

**TERMINAL SLIDING MODE CONTROL  
BASED ATTITUDE CONTROL OF 2-DOF TWIN  
ROTOR SYSTEM**



**ADNAN SHARIF  
REG # 51168**

**BAHRIA UNIVERSITY ISLAMABAD  
KARACHI CAMPUS**

## Approval for Examination

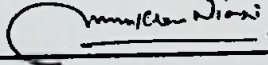
Scholar's Name: Mr. Adnan Sharif

Registration No. 51168

Programme of Study: MS(EE)

Thesis Title: Terminal Sliding Mode Control based Attitude Control of  
2-DOF Twin Rotor System

It is to certify that the above scholar's thesis has been completed to my satisfaction and, to my belief, its standard is appropriate for submission for examination. I have also conducted plagiarism test of this thesis using HEC prescribed software and found similarity index 17 % that is within the permissible limit set by the HEC for the MS degree thesis. I have also found the thesis in a format recognized by the BU for the MS thesis.

Principal Supervisor's Signature: 

Date: 15/07/2020

Name: Engg. Muhammad Yasir Amir Khan

## AUTHOR'S DECLARATION

I, Adnan Sharif hereby state that my MS thesis titled "Terminal Sliding Mode Control based Attitude Control of 2-DOF Twin Rotor System" is my own work and has not been submitted previously by me for taking any degree from this university Bahria University Karachi Campus (Name of University) or anywhere else in the country/world.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw/cancel my MS degree.

Name of Scholar: Adnan Sharif

Date: 15-7-2020

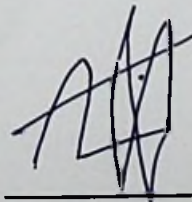
## Plagiarism Undertaking

I, solemnly declare that research work presented in the thesis titled "Terminal Sliding Mode Control based Attitude Control of 2-DOF Twin Rotor System" is solely my research work with no significant contribution from any other person. Small contribution / help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Bahria University towards plagiarism. Therefore I as an Author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred / cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS degree, the university reserves the right to withdraw / revoke my MS degree and that HEC and the University has the right to publish my name on the HEC / University website on which names of scholars are placed who submitted plagiarized thesis.

Scholar / Author's Signature: \_\_\_\_\_



Name of Scholar: Adnan Sharif

# ACKNOWLEDGMENT

All thanks to my creator The Allah Almighty who makes me able to complete my thesis in efficient way. Without his help I will never be able to do anything. I would like to express my deep gratitude to my parents, teachers, friends and all other individuals that helped me in my research especially to my supervisor Engr. Muhammad Yasir Amir Khan who guides me throughout my research work and without his guidance it will be impossible for me to complete my thesis. His vision, guidance and motivation throughout my research helped in successful completion of my thesis. I am also very thankful to my Professors for their invaluable guidance and help in my work. Their sincerely instructions helped often in my research work. It was a great honor for me to work and study under the instructions of my Supervisor and teachers.

In the last I am also really thankful to my classmate Mr. Farhan Ahmed Qureshi for his cooperation in my thesis. His guidance and patience helps frequently throughout my research work.

# ABSTRACT

A Twin rotor system (TRS) is a highly nonlinear and unstable multi-input multi-output system. Control of a such system is a challenging problem which has attracted a lot of research effort. In this thesis an Integral Terminal Sliding Mode Control (ITSMC) based design for attitude control of TRS is proposed that assures disturbance rejection with asymptotic stability. The proposed ITSMC uses second order Integral Terminal Sliding surface which guarantees trajectory tracking. Lyapunov based stability analysis and MATLAB based simulation is used to support the validity of proposed controller. Further hardware implementation is made to verify the effectiveness of the proposed controller.

## Table of Contents

| Chapter | Title                                                                      | Page |
|---------|----------------------------------------------------------------------------|------|
|         | Acknowledgment                                                             | vi   |
|         | Abstract                                                                   | vii  |
|         | Table of Contents                                                          | viii |
|         | List of Tables                                                             | x    |
|         | List of Figures                                                            | xi   |
| 1       | Introduction                                                               | 1    |
|         | 1.1 Overview                                                               | 2    |
|         | 1.2 Problem Statement                                                      | 4    |
|         | 1.3 Objectives and Scope                                                   | 4    |
|         | 1.4 Motivation                                                             | 4    |
|         | 1.5 Assumptions and Limitations                                            | 6    |
|         | 1.6 Methodology                                                            | 6    |
|         | 1.7 Thesis Outline                                                         | 7    |
| 2       | Literature Review                                                          | 8    |
|         | 2.1 Control Techniques on TRS                                              | 8    |
|         | 2.2 TSMC Based Control Techniques                                          | 10   |
| 3       | Mathematical Model of 2DOF TRS                                             | 12   |
|         | 3.1 Forces on Pitch Axis                                                   | 12   |
|         | 3.1.1 Thrust Generated by Main Motor ( $\mathcal{T}_{mm}$ )                | 14   |
|         | 3.1.2 Vertical affect of Tail Motor on Pitch Motor ( $\mathcal{T}_{tm}$ )  | 14   |
|         | 3.1.3 Total Disturbance on Pitch Axis ( $D_{mm}$ )                         | 15   |
|         | 3.2 Torque on Yaw Axis                                                     | 18   |
|         | 3.2.1 Horizontal affect of main motor on tail motor ( $\mathcal{T}_{mt}$ ) | 20   |
|         | 3.2.2 Thrust due to yaw motor ( $\mathcal{T}_{ym}$ )                       | 20   |
|         | 3.2.3 Disturbance on Yaw Axis ( $D_{ym}$ )                                 | 20   |
|         | 3.3 Summary                                                                | 24   |
| 4       | State Variable Form and Linearization                                      | 25   |
|         | 4.1 State Variable Form                                                    | 25   |
|         | 4.2 State Variable Form of TRS                                             | 26   |
|         | 4.3 Linearization                                                          | 28   |
|         | 4.4 Linearization of TRS                                                   | 30   |
|         | 4.5 Summary                                                                | 33   |
| 5       | Integral TSMC and its Stability Analysis                                   | 34   |
|         | 5.1 Integral TSMC                                                          | 34   |
|         | 5.2 Integral TSMC for TRS                                                  | 35   |
|         | 5.2.1 Integral TSMC design for Pitch Angle                                 | 35   |
|         | 5.2.2 Integral TSMC design for Yaw Angle                                   | 38   |
|         | 5.3 Summary                                                                | 41   |
| 6       | Simulation and Experimental Results                                        | 42   |
|         | 6.1 Simulation Results                                                     | 42   |

|       |                                          |    |
|-------|------------------------------------------|----|
| 6.2   | Experimental Results                     | 50 |
| 6.2.1 | Hardware Description Of TRS              | 50 |
| 6.2.2 | Pre-requisites and MATLAB® Configuration | 53 |
| 6.2.3 | TRS Response                             | 55 |
| 6.3   | Summary                                  | 58 |
| 7     | Conclusion and Future Work               | 59 |
| 7.1   | Conclusion                               | 59 |
| 7.2   | Future Work                              | 60 |
|       | Appendix A: Proof of Theorem 1           | 67 |