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FUZZY LOGIC CONTROL OF A LABORATORY MAGNETIC LEVITATION SYSTEM

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ABSTRACT

This paper deals with the Fuzzy Logic control of a Magnetic Levitation system [1] available in the Robotics and Control Laboratory at Duke University. The laboratory Magnetic Levitation system primarily consists of a metallic ball, an electromagnet and an infrared optical sensor. The objective of the control experiment is to balance the metallic ball in a magnetic field at a desired position against gravity. The dynamics and control complexity of the system makes it an ideal control laboratory experiment. The students can design their own control schemes and/or change the parameters on the existing control modes supplied with the Magnetic Levitation system, and evaluate and compare their performances. In the process, they overcome challenges such as designing various control techniques, choose which specific control strategy to use, and learn how to optimize it. A Fuzzy Logic control scheme was designed and implemented to control the Magnetic Levitation system. Position and rate of change of position were the inputs to Fuzzy Logic Controller. Experiments were performed on the existing Magnetic Levitation system. Results from these experiments and digital simulation are presented in the paper.

KEYWORDS

Magnetic Levitation System, Fuzzy Logic Control, Membership Functions.

INTRODUCTION

The Magnetic Levitation system used for the experiment was manufactured and supplied by M/S Feedback Ltd. of Crowborough, UK.

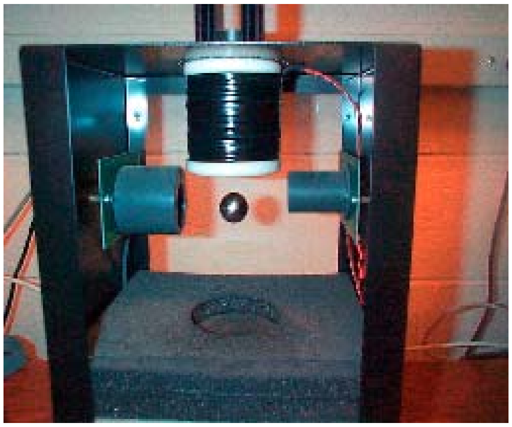

Figure 1: Photograph of the Magnetic Levitations System.

Figure 1 is a photograph of the Magnetic Levitation system. The schematic diagram of the system is shown in Fig. 2. The set up mainly consists of an electromagnet, a metallic ball and a photo sensor. The electromagnet exerts the electromagnetic force to balance the metallic ball in air against gravity and the photo sensor detects the position of the ball. Depending on the feedback error signal (the difference between the desired position and the instantaneous position), the current flowing through the electromagnet is increased or decreased appropriately to maintain the ball at the desired position. The non-linear dynamics of the Magnetic Levitation system makes the ball highly unstable.

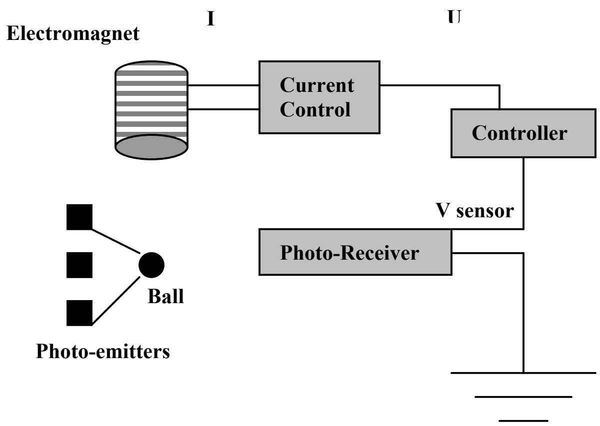

Figure 2: Schematic Representation of the Magnetic Levitation System.

Various conventional and unconventional control strategies [2, 3] can be applied to control the system. Here, Fuzzy Logic is used for controlling the Magnetic Levitation system. The system has been widely used in the past as a control laboratory experiment to illustrate and evaluate the performance of different control strategies. The main objective of this experiment is to introduce the students to both conventional as well as unconventional control techniques.

Course Description

This laboratory control experiment demonstration is designed to support courses at both graduate and undergraduate levels. At the graduate level it supports the course ME 230, Modern Control and Dynamic Systems. The major objectives of this course are to develop a facility with dynamic modeling, analysis and feedback control of complex physical systems. These are achieved by understanding the primary differences between linear and non-linear systems, methods of modeling, analysis, and design using the conventional and unconventional control techniques in both time and frequency domains, and applying the procedures currently in use for stability analysis and controller synthesis.

All laboratory sessions held at the Robotics and Control Laboratory are only for demonstration and do not carry any extra credits. These laboratory sessions consist of demonstration of both unconventional and conventional control strategies. The experiment described in this paper falls into the class of unconventional control techniques. The laboratory demonstration for control of a complex physical system (such as Magnetic Levitation System) that is non-linear in nature using the unconventional control technique (Fuzzy Logic Control) helps in achieving the course objectives mentioned earlier.

At the undergraduate level it supports the course ME 125, Measurement and Modeling of Dynamic Systems. The primary objective of this course is to develop competence in modeling, analysis, simulation, measurement and control of physical systems. These laboratory demonstration experiments introduce the students to both conventional and unconventional control techniques. This introduction helps them to enhance their knowledge and grasp the concepts involved through visualization of various techniques applied in controlling a complex physical system.

Conventional control techniques such as State Space and PID control and unconventional control techniques such as Neural Networks were also used to demonstrate the experiment. A comparison between the performance of PID and Neural Networks controllers on Magnetic Levitation System was presented in Reference [2].

Objectives of the Experiment

This demonstration experiment mainly aims at:

1. Introducing the students to the practical application of an unconventional control technique (i.e., Fuzzy Logic Control) on a complex physical system.

2. Providing the students with a detailed analysis of the complexity of the physical system and the procedure involved in controlling the system using Fuzzy Logic Control.

3. Assessing the students' understanding by giving them an assignment to design a Fuzzy Logic Controller to control any one of the other two non-linear physical systems (Inverted Pendulum and Pendubot) available in the laboratory.

4. Explaining to the students the errors if any, in their design and implementation of Fuzzy Logic Controller and helping them to improve upon their proposed solution.

EXPERIMENTAL SET UP

The electromagnet (see Figure 2) consists of an iron core with a diameter of 25 mm. The electromagnet coil has a diameter of 80 mm with a total resistance of 22 Ohm. The coil has 2850 turns and an inductance of 277 mH at 1KHz and 442 mH at 120 MHz. The photo sensor measures the position of the ball and is infrared based. The system has two types of controllers -- a lead compensation controller and a software driven controller. The lead compensation controller can control the gain and bandwidth characteristics. However, the software driven controller is used for the experiment as it makes the design process easy. The software consists of a real time kernel (RTK), communication functions, an external interface and a Windows NT kernel mode device driver. The RTK monitors a set of real time tasks and forms a basis for controlling the Magnetic Levitation system in a windows environment. It also controls the signal flow from and to the Magnetic Levitation system. The RTK is in the form of dynamic linked library (DLL).

Special functions provided by the manufacturer for communication between RTK and MATLAB environment help in selecting the required control algorithm and tweaking the parameters from MATLAB. The prepared RTK/DLL library and the interface software support the external DLL libraries. The application of user-defined control algorithms is made feasible by the use of these external DLL executables. The Fuzzy Logic based controller was prepared in Visual C++ and the required DLL library was created.

FUZZY LOGIC CONTROL

Fuzzy Logic [4, 5] is considered to be a rapidly developing technology for application in sophisticated control systems. Lotfi Zadeh originally introduced fuzzy set theory in the 1960's. It was designed to mathematically represent uncertainty and vagueness in the problems apart from providing a formalized tool to deal with the imprecision present in these problems. Fuzzy set theory implements the classes of data whose boundaries are not sharply defined. Fuzzy Logic can be used to handle approximate information in a systematic way. Hence, it is considered to be ideal for controlling non-linear systems or systems with complex dynamical models.

The main advantage of Fuzzy Logic lies in that it can encode expert knowledge directly with the help of rules with linguistic labels. Because of the rule based operation, any reasonable number of inputs can be processed and numerous outputs are generated.

In the present application, the controlled variable is the current applied to the electromagnet. The two input variables applied to the fuzzy control system are the position and the time rate of change of position of the ball. The following symbols were used to represent the membership functions:

N= Negative
P= Positive
Z= Zero

These linguistic variables were used to form " IF X AND Y THEN Z" type of rules to define the relationship between input and output. Consequently, nine fuzzy rules were constructed which defined the particular state of the Magnetic Levitation system. The rules also defined the output state i.e., current applied to the electromagnet for a given set of position and for the time rate of change of position of the ball. The Membership functions of input 1 (position of the ball), input 2 (time rate of change of position of the ball) and the output (current) of the Fuzzy Logic Controller are shown in Fig. 3, Fig. 4 and Fig. 5 respectively. Figure 6 shows the layout of the Fuzzy Logic Controller.

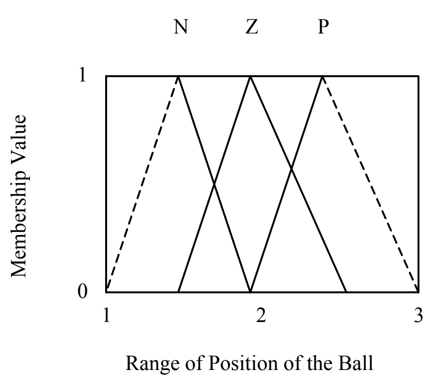

Figure 3: Membership Functions of Input 1 of the Controller.

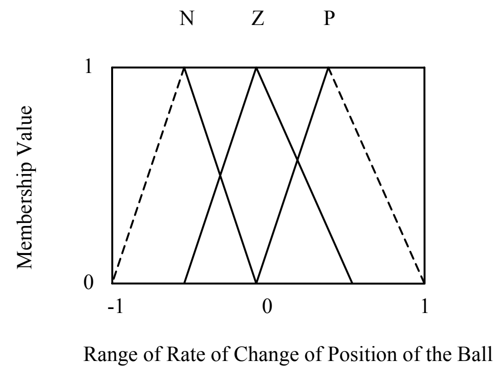

Figure 4: Membership Functions of Input 2 of the Controller.

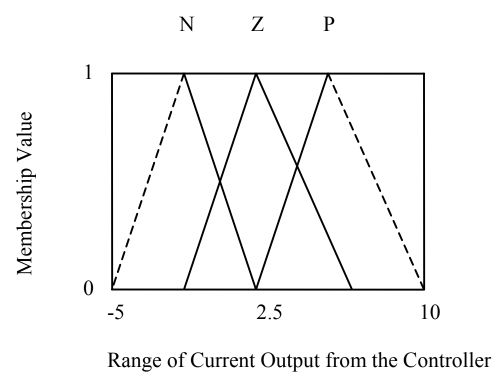

Figure 5: Membership Functions of the Output (Current) of the Controller.

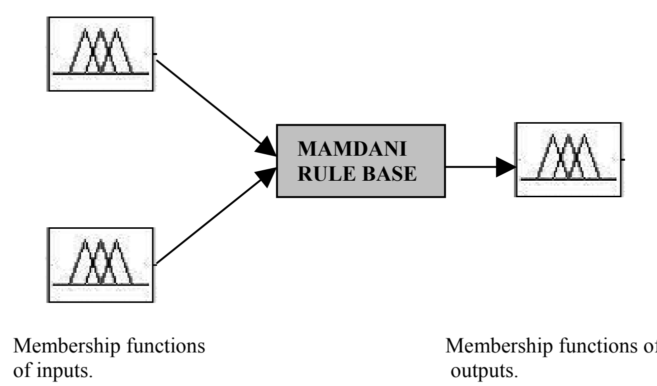

Figure 6: Layout of the Fuzzy Logic Controller.

		POSITION		
		N	**Z**	**P**
RATE OF CHANGE OF POSITION	**N**	N	N	Z
	Z	N	Z	P
	P	Z	P	P

Table I: FUZZY RULE MATRIX

The top row in Table I corresponds to the position and the first column corresponds to the rate of change of position of the ball in the magnetic field. Each element in Table I describes the desired output current for a given set of position and the time rate of change of position. For example, if the position is "positive" (i.e., above the desired 2 inch mark) and the rate of change of position is "negative", then the output current is "zero". Fuzzy Membership functions quantify the degree to which some variable belongs to some class. These rules were subsequently defuzzified to calculate a crisp or sharp (numerical) output. The above scheme was implemented and executed in C++ language.

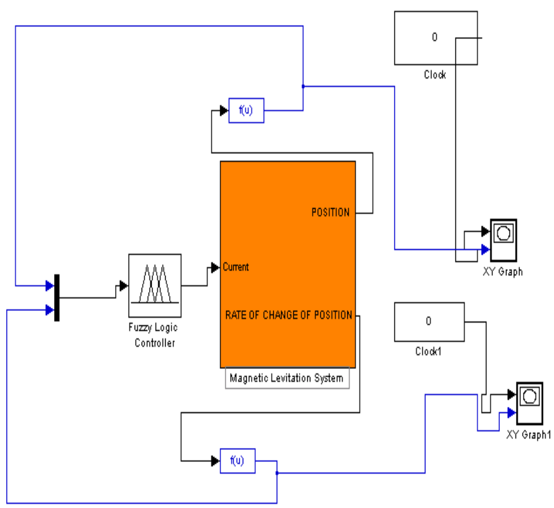

Figure 7: Block Diagram of the Fuzzy Logic Control Simulation.

The schematic layout for the simulation using the Fuzzy Logic control is shown in Fig. 7. Simulation of the experiment is performed using the tools available in the MATLAB software. Fuzzy Logic Controller block is obtained from the Fuzzy Logic Tool Box and the rules for the Fuzzy Logic Controller are defined. This Fuzzy Logic Controller is then used to control the current, which is the input variable for the Magnetic Levitation system block. The Magnetic Levitation system block consists of a series of function blocks that calculate the position and the rate of change of position of the ball, which form the output of the system. The function block f(u) consists of an expression for converting the position and rate of change of position from meters and meters per second to inches and inches per second respectively. The position and the rate of change of position of the ball are in turn the inputs of the Fuzzy Logic Controller. The blocks XY Graph and XY Graph 1 plot the change of position and rate of change of position of the ball with respect to time.

Figure 8 is the plot showing the ball position with time on the X-axis and position on the Y-axis. Figure 9 shows the time rate of change of position of the ball versus time. These results are obtained via simulation using Fuzzy Logic Tool Box available in the MATLAB software. The simulation clearly shows that the position of the ball nearly approaches the desired value of 2 inches after 10 seconds (Fig. 8) and the rate of change of position approaches almost a zero value. The numerical value reached 0.0029 inch/sec within a time period of 10 seconds (Fig. 9).

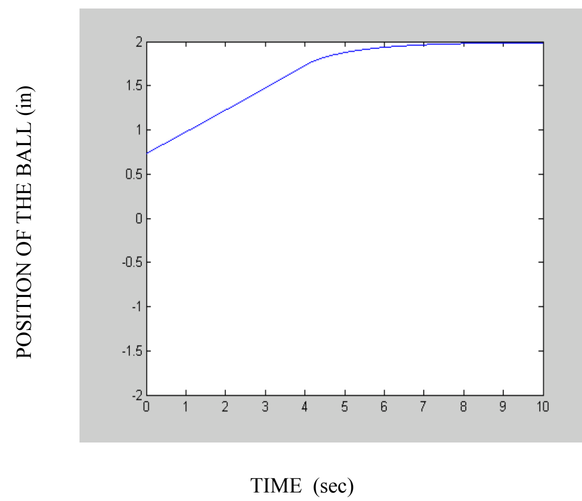

Figure 8: Position of the Ball versus Time (Fuzzy Logic Control Simulation).

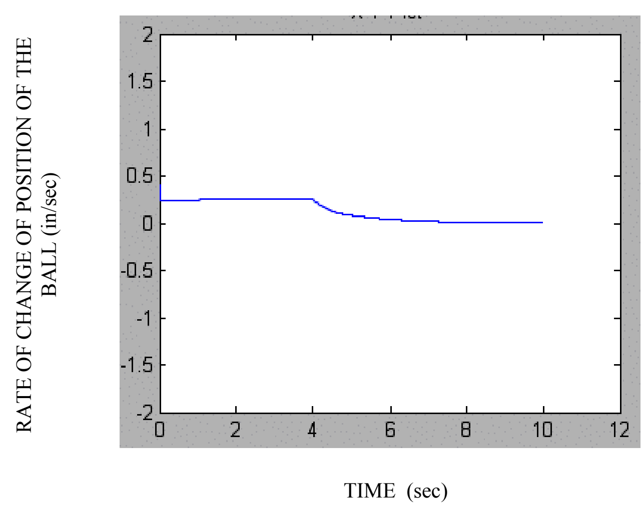

Figure 9: Rate of Change of Position of the Ball versus Time (Fuzzy Logic Control Simulation).

EXPERIMENT

The metallic ball position measured by the infrared sensors is converted to a digital signal via an analog to digital (A/D) converter. The computer receives the digital signal and passes actual and desired position to the control algorithm. Signals received from the control algorithm are converted back to analog signals via digital to analog (D/A) converter. It is possible in the Magnetic Levitation system to either use the inbuilt control algorithms, or to design and implement a different control algorithm. For this experiment, the Fuzzy Logic controller was designed, implemented and executed in C++ language. The following procedure was followed to carry out the laboratory experiments:

1. The Fuzzy Logic controller for the Magnetic Levitation system was designed.

2. Control action was tested using offline-testing program provided with Magnetic Levitation system.

3. Desired position of the steel ball was set to be at a distance of two inches from the center of infrared sensor.

4. The ball was released from the datum in the magnetic field after starting the operation of the system controller.

5. A graph showing the actual and the desired position over time was plotted.

6. Time required for the ball to stabilize was noted in the graph obtained in step 5.

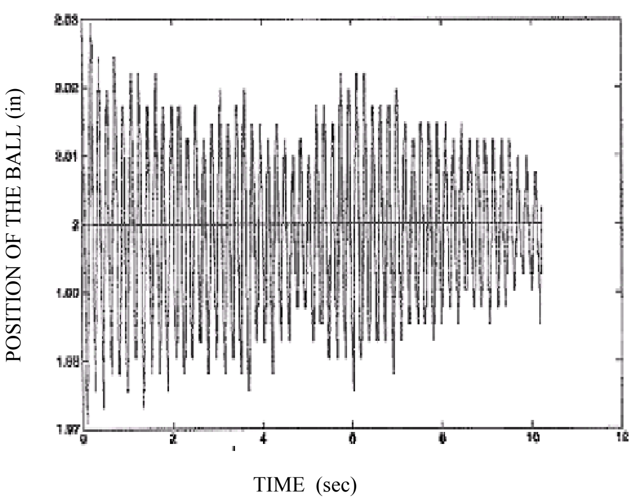

Figure 10: Experimental Results for Position of the Ball versus Time using a Fuzzy Logic Controller.

RESULTS

Figure 10 shows the experimental results obtained by implementing the Fuzzy Logic control on Magnetic Levitation system. It shows that the ball position stabilizes within a range between 1.97 inches and 2.03 inches (i.e., within ± 0.03 inch of the desired position) after 10 seconds, which is quite acceptable.

The Fuzzy Logic controller can be further tuned to obtain even better results. To automate the tuning process, Neural Networks can be used in combination with Fuzzy Logic. The hybrid controller thus obtained by using the Neural Networks to train the membership functions of the Fuzzy Logic controller can not only automate the tuning process of the Fuzzy Logic controller, it is also capable of overcoming the individual limitations posed by the Neural Networks or Fuzzy Logic control techniques.

CONCLUSIONS

The results obtained from both the experiment and the simulation have shown that it is feasible to control the Magnetic Levitation system not only by the conventional control methods that are supplied by the manufacturer but also via unconventional intelligent control techniques such as Fuzzy Logic. The model for the controller was presented to the students and they were asked to control the Magnetic Levitation system with the help of the Fuzzy Logic controller. Later, they were given an assignment to design a Fuzzy Logic Controller to control one of the two non-linear physical systems (i.e., Inverted Pendulum and Pendubot) available in the laboratory. A few of them were successful in designing an efficient Fuzzy Logic Controller for the system of their choice, while the others did not do so well, and had a few drawbacks in their controller design. This is quite satisfactory considering the fact that no further guidance was provided to the students after the demonstration experiment was conducted.

This experiment in particular was successful in introducing the students to the practical application of an unconventional control technique (i.e., Fuzzy Logic Controller). The detailed analysis showed the students the complexity of the physical system (Magnetic Levitation System) and the procedure involved in controlling it using Fuzzy Logic. It also helped them in acquiring analytical skills to analyze other complex physical systems and control them using a Fuzzy Logic Controller. Assignment given to the students was also helpful in assessing their level of understanding apart from giving them a practical experience of analyzing and controlling a complex physical system. Finally, the feedback provided to the students helped them in eliminating their mistakes and building confidence in controlling complex physical systems.

The most attractive feature of the Fuzzy Logic controller is that it is model independent and a mathematical representation of the system or any detailed analysis is not required. These experiments introduce the students to unconventional intelligent control techniques which are generally more effective compared to the conventional control techniques such as State Space or PID control that were provided as inbuilt control modes for the Magnetic Levitation system. The students found the experiment to be very interesting as it introduced them to an unconventional control technique that requires no mathematical model.

In summary, the Magnetic Levitation system provides an excellent test bed in a controls laboratory setting for exploring the performance of a variety of control strategies. Working with this test bed, the students are able to analyze and appreciate the difference between an unconventional control technique and the conventional control techniques, which they used in earlier experiments. At Duke University, the Magnetic Levitation system available in the Robotics and Controls Laboratory was used to demonstrate the use of different control techniques (both conventional and unconventional) in control system courses. The experiments were carried out at both the undergraduate and the graduate level control laboratory sessions. The main purpose of these experiments was to introduce them to a variety of control techniques and provide this knowledge to help them develop their skills in choosing the most suitable technique for controlling a given dynamic system.

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