Tuning of Ball and Beam System using Cascade Control

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ABSTRACT

This project presents a new strategy to approach cascade control tuning by using image processing and machine learning to generate required control parameters to be set into the controller. For test bed purpose a ball balance upon a horizontal beam is used which is actuated with a stepper motor, angle of the balance to be scanned by a camera and analyzed using python alongside an ultrasonic sensor to measure real time distance to the ball, set point to be set by user and control action generated upon generating required information from hardware frame.

Keywords— Ball Balance, Cascade Control, Image Processing

I. INTRODUCTION

Ball and Beam system is a familiar laboratory setup used for control experiments. It consists of a long beam which can be tilted by a servo or electric motor together with a ball rolling back and forth on the top of the beam. It is required that the ball remains in contact with the beam and the rolling occur without slipping, which imposes the constraints on the rotational acceleration on the beam. A schematic diagram of the Ball and Beam system. Although PID control is an efficient technique for the handling of non-linear systems but modeling these systems is often troublesome and sometimes impossible using the laws of physics [1]. Therefore, using a classical controller is not suitable for nonlinear control application.

Cascade control can improve control system performance over single-loop control whenever [5] either: Disturbances affect a measurable intermediate or secondary process output that directly affects the primary process output that we wish to control; or the gain of the secondary process, including the actuator, is nonlinear. In the first case, a cascade control system can limit the effect of the disturbances entering the secondary variable on the primary output [2]. In the second case, a cascade control system can limit the effect of actuator or secondary process gain variations on the control system performance. Such gain variations usually arise from changes in operating point due to set point changes or sustained disturbances.

Almost all industrial process change over time for various reasons like equipment change, change in operating conditions of the units, change in market demand [3]. Consequently, a conventional control technique may not provide effective control of complex processes where process parameters can occur significantly, but cannot be measured or anticipated. The classic control methods are normally a feedback method relies on monitoring the change in the process variable with respect to the set point and control designed for worst case scenarios [2]. Alternatively, adaptive control strategies are available where controller parameters and/or control structure are modified online as conditions change. System delays can be usually encountered in the real world. When the system involves propagation and transmission of information of material, the delay is certain to occur [4]. The presence of such delays complicates the system analysis and the control design. Such process may be called as dead time process. For processes with long time delays it is often difficult to achieve good control using PID control strategies. As we shall demonstrate, cascade control can be usefully applied to any process where a measurable secondary variable directly influences the primary controlled variable through some dynamics [6]. We will also demonstrate that despite frequent literature statements to the contrary, inner loop dynamics do not have to be faster than the outer loop dynamics [9]. However, the traditional cascade structure and tuning methods must be modified in order for cascade control to achieve its objectives when the inner loop process has dynamics that are on the order of, or slower than, the primary process dynamics

With latest technological advancement in control systems and embedded system we can use image sensors to generate real time process parameters instead of using multiple sensors, with the use of image processing application of required control action in a cascade PID loop is possible with the help of an acting real time embedded system with near to 0 delay in process. Easily available embedded systems such as Arduino can be implemented alongside MATLAB for generating a regulated control action by observing system feedback and set point values [12]. A physical sensor can also be used to regulate accuracy in the current process by generating accurate disturbances from the user set point. By using

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image data processing, software tools, control design, implementation of cascade control can become easier as software generated algorithms calculate best possible control action using machine learning which can lead to a better tuning strategy.

II. METHODOLOGY

The motive behind this project is to develop a hardware model for ball and beam balance system to assess stability and control for using Arduino and image processing with raspberry pi. Our aim is to observe the output response of the system with single loop configuration with no feedback, multi-loop configuration with no feedback, single and multi-loop with feedback. Performance criteria of the system is analysed and concurrent experimentation is carried to view system response with different Kp, Ki, Kd values for a PID controller. Camera is interfaced with raspberry pi to detect visual anomalies for the change in the system's set point for which controller's response is to be checked for corrective action. System design consideration to be robust and reliable. Automatic PID tuning is performed using embedded C so that the system parameters can adjust to deal with unknown disturbances to the hardware model [7]. Cascade control methodologies are used alongside primary and secondary controller, output and system response are accordingly analysed.

Ball and beam system is a non-linear system which is an unstable open loop system. The output changes as position of the ball changes on the beam which rapidly changes the tilt angle of the beam hence requiring rapid change in input for robustness of the system [6]. Hence the system is classified as an open loop unstable system. It is not an easy task to maintain the position of the ball at required set-point due to its constant changing acceleration on the plane [8]. One end of the beam is attached mechanically with a lever arm which is adhered to a servo motor to which appropriate control signal is provided to keep the position of the beam with accordance to the set point allowing the ball to stabilize [11]. Here we can apply proper control strategy with feedback like single look PID control or as discussed in this report multi-loop control strategies to keep the system at a stable condition. The ball beam balance has two-degree freedom on X and Y axis respectively. Position of the ball and angle of the beam is controlled by providing voltage (control signal) to the servo motor which is actuating.

Here the cascade control system is used to calibrate the angle of the beam in order to control the position of the ball. It is known that when ball moves on the beam it will exhibit 'v' acceleration. Hence the ball's position can be controlled by altering acceleration on the beam. It shows that there are two integrator and dynamical properties of the beam which are an important feature that make it highly unstable and a non-linear system.

With accordance to ball beam system's non linearity disturbances are also caused by mutation and noise of the system [9]. Dealing with MIMO system an image processing unit is created using open cv and camera as the secondary controller to provide adaptive feedback control, distance of deviation of the ball on the beam is them analyzed with ultrasonic sensor's output to provide a better control action which leads to a better control and stabilized effect on the system. This process is also meaning full and improves the recovery rate and overcomes the underlying offset error in the system.

III. PRIOR APPROACH

Ball beam balance hardware model is controlled using multi-loop control cascade strategies. In this report an appropriate embedded system is designed to acquire the real time position of the ball on the beam using HCSR04 distance measuring sensor (Ultrasonic Sensor) interfaced with Arduino Uno (Microcontroller), for visual real-time tracking of the ball Sony IMX219 8-megapixel sensor interfaced with Raspberry pi 3b using MIPI camera serial interface present on board.

Sony IMX219 8-megapixel sensor with Raspberry pi 3b acts as the primary controller for the system, which is responsible in tracking the ball's colour and distance with initial starting point, this assessment provides an output which will be the deviation of the process from set point in 'cm'. Ultrasonic sensor interfaced with Arduino Uno acts as the secondary controller which is also measures real time distance from initial point to the moving object in real-time, 9G pro servo motor is interfaced with the Arduino Uno's PWM pin which provides voltage signal which adjusts the angle of the arm attached to the motor hereby actuating the arm connected with the beam by changing its angle to control velocity of the ball.

Cascade Control

Cascade control is an advanced application of PID which improves control systems which have time lag. Hence this system is slow to respond to disturbances its performance gets affected. Cascade control brings out the positive impact to the system. Cascade control can be applied to vast number of systems where measurable secondary variable influences the primary controllable variable via system dynamics. Inner loop is responsible to reduces the overall variation experienced by the processes [12]. Hence the inner loop is able to respond to disturbances faster than the outer loop, it reduces the impact of the disturbances and limits the degree of variation exhibited by the process. The inner loop is also situated near to the disturbances occurring in the system,

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this inner-outer loop jurisdiction allows faster response to overcome disturbances in the system.

In this report cascade control schematic is used to tune the hardware model to achieve a stable system output response.

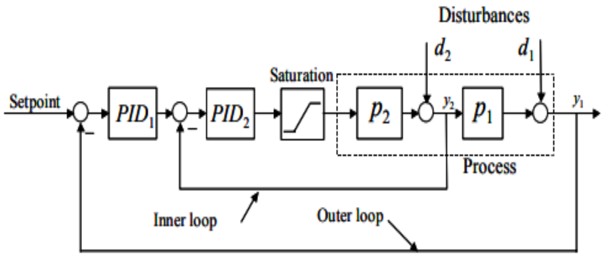

Figure 1: Basic Cascade Control Loop Block Diagram

IV. OUR APPROACH

Mechanical model of ball beam system is interfaced with the actuating part which is the servo motor which is responsible for the control of acceleration of the ball and control of beam's angle.

Fig 2a and 2b are front and top view of the actual hardware configuration of the ball beam balance model. From fig 3 9g pro servo motor is controlled by PWM (pin 8) signal generated by the microcontroller Arduino Uno, servo motor is connected with Arduino Uno using male to female jumper cables, Vcc for the motor is 5V supply. HCSR04 is connected to Arduino on 5v power rail, its trig and echo pins are connected to pin 2 and 3 of the Arduino respectively. Ultrasonic sensor to be responsible to measure the real time distance of the moving ball on the beam and servo motor will act accordingly to adjust the position and velocity of the ball according to the feedback available from HCSR04 (distance). These two modules are connected to Arduino Uno.

From fig 4 the Raspberry pi 3B and Sony IMX219 8-megapixel sensor are interfaced using MIPI camera serial interface present on board of the Raspberry pi, camera's connection strip is connected to the CSI MIPI interface on the board accordingly.

From fig 5 which shows interfacing between two controllers Raspberry pi3b and Arduino Uno, Sony camera interfaced with Raspberry pi's algorithm calculates the position of the ball from the set point, camera tracks the ball in real time and calculates the distance in cm and send the data to Arduino Uno using I2C communication protocol. After sending the data Arduino provides required PWM signal to the servo motor for actuation of the beam correcting the positon of the ball to the required set point.

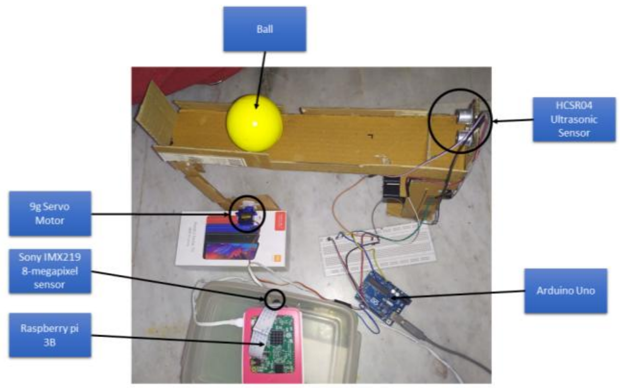

Figure 2a: Implemented hardware setup (Top View)

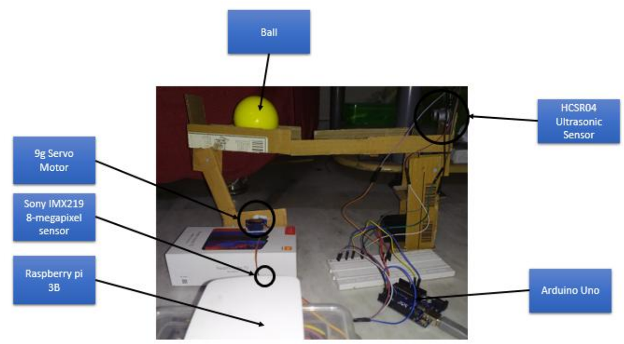

Figure 2b: Implemented hardware setup (Front View)

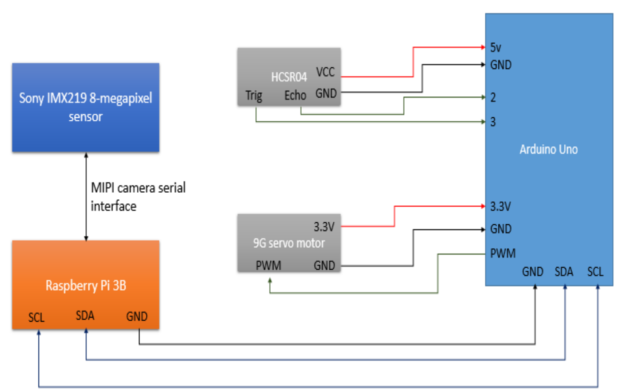

Figure 3: Interfacing between Arduino Uno and Raspberry pi

V. CONCLUSION

A detailed analysis has been performed on ball beam balance system using multi-loop control. Hardware model was designed with accordance to physical specification and software counterpart was made to interact with it using computer vision and distance sensor. The output of multi-loop ball beam balance control clearly shows better stability in terms of rise-time and overshoot

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which got decreased by providing a robust primary controller. Image tracking of variable allows the opportunity of asses the impending disturbances up to what degree would they effect the controlled process. Control action's response was improved by a large margin for Kp, Ki, Kd values generated from assessing open cv's response of deviation from set point which quickly auto-tuned for providing appropriate control action to counteract with the system and disturbances.

This experiment of ball beam balance can be further scoped for discovery of better control strategies with hardware models. Further simulation and different experiments can be performed for much better stability models. Next stage would be where accelerometer can be used to map the concurrent angle of the beam and provide a live feedback loop was a better control action and disturbance understanding. System can be taken from 2-degree freedom to 3-degree freedom real time system and check its output response.

These types of control strategies are useful in automation industries where a process variable needs to be stable and tackle with different types of disturbances in order to perform optimally.

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