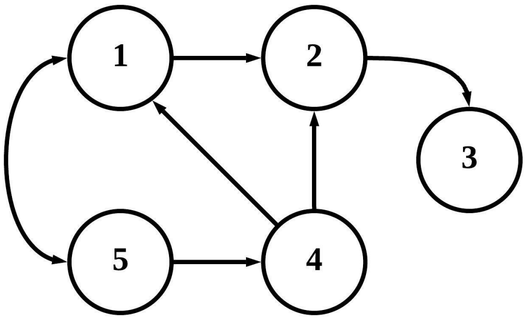

Figure 2.1: Directed Spanning Tree Connection Topology.

Multi-agents must be represented in the graph network in the same manner as other communication networks in order to accomplish the same goal. This topic was examined in depth in [15], focusing on the perspective of graph theory with regard to multi-agent systems, where the attributes of these agents were referred to as action triggers.

2.2.2 Eigenvalues and eigenvector

Eigenvalues and eigenvectors are an important link in the Laplacian matrix for designing consensus control. This section provides a detailed explanation of eigenvalues and eigenvectors [16]. For a square matrix $A = C^{n \times n}$, the eigenvalues of A are defined as the solutions of the equation

$$det(\lambda I - A) \tag{2.1}$$

where I is defined as

$$I = diag(1) \in \mathbb{R}^{n \times n} \tag{2.2}$$