CHAPTER 1

INTRODUCTION

CHAPTER OUTLINE

This chapter is arranged in the following way. In Section 1.1 research background and motivation are addressed. The detailed literature survey is done in section 1.2. The research objectives are discussed in Section 1.3. It also summarizes the significance, contribution and research methodology of this thesis.
Chapter-1: INTRODUCTION

1.1 Background

Control science is an area of study that provides a mean to produce algorithms which make the systems (or plants) to behave in a desirable manner. It addresses the stability and performance of the system which is characterized by error size and the tendency of errors to grow or converge. However, use of these tools of control science to produce good control system designs is met by a number of obstacles. Two major difficulties to be dealt in this work are uncertainties and nonlinearities in the input-output representation of the plants [1-3]. Control system design relies on mathematical representations of systems that characterize how the real systems evolve in time for given situations (initial conditions) and external stimulus (inputs). For the designing of a control strategy to attain the desired performance, an accurate and precise mathematical model of the physical system is required and it is a non trivial task to obtain such an effective model for most of the physical systems, as some system characteristics are difficult to be derived mathematically with specified level of accuracy. There will typically be discrepancies between the actual plant and the mathematical model developed for controller design. These inaccuracies can be due to uncertainties regarding system dynamics, finite dimensional representation, linearization, model reduction, neglected secondary dynamics, or unforeseen system changes. In addition to uncertainty in the system dynamics, there is often also uncertainty in the environment where the system is operating. Controller designing aspects related with the control of systems having uncertain or unmodelled dynamics is being treated as a challenging issue in the control theory.

Model uncertainty can be broken down into parametric uncertainty (structured uncertainty) and unstructured uncertainty [3]. Parametric uncertainty is often easier to characterize. For example, the inertia of the flexible link may be known to lie between a lower and upper amount. An example of unstructured uncertainty is unmodelled dynamics (i.e. actuator dynamics or higher flexible modes). These uncertainties play a vital role as far as the stability and other performance aspects of the system are concerned and are therefore required to be considered while designing a controller. In few cases, the statistical characterization of the uncertainties in the plant dynamics may be approximated and some norm bounded constraints may be applied to the uncertainties, however it results in a conservative controller design [4-7]. In many systems, the cancellation of nonlinearities is not exact due to modeling inaccuracies,
uncertainties, the existence of immeasurable states and time lags. Also the linear time invariant controllers designed for the linearized model of the nonlinear systems, either through coordinate transformation or nonlinearity cancellation, do not offer an efficient and accurate control as the considerable nonlinear states are been neglected. This may have serious consequences if such hidden nonlinear modes are not adequately controlled. In such conditions intelligent controllers have to be implemented. Adaptive control has been believed as a breakthrough for realization of intelligent control systems. Even with the parametric and model uncertainties, adaptive control enables the control system to monitor the time varying changes and manipulate the controller for desired performance. The closed-loop stability of an adaptive control system is established by Lyapunov's second method. The advantages of adaptive control come from the fact that adaptive controllers can adapt themselves to modify the control law based on estimation of unknown parameters by recursive identification algorithms. Hence the area of adaptive control has close connections with system identification, which an area is aiming at providing and investigating mathematical tools and algorithms that build dynamical models from measured data [8-12].

Time delay, either in state or in control input is another serious practical problem which severely affects the performance of the dynamic systems. Time delays are found to exist in many dynamic systems e.g. chemical processes, rolling mill, biological systems, metal cutting process etc. Time delay occurs in physical systems due to so many reasons like finite capability of information processing among various parts of system, inherent phenomenon like mass transfer flow and recycling and /or byproduct of computational delay [13-15]. Existence of time delay may lead towards the oscillations, degradation in the performance or even sometimes to instability. There may be single point delay or multiple point delay present in the system. Discussions on delays and their effect on stabilization /destabilization of control systems have attracted the interest of several researchers in recent years [13-18]. Mainly the results cited in the literature are based on two approaches: Lyapunov-Krasovskii theorems based approach and Razumikhin theorem based approach. The results obtained are having a variable degree of conservatism. Controller design for time delay systems have widely been considered in last few years.

In most of the practical systems, the magnitude of control signal is always limited to a certain range due to the physical input saturation on actuators. Actuator saturation is the potential problem control system which often severely limits the system performance, giving rise to
inaccuracy or even leading to instability. This issue even becomes more sensitive if the control effort approaches to its maximum value and last at that value for a longer time span as it may damage the actuator. The development of adaptive control schemes for the systems having input saturations has been a task of major practical interest as well as theoretical significance. Few control strategies for the systems having input constraints are cited in the literature. These techniques are based on augmentation of base line control scheme with additional control components to deal with actuator saturation. Most of the research in this topic is focused on one of the strategies:

1. Model predictive control: Actuator saturation is dealt as constraint of optimization at each iteration [19,20].
2. Antiwindup control: The principle controller is augmented with some additional dynamics to counteract the negative consequences of saturation [21,22].
3. The Design of modified state feedback controllers such that the stability is guaranteed even under condition of saturation or reshaping of control law so that saturation does not occur at all [23].

Designing of tracking controller is an active area of research since last decade; the problem is addressed by several researchers for various classes of linear and nonlinear systems. Most modern nonlinear design techniques are developed assuming state feedback, which means that measurements of all states are available. However, in practical control problems, usually not all states are measured due to economical or technical reasons. Thus, observer design techniques are needed to implement state-feedback control by output feedback. For several processes only output is available for measurement due to inherent characteristics of the plant or unavailability of feasible sensor locations. In such cases, controller strategies rely on output feedback or construction of a state estimator (observers) which estimates the states of the plant. Schemes dealing with output feedback control and observer based control are cited in the literature for various classes of the systems [23-28]. Designing an observer is equivalent to derive a system which is driven by output measurement $y$ of original system and reconstruct the system states $\hat{x}$ in an asymptotic manner to track the state of the original system.

In the case of linear systems, both the well known Kalman filter and its deterministic analogue realized by Luenberger's observer, offer a comprehensive solution to the problem under consideration. However, most chemical and physical processes are inherently nonlinear and
nonlinear observers need to be designed that are capable of directly coping with the process nonlinearities. The nonlinear observer design problem is much more challenging and has received a considerable amount of attention in the literature leading to various approaches with different methodological characteristics [29,30]. In the field of nonlinear systems, the nonlinear observer design problem is much more complicated and so far there is no systematic complete solution found. However there have been constant attempts to attack the problems from different angles. Notably, there are four main approaches: Lyapunov-based observer design approach, linearization approach, structure-based high-gain observer design approach, Kazantis and Kravaris approach. Nonetheless, there is still no systematic and complete versatile approach existing to deal with general nonlinear observer design problem. Each of these approaches can only deal with certain class of systems.

Observers may broadly be classified in two categories; Full order observer and reduced order observer. Full order observer estimates all the states of the system and is useful for such systems where only the output of the system is available for the measurement. There exist certain systems where it is feasible to measure some of the states while the remaining ones are not measurable. Such systems need an observer design to estimate only unmeasured states so as to have high system efficiency and accuracy. For such systems, second category of observers is introduced, named as reduced order observer [32-36].

Designing of an observer for systems having unknown dynamics is an active area of research. Such observers, referred as adaptive observers, mainly emphasizes on simultaneously estimating the unknown states and uncertainties of a class of nonlinear systems. An adaptive observer performs the role of state estimation as well as parameter identification. It comprises two coupled algorithms for the tasks. The state estimation algorithm works under unknown parameters, where updated parameters are used for estimating state variables. The parameter identification algorithm is also based on measured outputs and estimated states. Various adaptive observer methods have been introduced for nonlinear systems with unknown parameters. The conventional design approach for adaptive observer mainly emphasizes on the designing of the observers for the systems where uncertainties follow Lipschitz condition, however it results in a conservative observer design and is applicable to limited class of systems. Designing of adaptive observers which uses approximation tools like Neural Networks (NN) or Wavelet Neural Networks (WNN) for system identification is new domain of research in the field of observer
design. Use of these system identification tools relaxes the Lipschitz restriction and hence it enhances the class of uncertain nonlinear systems under consideration. Owing to the universal approximation property of these identification tools, the results provided by these observers are highly accurate in comparison to conventionally designed adaptive observers.

The problem of system identification is to estimate the underlying system characteristics using empirical input-output data from the system. Neural networks such as multilayer perceptrons have been proved as an efficient approximation tool due to their universal approximation property. They provide a generic black box functional representation and are capable of approximating any continuous function defined on a compact set in $\mathbb{R}^n$ with arbitrary accuracy. Due to these attractive features, neural networks are successfully employed in the control design; however there are certain difficulties associated with NN based controller design\[43,44\]. The basis functions are generally not orthogonal or redundant, i.e. the network representation is not unique and is probably not the most efficient one. Furthermore, the convergence of neural networks may not be guaranteed. Even when it exhibits a good convergence rate, the training procedure may still be trapped in some local minima depending on the initial settings. In addition, approximation errors and external disturbances cannot be efficiently attenuated. Hence, performance and even stability may not be guaranteed. Recently by combining the idea of neural networks and the merits of wavelets, a wavelet neural network was developed by Zhang and Benveniste \[45\]. Wavelet networks are feed-forward neural networks using wavelets as activation function. In wavelet networks, both the position and the dilation of the wavelets are optimized besides the weights. Due to their space and frequency localization properties, learning capability of WNN is superior to conventional neural networks. Training algorithms for WNN converge in smaller number of iterations than for conventional neural networks \[46-50\]. These WNN combines the capability of artificial neural network for learning ability and capability of wavelet decomposition for identification ability. Kreinovich has proven that wavelet neural networks are asymptotically optimal approximators for functions of one variable. Wavelet neural networks are optimal in the sense that they require the smallest possible number of bits to store for reconstructing a function within a precision $\epsilon$. Thus WNN based control systems can achieve better control performance than NN based control systems.

The major limitation of conventional WNN is its static characteristics which appear due to its feedforward nature. So these networks are not very effective under the frequently changing
operating conditions and dynamic properties as they cannot adapt rapidly under such circumstances. To overcome this problem, a feedback mechanism is inserted in conventional WNN giving rise to either Output Recurrent Wavelet Neural Network (ORWNN) or Self Recurrent Wavelet Neural Network (SRWNN). These recurrent networks combines the properties of recurrency with the convergence properties of WNN to solve the complex control problems [51-54].

Reinforcement learning (RL) is a class of algorithms for solving multi-step, sequential decision problems by finding a policy for choosing sequences of actions that optimize the sum of some performance criterion over time [55]. In RL problems, an agent interacts with an unknown environment. At each time step, the agent observes the state, takes an action, and receives a reward. The goal of the agent is to learn a policy (i.e., a mapping from states to actions) that maximizes the long-term return. Actor-Critic algorithm is an implementation of RL which has separate structures for perception (critic) and action (actor) [56-59]. Given a specific state, the actor decides what action to take and the critic evaluates the outcome of the action in terms of future reward (goal).

A two degree of freedom, two dimensional force model of metal cutting system is considered in this thesis to verify the effectiveness of the proposed strategy. A metal cutting process involves the continuous removal of material from the workpiece in the form of chips by feeding the cutting tool. However its multi-part assembly results in a complex dynamic structure, which is subjected to vibrations. These vibrations, known as chatter, must be suppressed to preserve surface finish, prevent tool and maintain the machining tolerances. There has been tremendous work done on the investigation of chatter mechanism and its suppression [60-63]. Few researchers have addressed this problem in their work and proposed certain strategies like appropriate model of the structures of machine tool, fixtures, tools, choosing appropriate tool geometric angles, spindle speed control, etc.

Recently, the advent of piezoelectric devices has attracted many researchers towards the applications of piezoactuators for metal cutting process [60]. Piezoactuators can rapidly expand and reach the nominal displacements on the order of microsecond, with an electrical voltage applied and pushing or pulling force can be excited with the large acceleration. The implementation of piezoactuators in the metal cutting process may suppress the undesirable chatter and provides high-precision positioning control.
In order to design an accurate control schemes for the chatter suppression by using piezoactuators, the exact dynamics of the systems and the relationship between the cutting force and chip thickness has to be completely known. Many dynamic models and corresponding controllers for the metal cutting process have been presented in the literatures [60-61]. Rather than using the commonly accepted linear Merchant model, the relationship of cutting force variation and chip thickness variation is treated as a hysteresis model, which has been proved to be able to explain the nonlinearity of the turning metal cutting process in a way that is much more accurate. In this case, the turning cutting systems can be described as a class of uncertain systems with hysteresis and time delay. The relationship between the cutting force and chip thickness fluctuation is treated as a hysteresis model. Hysteresis has been recognized as one of the factors that cause chatter in metal cutting process. Hysteresis is very complicated, nonsmooth nonlinearity which makes the controller design and analysis a complicated task. In addition, the effect of time delay, unavoidably resulting from the regenerative chatter effect of turning, is another major factor to be considered. Obviously, the combination of the hysteresis and time delay has proposed a challenging topic for the controller design in metal cutting process. In this work an adaptive full order and reduced order observer is proposed for metal cutting process. The WNN is implemented to approximate the uncertainties present in the system.

These motivate us to consider the designing of WNN observer based adaptive tracking controller for a class of uncertain nonlinear delayed systems subjected to actuator saturation using reinforcement learning. WNN are used for approximating the system uncertainty as well as to optimize the performance of the control strategy. The effectiveness of the proposed control scheme is verified through simulation on a two degree of freedom metal cutting process.

1.2 Literature Review

The problem of state reconstruction for linear deterministic systems with known dynamic models was dealt by Luenberger [1-3]. The idea was further developed for uncertain systems by other researchers.

X. He et. al.[4] considers the problem of constructing a reliable tracking controller such that the output of resulting of closed-loop linear systems asymptotically tracking reference output. The main results are a sufficient condition for the existence of such a controller and the design...
method of this controller. T.R. Oliveira et. al.[5] proposed an output feedback sliding mode controller for linear uncertain systems with unknown control direction based on monitoring functions. Nonlinear systems were also considered but restricted to output dependent nonlinearities. Global or semi-global exact output tracking was obtained.

Z. Yun et.al.[6] investigated the output-feedback stabilization control problem for a class of nonlinear uncertain systems. An observer is designed to estimate the system states using integral backstepping approach together with completing square technique. The output-feedback stabilization control is constructively designed such that the closed-loop system is asymptotically stable. P. Pagilla and Y. Zhu [7] proposed observer design for Lipschitz nonlinear systems. But it is applicable only to a certain class of nonlinearities which satisfies Lipschitz condition.

K. M. Chang [9] proposed a model reference adaptive control for uncertain systems with sector-like bounded nonlinear inputs, which is a conservative and bounded solution. H. Zhaobin and C. Li [10] implemented the adaptive control schemes to a free floating dual arm space robot system in joint space to verify the effectiveness of adaptive control technique.

G. S. Chen et. al.[11] presented a robust control designs of a complex nonlinear system which can be modeled by a dynamic neural network. Two kinds of new $H^\infty$ control design methods are developed. One tries to attenuate both modeling error and the external disturbance to a prescribed level via the $H^\infty$ control term, the other tries to attenuate the external disturbance only via the $H^\infty$ control, whereas the modeling error is dealt with by a sliding mode control term.

M. Stefanovic and M.G. Safonov [12] A formal theoretical explanation of the model-mismatch instability problem associated with certain adaptive control design schemes is proposed, and a solution is provided. To address the model-mismatch problem, a primary task of adaptive control is formulated as finding an asymptotically optimal, stabilizing controller, given the feasibility of adaptive control problem.

E. Fridman and U. Shaked [13], P. Gongyou et. al.[14] and M.S. Mahmoud et. al.[15], have discussed the complexities like chaotic behavior, destabilization and other complex nonlinearities induced by the presence of delay either in state or input or in both and also presented an optimal tracking control design of for linear time delay systems. While Z.G. Zhang
et. al.[16] and R. Kojima et. al.[17] implemented the controller strategy for the delayed systems to real time systems like Quadruped Robot and Micro UAV to illustrate the effectiveness of the proposed control solutions. M. Wang and S. S. Ge [18] extended the design of controller for delayed systems to a class of pure-feedback nonlinear systems with multiple unknown time-varying delays.

M. Chen et. al.[19], N. Takagi et. al.[20], F. Morabito et. al.[21] and J. Zhou et.al.[22] have discussed the control strategies to deal with actuator saturation like model predictive control, antiwindup strategy and reshaping of control law to avoid saturation. The strategy proposed in [19,20] is based upon the augmentation of baseline controller with additional dynamics developed in order to recover the lost part of the system states during the saturation state of the actuator so as to avoid the detuning of controller parameters. Proposed scheme is computationally complex and somewhat better results than the proposed ones can be obtained by incorporating some intelligent tools like neural network etc. Scheme proposed in [21-22] utilizes the dynamic error based control component deal with actuator saturation basic limitations of the proposed schemes is that they require the complete knowledge of input and output of actuator, however actuator output is not available in several real time control systems.

H. Lens and J. Adamy [23] proposed a design method for observer based linear control of linear time invariant (LTI) systems subjected to input constraints. A state feedback controller is proposed to assure the stability of the system even under saturation or such that the saturation does not occur at all.

Z. Yun et. al.[24], Y. Zhu and P. R. Pagilla [25] and D. Y. Li and M. S. Wei [26] proposed an observer controller strategy for nonlinear uncertain systems. The proposed observers are adaptive in nature so as to incorporate the uncertainties present in the systems. H. Bouadi, and M. Tadjine[28] and F. Abdollahi et. al.[31] verified the efficiency of the proposed adaptive nonlinear observers by implementing the design to real time systems. N. Kazantzis and R. A. Wright[30] extended the design for the delayed output measurements. The observer schemes presented in [24-31] are full order where it is assumed that none of the states are available for measurement. But in most of the real time problems few states are always measurable.
The reduced order observer solutions for the uncertain nonlinear systems are proposed by V. Sundarapandian [32], Z. F. Lai and D. X. Hao[33] and R. L. Mishkov [34]. The work in [32] is a geometric study of reduced order observer design for nonlinear systems which is applicable for Lyapunov stable nonlinear systems with a linear output equation. The error convergence for the reduced order estimator for nonlinear systems is established using the center manifold theory for flows. In [33] and [34], a reduced-order observer design method is developed under the assumption that a linear matrix inequality (LMI) has positive definite matrix solution and the reduced-order observer gain matrix is computed by the solution of LMI. By a linear transformation, a reduced-order observer which does not contain the information of the derivative of the system output is provided. G. Bartolini [36] proposed a reduced order observer design for nonlinear non-affine systems. The proposed design approaches in for adaptive observers for a class of nonlinear systems having Lipschitz nonlinearities and parametric uncertainties. Here the conservatism observed in the designing of conventional observers for nonlinear systems is relaxed to some extent but the proposed control strategy is applicable only to that class of nonlinearities which satisfy the linear in parameter condition.

F. Abdollahi et.al.[31] have developed an (NN) based observer for general multivariable nonlinear systems. The proposed observer uses a nonlinear-in-parameters neural network and can be applied to systems with higher degrees of nonlinearity without any a priori knowledge about system dynamics. The proposed tuning laws utilize signum function which may lead to the problem of chattering thereby degrading the performance of the system.

Combining the approximation properties of neural networks with the features of wavelets, Zhang and Benveniste [37] presented wavelet network as an alternative to feedforward neural networks for approximating arbitrary nonlinear functions. The characteristics of various wavelets are explored by S. G. Mallat [37], C. Cattani [38], M. Lai [39], O. Rioul and M. Vetterli [40], T. Flaherty and Y. Wang [41] and C. S. Burrus and J. E. Odegard [42]. K. S. Narendra and K. Parthasarathy [43] have explored the system identification capabilities of neural networks and implemented them to the control of uncertain nonlinear systems.

J. Zhang et. al.[44] and B. Delyon et.al.[46] have discussed the approximating properties and other salient features of wavelet networks. Due to their space and frequency localization...
properties, wavelet neural network outperforms multilayer perceptrons in dealing with curse of dimensionality and nonstationary signals and in faster convergence speed.

Polycarpou et al.[47], R.J. Wai and H.H. Chang [48] and C.F. Hsu et.al.[49] have presented wavelet based adaptive controller strategies for various uncertain systems. Wavelet networks are used for approximating functional uncertainties. Tuning laws are proposed for online tuning of wavelet parameters. The proposed strategy uses the backstepping technique and so the design strategy is confined only to those classes of nonlinear systems where the nonlinearities are differentiable up to the required order. A. Kulkarni and S. Purwar [50] proposed a wavelet based control strategy for nonregular systems with input constraints. However, the WNN has a disadvantage that it can be used only for static problems due to its feed forward network structure. That is, the WNN is not the most suitable in solving temporal problems like predicting the behaviors of complex chaotic systems.

S. J. Yoo et. al.[51,52], M. Li and D. Liu [53] and C. J. Lin and C. C. Chin [54] proposed a self recurrent architecture of WNN to overcome the limitations associated with conventional WNN. The proposed SRWNN is a modified model of the WNN which has a mother wavelet layer composed of self-feedback neurons. Since a self-feedback neuron can store past information of the network, it can capture the dynamic response of the system. This modification allows the SRWNN to be applied well to the complex chaotic systems, though the SRWNN has less wavelet nodes than the WNN. Thus, the structure of the SRWNN can be simpler than that of the WNN. Accordingly, the SRWNN is more suitable in real time control application than the WNN.

P. He and S. Jagannathan [55] proposed an optimal NN based observer design with an adaptive-critic-based neural network (NN) controller in discrete time to deliver a desired tracking performance for a class of nonlinear systems in the presence of actuator constraints. The adaptive critic NN controller architecture based on state feedback includes two NNs: the critic NN is used to approximate the "strategic" utility function, whereas the action NN is employed to minimize both the strategic utility function and the unknown nonlinear dynamic estimation errors. The critic and action NN weight updates are derived by minimizing certain quadratic performance indexes. The proposed reinforcement learning based design in [55] is further been implemented on real time systems in [56-59].
Chapter-1: INTRODUCTION

To verify the effectiveness of the proposed scheme, two degree metal cutting process, is also been considered in this thesis. J. Wang et. al.[60], S. E. Oraby and A. M. Alaskari [61] proposed a model of a turning process as a two degree-of-freedom uncertain system in order to suppress chatter in turning. A piezoactuator, the structure of which is independent of the tool holder in the machine, is introduced for the regulation of the cutting tool displacement. An adaptive control law is proposed which significantly eliminates the chatter phenomena. A comprehensive study of the frictional chatter occurring during metal–cutting process is given by M. Wiercigroch and A. M. Krivtsov [62]. A general mathematical model of the machine–tool–cutting process is established, and then a high-accuracy numerical algorithm is developed. A two-degree-of-freedom model of orthogonal metal cutting is also examined. A.H. Elsinawi and S. Emam [63] presented an active control of tool position in the presence of nonlinear cutting force and machine tool dynamics in orthogonal cutting.

1.3 Objectives and Approaches

The work was started with the following objectives:

1. Designing of wavelet adaptive full order observer based control scheme to assure the global asymptotic stability of a class of delayed uncertain nonlinear systems subjected to actuator saturation.

2. Designing of a reduced order observer for the same class of the system.

3. Use of wavelet network to mimic the uncertainties present in the system.


5. Inserting the recurrency in the WNN architecture to enhance the capability of WNN to approximate the uncertainties in the highly dynamic systems.

6. A robust control component is inserted to deal with wavelet uncertainties as well as external disturbances with unknown limit.

7. Designing of a wavelet based saturation compensator with an objective to reshape the control action whenever it tries to exceed the saturation limits thereby preventing the detuning of plant and controller variables. The saturation compensator will be augmented with baseline controller.

8. Delay independent control strategy due to which no additional control component is required with the baseline control which assures stability for any value of delay.
9. Verify the effectiveness of the proposed tracking control strategy to two degree of freedom, two dimensional model of metal cutting process through simulation.

To achieve the above goal, plan of action was:

i. Analytical study of the nonlinear systems with completely known dynamics and partially known dynamics which includes parametric and functional uncertainties, effects of various real time constraints like actuator saturation, time lag on the system performance. Analysis of the existing observer based control strategies for the above mentioned classes of nonlinear systems.

ii. Empirical analysis of various system identification tools like neural networks and wavelet neural networks in terms of their convergence time, accuracy and precision.

iii. Comparison of approximation properties of wavelet networks with different mother wavelets like Mexican hat, Shannon, Morlet etc. through a software simulation.

iv. Designing of wavelet adaptive observer (full order and reduced order) based control scheme for the system under consideration.

v. Designing of secondary control components like wavelet based adaptive saturation compensator, robust control term for the effective control of system.

vi. Designing of Actor- Critic architecture for the optimal WNN.

vii. Development of tuning laws for the online tuning of wavelet parameters through gradient descent technique.

viii. Development of a mathematical framework based on the Lyapunov-Krasovskii functional in order to prove analytically the global asymptotic stability of the concerned system with the proposed observer based control strategy.

ix. Carry out the simulation to illustrate the effectiveness of the proposed strategy.

x. Implementing the proposed control scheme to the model of a two degree of freedom metal cutting process to verify the feasibility of the proposed strategy through simulation.