CHAPTER 1

INTRODUCTION

1.1 RATIONALE

In the industrial world, process refers to an interacting set of operations that leads to the manufacture or development of some product. This end product must have certain specified properties which depend on the conditions of the reactions and operations that produce them. The control is used to create the steps necessary to assure that these conditions produce correct properties in the product. Therefore, one of the important objectives of the process control is to maintain the properties of a product at some specified values as the manufacturing process proceeds. Hence, some or all the variables of the process must be maintained at specific values.

Typical industrial chemical plants are tightly integrated processes which exhibit nonlinear behavior and complex dynamics properties. They usually have two or more controlled variables requiring two or more manipulated variables. Those processes with more than one controlled variable and more than one manipulated variable are known as Multi Input Multi Output (MIMO) systems.

The nonlinear, interacting nature of multivariable chemical processes necessitates the development of solid control methodologies that are capable of coping with both nonlinearities and interactions. However, in the process control field, the customary approach has been to neglect the
nonlinearities by approximating the nonlinear model by a linear one and to apply linear theory to design linear controllers. In the case of processes with significant nonlinearities, the linear analysis is valid only in an infinitesimally small neighborhood of the operating point. Recently, there has been a considerable effort to design controllers for nonlinear systems so that the closed loop response of a nonlinear system is exactly linear in a global sense. Input/output linearization involves finding nonlinear state feedback laws so that the input/output behavior of the closed-loop system is linear. In the case of Single Input-Single Output (SISO) systems, the problem is completely solved and explicit formulas for the input/output linearizing state feedback laws are available. In this work, the state feedback law is applied to a nonlinear process that is to be linearized. The different external linear controllers are used for setpoint tracking and rejection of disturbances. This yields a control structure called the Globally Linearizing Control (GLC) which responds like linear system (Kravaris and Chung 1987). This type of control is tried in this work for a MIMO nonlinear system with equal number of inputs and outputs.

For implementing Global linearizing algorithm to a MIMO process, the following important factors are to be considered:

- Relative order must be finite.
- Non-linear models to be fairly accurate.
- States are assumed to be measurable.
- Non-linear observers are difficult to design.
- The whole concept is based upon continuous time mathematics whereas most advanced control implementations are in discrete time.
Kravaris and Soroush proposed a control strategy which is called the MIMO globally linearizing control. This work reports the application of the decoupling and linearization control theory to two chemical control processes, a Level-Temperature cascaded process and a Level-pH cascaded process.

Compared with Single Input Single Output (SISO) counterparts, MIMO systems are more difficult to control due to the existence of interaction among input and output variables. For a MIMO process, interaction means when a parameter is varied, it will automatically affect other parameters (George Stephanopoulos 1999). The MIMO system can be decoupled into SISO systems by a suitable technique. In a decoupled SISO system, no interaction exists.

The decoupling and linearization algorithms are applicable to Induction motors, boiler systems, continuous stirred tank reactor (CSTR) systems and also can be extended to DRDO jet engine applications.

1.2 LITERATURE SURVEY

Willjuice Iruthayarajan and Baskar (2009) presented the performance comparison of Evolutionary Algorithms (EAs) such as Real Coded Genetic Algorithm (RCGA), Modified Particle Swarm Optimization (MPSO) of 2 inputs and 2 outputs process. Juan Garrido et al (2011) presented an extension of the inverted decoupling approach to quadruple tank plant. Input-Output pairing for linear and nonlinear multivariable system is proposed in Bijan Moaveni and Ali Khaki Sedigh (2007). Design of decoupling matrix for a multivariable Two Input-Two Output (TITO) process is presented by Francisco Vazquez and Fernando Morilla (2002). He also
proposed decentralized PID controller. The advantage of this methodology is that, it does not need a transfer function matrix with the system model but requires a representation with frequency response. Branislav Jevtovic and Miroslav Matausek (2010) explained about the ideal decoupler D(s) and PID controller optimization under constraints on the robustness and sensitivity to measurement noise. Also, he recommended this algorithm for Three input-Three output systems.

Qiang Xiong and Wen-Jian Cai (2006) demonstrated the concepts of energy transmission ratio effective relative gain, and equivalent transfer function matrix for a closed loop control system. The advantages of the method are, this design method is simple, straightforward, and easy to understand by field engineers and is embedded into the computer control systems. Arrieta et al (2010) developed a PID controller applied for CSTR system. Maghade and Patre (2012) developed a PI controller to two input-two output process including a level–temperature reactor.

Multivariable linearizing control approach has been designed by Cedric Damour et al (2011). Simulation results indicate that the proposed strategy improves setpoint tracking, even in presence of noise, disturbances and modeling error. But it is applied for the simple system. Prodromos Daoutidis et al (1990) methodology is successfully applied to a continuous polymerization reactor. In the work of Batool Labibi et al (2009), nonlinear model is linearized for its operating points.

Chang-Chieh Hang and Lisheng Cao (1996) have presented setpoint weighting technique to achieve a good reduction of the overshoot of the setpoint response without sacrificing the rise time. Ali et al (2012) compared the performances of BSC and GLC schemes designed on the
reaction invariants model of a pH process. Performance of the proposed GLC design based on reduced order model has been compared with that of adaptive back stepping controller.

Dynamic setpoint weighting is proposed by Rajani Mudia and Chanchal Dey (2011). Multi model decoupling procedure has been integrated into the GMC frame work by James and Peter (1997). Yudi Samyudia and Peter Lee (2004) presented a simple iterative approach to robust Generic Model Control with H infinity controller. Marshal et al (2001) Multi-Model Decoupling (MMD) procedure, has been integrated into the GMC framework. It is informed that the advantages of MMD-GMC over conventional GMC remained significant even with significant process / model mismatch for low to mid purity columns. Scott Flathouse and James Riggs (1996) proposed automatic tuning PID controller in Continuous Stirred Tank Reactor (CSTR), distillation column. In this work, GMC controller tuned with the Auto Tune Variation (ATV) tuning procedure is compared with a GMC controller with optimal tuning. Dunia and Edgar (1996) evaluated the basic GMC algorithm applied to single input single output linear processes and provided insight regarding its limitation to ensure robust stability. The effect of sampling time on the reference trajectory for discrete systems is analyzed to avoid unstable responses for perfect models. The IMC controller is used along with GMC. Adaptive Generalized Generic Model Control (AGGMC) is proposed by Wang et al (2003) for a class of nonlinear time-varying processes by use of a Modified Strong Tracking Filter (MSTF). It inherits all the advantages of Generic Model Control (GMC) and extends GMC to nonlinear time-varying processes with relative orders larger than one.

Massimiliano and Antonio (2010) proposed a methodology for the performance assessment and retuning of PID controllers for integral process.
Barraud et al (2009) analyzed the problem of controlling the pH, in a batch reactor where precipitation occurs. Halevi et al (1997) focused on the identification of the desired critical point which is the crucial part of the tuning process. Variety of modifications on the Z-N rules can be easily incorporated in the auto tuner. Truong Nguyen Luan Vu et al (2007) proposed an efficient method of designing multi-loop PID controllers. The proposed method uses a parameter tuning rule to effectively reduce the dimension of the search space used for finding the optimum PID parameters.


Thomas Kendi and Francis Doyle (1997) presented a multivariable approach to nonlinear anti-windup control. Rajni Jain and Vinopraba (2009) explained the implementation of conventional controller and multi model controller for a laboratory scale linear MIMO process. Problem of nonlinearity in MIMO systems is not handled efficiently using multi model based controller strategy. Xiang Li and Thomas Marlin (2011) developed a new robust MPC method to ensure feasible trajectories for feed forward and feedback control of uncertain dynamic systems based on a bi-level stochastic formulation for the optimization of closed-loop dynamics. Damir Vrancic et al (2011) presented the application of Multiple Integration (MI) technique
and Magnitude Optimum (MO) criterion in the control of multivariable processes by using inverted decoupling approach.

Weijie Wang et al (2009) proposed a tuning method for decentralized PI/PID with set-point weighting of 2 Degrees of freedom PI/PID controller. This technique is verified for 2x2, 3x3, and 4x4 models.

Alberto Herreros et al (2002) presented Genetic Algorithm (GA) for the class of multiobjective optimization problems that appear in the design of robust controllers. Valarmathi et al (2009) presented an application of Real-Coded Genetic Algorithm (RCGA) for system identification and controller tuning in process plants. The simulation result shows that the GA is able to tune the PID controller satisfactorily and able to regulate the set-point tracking with minimal overshoot and fast rise time in all the cases.

Tan et al (2005) described the use of Computational Intelligence (CI) techniques for designing a Wiener model controller to perform pH control. A Multiobjective Evolutionary Algorithm (MOEA) is employed to determine the parameters of the PID controller that are used to regulate the linearized pH plant. Son et al (2004) proposed a new genetic algorithm to select the optimal architecture of the neural network and compared with that of engineers experience.

Gibon et al (2000) proposed a methodology for observer synthesis for a class of chemical reaction processes. Incorporation of an observer into a state feedback controller results in output feedback controller. Abderraouf Gaaloul and Faouzi Sahli (2009) dealt with the control problem of a MIMO process represented by a quadruple tank process through the use of a recently proposed output feedback controller. Stefan Hui and Stanislaw Zak (2005) proposed two different classes of observers for systems with unknown inputs.
The work of Elom Domlan et al (2011) presented the application of a multiple model approach for the design of a soft sensor aiming at predicting the quality of the product of a separation unit in oil sands processing. Krzeminski and Kaczor (2004) presented the design of a perfect reduced order unknown input observer for standard systems. Yan Ming Fu et al (2004) dealt with the Unknown Input Observer (UIO) design problem for a class of linear time-delay systems. Based on these conditions and Lyapunov stability theory, two design algorithms are proposed.

Most of the researchers used Taylor series method to linearize the nonlinear system when working with nonlinear MIMO system extensively. Taylor series method is suitable for lower order interacting systems. For an interacting nonlinear MIMO system, nonlinear parameter is converted into the linear form by using Taylor’s series method. It can be used only for linearizing simple first order systems. It doesn’t work well with nonlinear interacting system.

The problem of nonlinearity in MIMO system is not handled efficiently using decentralized controller strategy. In the existing works, simple decoupling and linearization algorithm is implemented, which is not suitable for highly noninteracting systems. Also servo responses are not discussed. To overcome these difficulties we have proposed methods which effectively decouple the system and produce a linear representation in state space.

1.3 SCOPE OF THE RESEARCH

The main goal of this work is to apply decoupling and linearization algorithm for a complex nonlinear interacting systems like Level-Temperature cascaded process and Level-pH cascaded process. In the Level-Temperature
cascaded process desired level and temperature is maintained individually by overcoming the interaction between the inputs and outputs. Similarly in Level-pH cascaded process desired level and pH is maintained individually by overcoming the interaction between the inputs and outputs.

The nonlinearities of the processes are very difficult to model. So the scope is to work with the nonlinearities of the process. Different linearization techniques are available to linearize the nonlinear equations (Curtis Johnson 2011). Generally MIMO systems can be classified as linear interacting MIMO system and nonlinear interacting MIMO systems. RGA and RNGA algorithms are used to eliminate the interaction of linear interacting MIMO system. Kravaris algorithm, Generic Model Control algorithm and Hirschorn’s algorithms are used to eliminate the interaction of nonlinear interacting MIMO system.

So the accurate decoupling and linearization algorithm is developed in order to overcome the deficiency of the previously mentioned algorithms. Here due to uncertainty or sudden unmodeled disturbances in the system, are also tackled effectively.

The specific objectives of the research are as follows:

1. To apply the linearization algorithms to solve the interaction problem in the selected MIMO processes.
2. To apply the linearization technique for the problem of a linear interacting MIMO system.
3. To apply RGA and RNGA algorithms to the process and obtain the result in decoupled form.
4. To design a suitable Auto Tuning PID controller for this process and to analyze its performance.

5. To apply three different decoupling and linearization algorithms for two nonlinear interacting MIMO systems, namely the Level-Temperature cascaded process and the Level-pH cascaded process and compare their performance.

(i) Kravaris Decoupling and linearization algorithm developed by Kravaris is applied for the processes and the performance indices are analyzed. The suitable controllers like PI, PI-SPW and FLC are designed for obtaining the desired output, in the presence of disturbances.

(ii) Generic Model Control (GMC) algorithm is applied for the nonlinear interacting MIMO processes; and the performance indices are analyzed. The suitable controllers like PI, PI-SPW and FLC are designed for obtaining the desired output, in the presence of disturbances.

(iii) Hirschorn’s algorithm is designed, developed and implemented. Then PI, PI-SPW, MPC controllers are implemented for the linearized MIMO process and the performance is analyzed. Genetic Algorithm based controller is used along with Hirschorn’s algorithm for linearizing and decoupling of the above processes.
4. Kalman estimation technique is implemented to get an estimate of the output even in the presence of unmeasurable disturbances. By adapting Kalman estimation, it is easy to design a controller for future prediction due to any deviation of the estimated output from true output.

5. The presence of unknown state becomes a serious drawback when implementing a state feedback control law. Such difficulty can be overcome through the design of an appropriate observer to estimate the missing states of a system, using the knowledge of its input and output. The three different observers (Luenberger observer, Kalman observer and Unknown Input observer) are designed and implemented for the system, which is linearized and decoupled by a selected decoupling algorithm.

1.4 ORGANIZATION OF THE THESIS

The programme of activities that were undertaken in order to fulfill the objectives are, various decoupling and linearization algorithms were developed and implemented in the selected MIMO processes. The details of the research are presented in seven chapters. The overall organization of the research that describes the application of Decoupling and Linearization algorithms and controllers for MIMO processes is shown in Figure 1.1.
Chapter 1 gives a brief introduction to MIMO process and motivation behind this research, the objectives and review of the related work, which provides the basic foundation of the research. Here, the development of the MIMO process involving interaction between liquid level and temperature and liquid level and pH are presented. Detailed survey of literature on the various control strategies for MIMO process is also given.

Chapter 2 discusses two models that are taken up for the decoupling process. They are Liquid Level-Temperature cascaded Process and Liquid Level-pH cascaded Process. Both these processes are highly nonlinear and interacting processes.

Chapter 3 describes the basics of RGA and RNGA algorithm. It also shows the implementation of RGA and RNGA for the given system. Performance is improved by adding an Auto tuning PI controller. The simulation results are observed and tabulated.

Chapter 4 presents the basics of Kravaris decoupling and linearization algorithm. The simulation is carried out for the two selected process models. The performance evaluation is carried out by implementing PI, PI-SPW, FLC controllers. The simulation results are observed and tabulated for analyzing the performance of the system.

Chapter 5 explains the basics of GMC algorithm. The simulation is done for the two selected process models. The performance evaluation of the proposed controllers PI, PI-SPW, FLC are carried out. The simulation results are observed and tabulated for analyzing the performance of the proposed controller.

Chapter 6 elaborates the basics of Hirschorn’s algorithm. This algorithm is tested for its effectiveness through implementation in two
models. The performance evaluation is carried out by comparing the performances of PI, PI-SPW, MPC controllers and Genetic Algorithm. From the simulation results, the performance indices of the controller are observed.

Chapter 7 deals with the implementation of estimator and soft sensor techniques. After the linearization of Level-Temperature MIMO process using Hirschorn’s algorithm, estimation is carried out using the Kalman estimator. Also, soft sensor techniques like Luenberger observer, Kalman observer and Unknown Input observer are also used for the linearized model of an interacting thermal non-linear process. From the simulation results, the performance is analyzed based on the error between the real and observed output.

Chapter 8 concludes with suggestions and scope for future work in the similar area of research.