Fuzzy Logic Based Ball on Plate Balancing System Real Time Control by Image Processing

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Abstract
Recently, new control methods have emerged along with developing control methods. Fuzzy logic is one of the new and developing control methods. In some cases, it is more adequate to control complex systems using fuzzy logic controller. In this study, a dynamic position of the ball on the plate was controlled by determining the angle of the plate in real time with fuzzy logic control method. The ball position was obtained by a digital camera and the image was processed in MATLAB/Simulink environment. Fuzzy logic algorithm was built according to the system under investigation. The output obtained from the serial port interface is sent to microcontroller card and the motors in the system are activated to the desired angle to keep the ball on the plate and to avoid falling of the ball. For this, a fuzzy logic controller was designed for ball balancing system on the plate. The system is controlled successfully and the controller performance are tested.

Keywords: Fuzzy Logic Control, Ball and Plate, Image Processing

INTRODUCTION

As mankind’s have been developed technology, they are always inspired from nature. The mechanical structure of the produced machines was developed by analyzing the outer structure of the entities in present nature. The decision making structure of the machines try also to behave like a human body. The situation in classical logic is either positive or negative. For example, light is either ON or OFF. Conventional control systems are inadequate for compensating complex systems. For example, over 20 degrees can be accepted as hot and under 20 degrees can be defined as cold. According to this theory, while 19.5 degrees is cold, 20.5 degrees is considered as hot. But the human mind does not use exact values. The article about fuzzy sets published in 1965 by Zadeh, an Azerbaijani scientist, has a mathematical model similar to that of human thought.

Although in the early times his model was not very popular, they started to be used in steam machines in 1970’s on and its popularity has increased. When designing a controller in traditional PID control, the mathematical model of the system may be needed. It is difficult and time-consuming to obtain a model of complex systems. PID does not give satisfactory results for the control of non-linear systems. There is no need to know the mathematical model of the system to be controlled in fuzzy logic. The fuzzy logic controller, on the other hand, is designed according to the instructions given by the expert who knows how the system reacts, or the results obtained by conducting experiments on the system. Fuzzy logic control gives good results in nonlinear systems. Fuzzy logic was only in theory in the first place, but nowadays it is widely used the industry [1,3].

MATLAB/Simulink software was used in the controller design, test and development process for the system. If a direct controller for the system was designed and produced, then it can be difficult to view and evaluate the results of the system. If the expected performance is not achieved with the designed controller, it is necessary to go back to the beginning and pass the production process again. This may cause to increase the design cost of the system in the sense of time and money. For this reason, the controller is designed in MATLAB/Simulink environment and the system is controlled in real time. In this way, we can easily observe the system inputs and outputs. If the controller’s performance is not at the desired level, the controller can be immediately configured and quickly tested on the real system in real time. This makes it easier to design the controller [4, 5].

In this study, the ball balancing system on the plate is designed as shown in Figure 1. The system designed was implemented and controlled as shown in Figure 2. The control of the system is difficult because of its nonlinearity. The parameter that is needed to control is the position of the ball. We obtain the position information of the ball by taking the image from the camera on the plate and process the captured image. The camera image was processed using the “Computer Vision System Toolbox” tool in the MATLAB / Simulink program. The position of the ball on the plate was determined. Fuzzy logic controller is designed with “Fuzzy inference System Editor” tool in MATLAB/ Simulink software. The control output generated by the fuzzy logic controller is sent to the microcontroller card. The microcontroller drives the servo motors which change the two axis inclination of the plate according to the value it receives.

Figure 1. The general structure of ball balancing system
METHODOLOGY

Image Processing

Recently, image processing algorithm is used in variety application. Binary, HSV and RGB space are used for distance, position, and velocity determination [6, 7]. The Simulink platform for “Image Acquisition Toolbox” to get the camera image in the “From Video Device” block is used. The raw image captured is shown in Figure 3. This image is in RGB space. The image is converted to grayscale for easy and fast processing. To separate dark ball on a white plate image is required to filter. The average of the color values of the image was found. This average is subtracted from the limit value obtained by the experiment. The resulting value is the threshold value. The color values of the ball because of the black background and white ball low and high color value of the plate. Color values are just below the threshold of the ball. To eliminate these gaps, “closing” the filter block is used. Afterwards, free from noise after two (binary) image was formed. The results obtained are shown in Figure 4. This image is to be achieved the position of the ball. The closed areas in the image clustering and labels “Blob Analysis” block is used. The value of the pixel area of the ball is known and Values outside this value are not evaluated. Thus, it does not react to other objects within the camera angle. “The Blob Analysis” in the output of the block, object information is taken diameter of the center coordinates or object. Reading is performed by filtration of the camera and image processing shown in Figure 5. The obtained data will be displayed on the raw image. The image of the “Draw Circles” in the ball center coordinates determined by the diameter of the ball apartment block and has drawn. The velocity of the ball, the previous coordinates from current coordinates to the “Draw lines” are drawn block. Coordinate information and the radius of the ball “Insert Text” it has been added to the image block. The resulting final image, “To Video Display” is displayed in real time block. The final image is shown in Figure 6. Operations performed are shown in Figure 7.
Fuzzy Logic Controller

Fuzzy logic controller is designed with FIS (Fuzzy Inference System) editor tool in MATLAB/Simulink software. The fuzzy logic controller has two input values. The first one is the error itself, and the other is the derivative of the error. The system needs to be controlled in two axes. For this reason, two fuzzy logic controllers are required, but in both cases the controller designed for one axis can be used for two axes because the system response is the same.

In fuzzy logic, it is first necessary to build a rule table. For this, there is a need of an expert’s opinion, or it may be based on the results obtained by testing. The quantized and discrete rule table was extracted as in Table 1, inspired by reference [8]. The rule table consists of 169 rules.

There are 13 membership functions for the inputs and outputs as seen in the rule table. The Gaussian membership function is used to obtain all intermediate values in membership functions. The membership functions of inputs and outputs are shown in Figure 8.

The fuzzy logic control surface resulting from the input and output functions is illustrated as shown in Figure 9. As seen, the transitions on the surface are very smooth, which means that a good controller is designed.

The control system created in the MATLAB / Simulink program is shown in Figure 10. The position information is obtained by processing the image captured from the camera. The position value is subtracted from the reference input and the error signal is determined. By taking the derivative of the error signal and the error signal is given as input to the fuzzy logic controller. There is one controller for the X and Y axes. Fuzzy logic generates values between 0 and 100 according to the values entered in the controller. The generated values are sent to the microcontroller card from com port via Wajung block set.

Table 1. The rules table System

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Figure 6. Final image including ball diameter and position information and velocity vector

Figure 7. Addition of coordinate and velocity vectors to the ball detected on the raw image

Fuzzy logic membership functions

The servo motor angles are adjusted according to the data received on the microcontroller card. The angle of the servo motors determines the slope of the plate. The diagram of the system is shown in Figure 11 [9].
RESULTS and DISCUSSIONS

The plate top balancing system was controlled by fuzzy logic control method. Experimental results have been obtained for different situations. First, in the case where the ball is sitting at zero position, the system response can be seen in Figure 12. As can be seen from the figure, there are about 20 pixels of steady state error and 15 pixels of oscillation value. The step response of the system is shown in Figure 13. Rise time is 0.2 seconds and the systems overshoot is 95%. The settling time is 1.9 seconds. The system response is shown in Figure 14 when the ball is left at a random spot on the active plate. In the new case, the ball is asked to follow the circular trajectory on the plate. As reference signal, while a cos function is given for one input and a sin function is given to another input. The response of the system to these inputs is shown in Figure 15.

CONCLUSIONS

In this study, a plate top balancing system was designed and implemented as a prototype. The fuzzy logic control controller for this system is designed. This system is controlled in real time by fuzzy logic in MATLAB/Simulink environment. The controller performance was improved by performing tests under different conditions on the system.

REFERENCES