SYNOPSIS OF THE THESIS

"DISCRETE-TIME SLIDING MODE CONTROL FOR NETWORKED CONTROL SYSTEM"

to be submitted for partial fulfillment of the requirement for the degree of

Doctor of Philosophy

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1. Introduction

Networked control systems (NCSs) are traditional feedback control loops closed through a real time communication network. That is, in networked control systems, communication networks are employed to exchange information (reference input, plant output, control input, etc...) between control system components (sensors, controllers, actuators, etc...). NCS has become popular in the field of control due to its distinct advantages such as low cost, reduced weight, simple installation and maintenance, resource sharing and high reliability. As a result, NCS have great potential in industrial applications such as manufacturing plants, smart grid, haptic collaboration, vehicles, aircrafts, robotics, spacecrafts etc... NCS generally possess a dynamic nature which results in various challenges for researchers in terms of random time delay, packet loss, multiple packet loss, packet disordering, resource allocation and bandwidth sharing. It is well known that the performance of NCS is significantly deteriorated due to these communication uncertainties. If these challenges are not handled properly, they may result in degradation of the system's performance. Among all these issues, time delay and packet loss are considered to be crucial issues in NCS that degrades the stability and control performance of closed-loop control systems.

The delays may be constant, time-varying, and in most cases, random. The nature of network delay mainly depends on the configuration of the communication medium. If the communication medium is configured using lease line concept then the delays are always deterministic in nature. And whenever the communication medium is shared by large number of devices then the delays are random in nature. It is worth to mention here that, the time required for the data packets to travel from sensor to controller and controller to actuator is defined as total network delay. The controller mainly suffers from sensor-to-controller delay. When such delay is transformed into discrete-time domain it mostly possesses non-integer type of values. Such network delays in discrete-time domain are defined as fractional delays which may be either deterministic or random in nature. So, it is important to compensate the effect of deterministic as well random fractional delay in discrete-time domain at each sampling instant.

Further, as mentioned above there are also possibilities of packet loss during the transmission of data packets from sensor to controller as well as controller to actuator. The packet loss takes place due to heavy network load, network congestion and node competition. In discrete-time domain, the network-induced delay greater than one sampling time is also considered as packet loss. The nature of delay and packet loss is mainly dependant on configuration of network medium.

In recent years, many algorithms have been studied for the stability analysis and control design of NCS in discrete-time domain that includes state feedback controller, H_∞, Model predictive controller and sliding mode controller etc... Among them Sliding Mode Controller is one of the robust control algorithms because of its invariance properties to parameter variation and uncertainties.

In the early stages of NCS, when modelling of random time delay was difficult to obtain, the most appropriate approach was to treat the random time delay as constant which are called as deterministic delays. Luck et al. [1, 2] introduced the concept of compensating the time delay in continuous-time domain. Yu et al. [3] designed multiple step delay compensator for NCS in the presence of dynamic noise and measurement noises. H. Chan [4] designed convetional form of memory feedback controller based on delay compensation method. D. Kim et al. [5] modelled an NCS as a switched system with constant input delays and derived the sufficient conditions for the system stability by using piecewise continuous Lyapunov methods. L. Montestruque [6] designed state feedback controller that compensates the effect of deterministic network delays in continuous-time domain.

Many researchers ([7], [8], [9], [10], [11], [12], [19], [25]) have laid their sincere efforts to model random time delays in last decade. Among them J. Nilsson et. al. [7] introduced the time stamp technique to model the random time varying networked delay. L. Zhang et. al. [8] and J. Dong et. al. [9] modelled random time delay using the concept of Markov Chain process in discrete-time domain. While, Yang et. al. [10] modelled random networked delay using Bernoulli's distributed white sequence approach. Y. Shi [11], modelled random delays using Markov chain process and designed output feedback controller to handle the effects of random delay. H. Gao et. al. [12] used an independent and identically distributed approach to model the time varying networked delay. Khanesar et. al. [19] modelled the random time delays using a uniform probability distribution function in continuous-time domain. Recently, A. Argha et. al. [25] proposed Bernoulli's white sequence approach for modelling the random time delay and proposed sliding mode controller in the presence of random time delay and packet loss.

As mentioned above, there are also possibilities of packet loss during the transmission of data packets from sensor to controller as well as controller to actuator. In the research works ([7]-[13],[23]), it is assumed that the packet loss within the communication medium takes place when networked delay is greater than sampling interval and based on that the mathematical model is derived. W. Kim et. al. [9] used Dirac delta probability function to derive the mathematical model of packet loss assuming the single packet loss situation. L. Zhang et. al. [8] considered the packet loss in correspondence with random time delay model. Similarly, Yang et. al. [10] also considered the same packet loss situation in connection with the random time delays. Y. Shi et. al. [11] assumed the packet loss situation while modelling the random time delays using Markov's chain process. Recently, H. Song et. al. [13] derived the packet loss model using Markov chain process. The model was validated for a single packet drop as well as successive packet drops. H. Li et. al. [23]

designed sliding mode predictive controller under mutiple packet transmission policy.

Many researchers also proposed time delay compensation and estimation techniques to compensate the effects of network delay in continuous-time domain like, Pade Approximation [14], [19], Smith Predictor algorithm [15], [17], Luenberger observer technique [21], Kalman Predictor [24] and Observer based predictor [16]. In discrete-time domain also, very few algorithms such as Zero-Order-Hold [20], Kalman Predictor [23], Luenberger output feedback observer [22] and time delay estimation [18] are proposed for compensation of time delay. Apart from these estimation techniques various reasearchers ([21], [26], [27], [28]) have contributed their work in designing the controllers based on ouput feedback method in networked control system. The Luenberger output feedback approach is widely used in designing the various controllers such as state feedback, network predictive, H_∞, SMC, etc... that takes care of network non-idealities (time delay, packet loss and matched uncertainty).

2. Motivation, Objective and Scope

It is worth to mention here that, the time required for the data packets to travel from sensor to controller and controller to actuator is defined as total network delay. When such delay is transformed into discrete-time domain it mostly possesses non-integer type of values. Such network delays in discrete-time domain are defined as fractional delays. The networked control system has sensor to controller fractional delay present in the feedback channel and controller to actuator fractional delay present in the forward channel. The nature of both these fractional delays depends on the type of the communication medium. In NCS, when the data packets are exchanged through real time communication medium the network delay always have the fractional delay. So, it is important to compensate the effect of deterministic and random type of fractional delay in discrete-time domain at each sampling instant in the presence of packet loss and matched uncertainty.

Although lot of work is done, fractional time delay compensation in the discrete-time domain is still under investigation. Most of the researchers have assumed the values of network delays in terms of an integer. But, in real time the delays may have non-integer type values. So, as per the authors best knowledge till date none of the researchers in the discrete-time domain have tried to study the effect of fractional delay in NCSs. The compensation of fractional delays occurring within the network is still an open research problem in NCSs in discrete-time domain. Apart from these, the controllers were designed based on the time delay approximation technique without considering the effect of uncertainty. Further, the control algorithm is implemented through digital processor and the communication is also carried out in digital signal form. This motivates the authors to explore the Discrete-Time SMC algorithm which compensates the fractional delay occurring within the network even in the presence of system uncertainties and disturbances.

This thesis presents novel algorithms for designing Discrete-time Sliding Mode Controller (DSMC) for NCS having both types of fractional delays i.e. deterministic and random alongwith different packet loss conditions i.e. single packet loss and multiple packet loss and matched uncertainty.

3. Summary of the Research Work

This thesis contributes mainly following:

- Firstly, a novel discrete-time sliding surface is proposed using the compensated state information and proposed a design of discrete-time sliding mode controller that encompasses deterministic type fractional delay and single packet loss. The Thiran's approximation technique is used for compensating the deterministic type of fractional delays. Two types of Discrete-time Sliding Mode Controllers are proposed that is Switching type and Non-switching type DSMC. The conditions for stability of the closed loop system using proposed controller are derived using the Lyapunov approach. The algorithms are checked with simulation also validated by the experimental results on servo system for various performance parameters. The proposed algorithms are also compared with conventional sliding mode controller using CAN and Switched Ethernet as network medium. The robustness properties of the algorithm are also checked with slowly varying matched uncertainties.
- The above algorithms use the state information for the controller design but in most of the control scenario only the output information is available. The thesis incorporates the multi-rate output feedback approach for the state estimation in the closed loop. The proposed multi-rate output feedback discrete-time sliding mode controller also performs well in the networked environment.
- Next, the thesis proposes the discrete-time sliding surface design for the random fractional delay and single packet loss that occur within the sampling period. The random delay is compensated using Thiran's approximation technique in the presence of packet loss situation. The random fractional delay is modelled by Poisson's distribution function and Packet loss are modelled by Bernoulli's function. The closed loop stability is proved using the Lyapunov function. The efficacy of proposed novel non-switching type of DSMC is endowed by simulation results and also experimentally validated by servo system.
- Further, the proposed algorithms extended for the random fractional delay with multiple packet loss situation. The simulation as well experimental results with various fractional delay situation and matched uncertainties show the efficacy of the proposed algorithms.

4. Proposed Contents of the Thesis

The outline of the thesis is as follows:

- **Chapter – 1** briefs about introduction and literature survey for NCS. The chapter discusses a brief introduction of NCS with conceptual model and different stuctures of NCS. Various issues related to NCS are also discussed.
- **Chapter – 2** discusses the Preliminaries of Networked Control System and Sliding Mode Control. In this chapter a basic block diagram of NCS with different types of time delays that affect the performance of the system are discussed. The origin of sliding mode controller in continuous-time domain and discrete-time domain are also briefly discussed. Lastly, various challenges of NCS with SMC are also highlighted.
- The main contribution of thesis design of discrete-time sliding mode control for deterministic type fractional delay is mentioned in **Chapter – 3**. In this chapter, the compensation of determinitic fractional delay is studied through Thiran's Approximation in the sliding surface. The discrete-time sliding mode control law is derived using proposed sliding surface with switching type reaching law. Further, the stability of the closed loop NCS is proved through Lyapunov approach. The efficacy of the proposed algorithm is tested under simulation enviornment and experimental enviornment.
- **Chapter – 4** briefs about the designing of non-switching type discrete-time sliding mode controller in the presencce of deterministic fractional delay and matched uncertainty. In this chapter, the design of control law is based on sliding surface derived using Thiran Approximation. Further, the stability of the closed loop NCS is proved through Lyapunov approach that ensures the finite time convergence of system states within the specified band. The efficacy of the proposed algorithm is tested under simulation enviornment, experimental enviornment and real-time networks.
- **Chapter – 5** describes the design of discrete-time sliding mode control using multirate output feedback approach with fractional delay compensation. In this chapter, the control signal is computed based on the output measurements available at the controller side and the fractional delay is compensated using Thiran approximation. The stability of the closed loop NCS with derived control law is proved using Lyapunov approach. The simulation results are carried out in the presence of network delay and matched uncertainty in order to prove the effectiveness of proposed algorithm.
- **Chapter – 6** describes the design discrete-time sliding mode controller for random communication delay and packet loss. In this chapter, the compensation of random fractional delay is studied using Thiran's Approximation with packet loss condition. The mathematical models of random fractional delay and single packet loss are derived using stochastic approach. The derived discrete-time sliding mode control

law is verified through simulation and implementation results in the presence of random fractional delay, packet loss and matched uncertainty.

- **Chapter − 7** discusses the mathematical model of multiple packet loss and design of discrete-time sliding mode control for multiple packet transmission. In this chapter, the discrete-time sliding mode control law is designed in the presence of multiple packets transmission. The multiple packet loss is modelled using probability function. The efficiency of the proposed algorithm is verified through simulaton and experimental results.
- The concluding remarks along with future scope and challenges are mentioned in **Chapter − 8**. In this chapter, final comments and future scope of discrete-time SMC algorithms are discussed. Lastly, various challenges are also listed that are still remain unsloved in network control system domain.

5. Conclusion

In this thesis, a novel idea of compensating the fractional delay in the sliding surface is introduced. The effect of fractional delay generated in NCS due to the presence of the communication medium is compensated using Thiran approximation technique. The sliding surface designed so that it slides along the predetermined surface according to fractional delays. Using this novel approach, a switching-type discrete-time networked sliding mode controller is designed which computes the control sequences in the presence of deterministic fractional delay and matched uncertainty. The stability of the closed loop system is assured by using Lyapunov approach. The efficacy of the proposed algorithm is tested on DC Servo motor setup with different network delays and external disturbances. The results were also compared with the conventional SMC. It is concluded that the fractional delay approximated using Thiran approximation is more efficient technique as it compensates the fractional networked delays then conventional discrete-time sliding mode control. The major drawback of switching type discrete-time sliding mode controller is that it generates more chattering. So, to overcome this issue a non-switching type discrete-time sliding mode controller is designed such that system states slide along the proposed compensated surface and maintain within the specified band. The stability of the closed loop system is assured using Lyapunov approach through proposed control law. The efficacy of the proposed algorithm is tested through illustrative example as well as DC servo motor setup with different deterministic fractional delays and matched uncertainty. The results were also compared with switching type SMC as well as conventional SMC. It is concluded that non-switching type SMC provides faster convergence without increasing the amplitude of control signal and offers better fractional delay compensation than switching-type SMC and conventional SMC. The efficacy of the proposed control algorithm is also tested under real-time networks using True-Time simulator. The performance of the control algorithm is checked using CAN and Switched Ethernet as a network medium in the presence of packet loss condition.

The concept of Thiran Approximation is further extended with Multi-rate Output feedback approach in which the sliding surface and control law are computed based on availability of the output information. The main advantage of using multirate output feedback approach is that the system states are computed using the output information available and the error between actual and estimated state variables becomes zero exactly after one sampling instant. Using this novel approach a multirate output feedback discrete-time networked sliding mode control law is derived that compute the control sequences in the presence of deterministic fractional delay and matched uncertainty. The stability condition of closed loop NCSs is derived using Lyapunov approach that ensures finite time convergence of system states in presence of network non-idealities. The effectiveness of the proposed algorithm is examined under different possible conditions through illustrative example.

Further, the concept of Thiran Approximation is examined for random fractional delays with single packet loss situation. The random fractional delay is modelled using Poisson's distribution function and packet loss is modelled using Probability distribution function. The discrete-time sliding mode controller is designed using compensated sliding surface in the presence of random fractional delays, packet loss and matched uncertainty. The stability of the closed loop system is derived that ensures finite time convergence in the presence of random fractional delay, packet loss and matched uncertainty. The effectiveness of the proposed control algorithm is examined through DC servo motor setup under random fractional delay and packet loss. The results proved that the control law derived using Thiran's Approximation compensates random fractional delay accurately even in the presence of single packet loss with probability of 30% as well as networked delays having values greater than sampling interval.

Lastly, the same concept is extended for random fractional delay with multiple packet loss situations. The multiple packet loss is also modelled using Probability distribution function while random fractional delay is modelled using Poisson's distribution. The discrete-time sliding mode control law is derived that compensates the effect of random fractional delay with multiple packet loss using compensated sliding surface. The stability of the closed loop NCS is assured through Lyapunov approach under multiple packet transmission. The efficiency of proposed control algorithm is verified through same DC servo motor plant under random fractional delay, multiple packet loss and matched uncertainty. The results proved that the proposed control law works efficiently and compensates the effect of random fractional delay even in the presence of multiple packet loss with probability of 20% as well as networked delays greater than sampling interval.

Patent, Publications and Acknowledgements

• Indian Patent

1. **A J Mehta**, **D H Shah**, **H A Mehta** and **R D Shah**, *Discrete-Time Sliding Mode Controller for Networked Control System with Random Fractional Delay*, **Application No. 201721015486**, May, 2017.

• Papers in Referred Journals

1. **D H Shah** and **A J Mehta**, *Fractional delay compensated discrete-time SMC for networked control system*, Digital Communication and Networks, Elsevier, Vol. 3, No. 2, May 2017, pp. 112-115.

2. **D H Shah** and **A J Mehta**, *Discrete-Time Sliding Mode Controller Subject to Real-Time Fractional Delays and Packet Losses for Networked Control System*, International Journal of Control, Automation and Systems, Springer, Vol. 15, No. 6, Dec.-2017, pp. 2690-2703.

3. **D H Shah** and **A J Mehta**, *Discrete-Time Sliding Mode Control with Disturbance Estimator for Networked Control System*, International Journal of Systems, Communication and Control , Inderscience, Under Review.

4. **D H Shah** and **A J Mehta**, *Discrete-Time Sliding Mode Control for Networked Control System with Random Fractional Delay and Packet Loss*, International Journal of Systems, Communication and Control , Inderscience, Under Review.

• Presentations in Conferences

1. **D H Shah** and **A J Mehta**, *Robust Controller Design for Networked Control System*, IEEE International Conference on Computer, Communication and Control Technology **(I4CT-2014)**, LangKawi, Malaysia. (ISBN- 978-1-4799-4555-9), Vol. 2, pp. 385-390, Sept. 2014.

2. **D H Shah** and **A J Mehta**, *Output Feedback Discrete-Time Networked Sliding Mode Control*, IEEE International Workshop on Recent Advances in Sliding Modes **(RASM-2015)**, Istanbul, Turkey. (ISBN-978-1-4799-8948-5), Vol. 1, pp. 143-150, April 2015.

3. **D H Shah** and **A J Mehta**, *Multirate Output Feedback Based Discrete-Time Sliding Mode Control for Fractional Delay Compensation in NCSs*, IEEE International Conference on Industrial Technology, Toronto, Canada **(ICIT- 2017)**, Torronto, Canada, (ISBN-978-1-5090-5319-3), pp. 848-853, March 2017.

4. **D H Shah** and **A J Mehta**, *Discrete-Time Sliding Mode Control Using Thiran's Delay Approximation for Networked Control System*, Submitted to 43rd Annual Conference of the IEEE Industrial Electronics Society, **(IECON- 2017)**, Beijing, China, pp. 3025-3031, Nov. 2017.

- **Acknowledgements**

1. Received International Travel Grant from Science Education and Research Board (SERB), New Delhi of 1 Lac to present the research paper in IEEE International Conference on Computer, Communication and Control Technology (I4CT-2014), Langkawi, Malaysia, 2014.

2. Received Partial Grant from Gujarat Technological University in the form of registration fees to present the research paper in IEEE International Conference on Industrial Technology (ICIT-2017), Toronto, Canada, 2017.

Bibliography

[1] R. Luck and A. Ray *"Delay compensation in integrated communication and control systems: conceptual development and analysis"*, Proceedings of American Control Conference (ACC90), May, 1990, pp. 2045-2050.

[2] R. Luck and A. Ray *"Delay compensation in integrated communication and control systems: implementation and verification"*, Proceedings of American Control Conference (ACC90), May, 1990, pp. 2051-2055.

[3] Z. Yu, H. Chen and Y.Wang *"Control of network system with random communication delay and noise disturbance"*, Proceedings of Control and Decision Conference, May, 2000, pp. 518-526.

[4] H. Chan *"Closed loop control of a system over a communication network with queues"*, International Journal of Control, Vol. 62, No. 3, 1995, pp. 593-501.

[5] D. Kim, J. Ko and P. Park *"Stabilization of the asymmetric network control system using a deterministic switching system approach"*, Proceedings of the 41st IEEE Conference on Decision and Control (CDC 02), 2002, pp. 1638-1642.

[6] L. A. Montestruque and P. J. Antsaklis *"On the model-based control of networked systems"*, Automatica, Vol. 39, No. 10, 2003, pp. 1837-1843.

[7] J. Nilsson, Bo Bernhardsson and Bjorn Wittenmark *"Stochastic Analysis and Control of Real Time Systems with Random Time Delays"*, Elsevier, Vol. 2, No. 3, 1997, pp. 13-20.

[8] Liqian Zhang, Yang Shi, Tongwen Chen, and Biao Huang *"A New Method for Stabilization of Networked Control Systems With Random Delays"*, IEEE Transactions on Automatic Control, Vol. 50, No. 8, 2005, pp. 1177-1181.

[9] Jiawei Dong and Won-jong Kim *"Markov-Chain-Based Output Feedback Control for Stabilization of Networked Control Systems with Random Time Delays and Packet Losses"*, International Journal of Control, Automation, and Systems, Vol. 10, No. 5, 2012, pp. 1013-1022.

[10] Fuwen Yang, Zidong Wang, Y. S. Hung, and Mahbub Gani *"H-infinity Control for Networked Systems With Random Communication Delays"*, IEEE Transactions on Automatic Control, Vol. 51, No. 3, 2006, pp. 511-518.

[11] Yang Shi and Bo Yu *"Output Feedback Stabilization of Networked Control Systems With Random Delays Modeled by Markov Chains"*, IEEE Transactions on Automatic Control, Vol. 54, No. 7, 2009, pp. 1668-1674.

[12] H. Gao, T. Chen, J. Lam,*"A new delay system approach to network-based control"*, Automatica, pp. 39-52, 2007.

[13] Heran Song, Shih-Chi Chen, and Yeung Yam*"Sliding Mode Control for Discrete-Time Systems With Markovian Packet Dropouts"*, IEEE Transactions on Cybernetics, 2016, pp. 1-11.

[14] N. T. Cac, N. X. Hung, N. V. Khang, *"CAN- based networked control systems: A compensation for communication time delays"*, American Journal of Embedded Systems and Applications, Vol. 2, No. 3, 2014, pp. 13-20.

[15] Y. Hikichi, K. Sasaki, R. Tanaka, H. Shibasaki, K. Kawaguchi, and Y. Ishida, *"A Discrete PID Control System Using Predictors and an Observer for the Influence of a Time Delay"*, International Journal ofModeling and Optimization, Vol. 3, No. 1, Feb.- 2013, pp. 1-4.

[16] B. del-Muro-Cuellar, M. Velasco-Villa, G. Fernat'ndez-Anaya, O. Jimet'nez-Ramt'irez and J. At' lvarez-Ramt'irez, *"Observer-Based Prediction Scheme for Time-Lag Processes"*, Proceedings of American Control Conference, June- 2007, pp. 639-644.

[17] M. Ono, N. Ban, K. Sasaki, K. Matsumoto and Y. Ishida, *"Discrete Modified Smith Predictor for an Unstable Plant with Dead Time Using a Plant Predictor"*, International Journal of Computer Science and Network Security, Vol.10 No.9, Sept. 2010, pp. 80-85.

[18] G. Jacovitti and G. Scarano, *"Discrete Time Techniques for Time Delay Estimation"*, IEEE Transactions on Signal Processing, Vol. 41, No. 2, Feb. 1993, pp. 525-533.

[19] M. A. Khanesar, O. Kaynak, S. Yin, H. Gao, *"Adaptive Indirect Fuzzy Sliding Mode Controller for Networked Control Systems Subject to Time Varying Network Induced Time Delay "*, IEEE Transactions on Fuzzy Systems, Feb. 2014, pp. 1-10.

[20] J. Xiong and J. Lam, *"Stabilization of Networked Control Systems With a Logic ZOH"*, IEEE Transactions on Automatic Control , Vol.54, No.2, Feb. 2009.

[21] J. Hespanha, P. Naghshtabrizi, Y. Xu,*"A survey of recent results in networked control systems"*, Proceedings of the IEEE, Vol. 95, No. 1, pp. 138-162, Jan.2007.

[22] W. Yang, L. Fan and J. Luo,*"Design of Discrete Time Sliding Mode Observer in Networked Control System"*, 2010 Chinese Control and Decision Conference, pp.1884-1887, July 2010.

[23] H. Li, H. Yang, F. Sun and Y. Xia,*"Sliding-Mode Predictive Control of Networked Control Systems Under a Multiple-Packet Transmission Policy"*, IEEE Transactions on Industrial Electronics, Vol.61, No.11, pp.201-221, Nov. 2014.

[24] D. Yue, Q. L. Han, J. Lam, *"Network-based robust Hinf control of systems with uncertainity"*, Automatica 41, pp. 999-1007, 2005.

[25] A. Argha, L. Li, W. Su Steven, and H. Nguyen, *"Discrete-Time Sliding Mode Control for Networked Systems With Random Communication Delays"*, Proceedings of American Control Conference, pp. 6016-6021, July 2015.

[26] J. Zhang, J. Lam and Y. Xia, *"Output feedback sliding mode control under networked environment"*, International Journal of Systems Science, vol. 44, no.4, pp. 750-759, 2013.

[27] Han Yu and Panos J. Antsaklis, *"Event-Triggered Output Feedback Control for Networked Control Systems using Passivity: Time-varying Network Induced Delays"*, IEEE Conference on Decision and Control and European Control Conference, pp. 205-210, 2011.

[28] Jinhui Zhang and Yuanqing Xia, *"Networked predictive output feedback control of networked control systems"*, IEEE Conference on Chinese Control Conference, pp. 205-210, 2011.