Real time implementation of Robust PID controller for stabilization of Ball Balancing Beam

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Abstract—positioning of an object in both symmetrical and asymmetrical system is required for accuracy and sustainability. The technique presented in this paper is to position an object at a given distance relative to origin. Positioning and stability is achieved by designing robust PID controller. The proposed technique is applied on a four bar mechanism using closed loop system to position the ball on a beam at a set point to investigate accuracy and efficacy of the system. Robustness of the system is increased by additional tuning of PID gains which counter external nonlinearities. The linear graph of position is achieved with minimum rise time. The promising result indicates the accuracy of system.

Keywords- Stabilization; Four Bar Mechanism; Ball Balancing beam; Controls; PID

I. INTRODUCTION

Control system is a device or a system which is used to develop a required output in a manner which is suitable for the user. This device can also be functioned by assembling different parts. There are two ways to function this system.

As in our ball balancing beam system first we are applying the simple open loop system to check the response.

An Open loop, as shown in Fig. 1, is a simple control system which processes the data on the bases of input and send it to the output for example fan connected through regulator for regulating the speed of fan.

Fig 1: Open Loop System

While closed loop control system is different and complex from open look as it gives the desired output by using the feedback that measures the error between the given input and set point as shown in Fig. 2. Set point is the control variable which tells the system to get output close to it or as it is.

Fig 2: Closed Loop System

Error value = Measured value – desired value

A. PID Controller

Also known as a ‘Proportional-integral-derivative’ controller. It is a closed loop feedback mechanism. Its main objective is to calculate the error value.

It is designed in a way that it controls the overall behavior of the system. It became an essential tool when process control emerged in 1940s. Today, more than 90% of control loops are PID type. All such controllers are based on microprocessors. It is undoubtedly the most important ingredient in a Control System.

Feedback returns the output to input by comparing the data with set point through sensor or any measuring device if it generates error so it repeatedly process until we get the desired output.

Proportional, integral and derivative are all dependent to the output as any change in each of their value changes the output result.

- Proportional term is known important part in closed loop system as it minimizes the overall error in system.

- Integral term is used to eliminate the final errors by adding even the smaller errors that are enough to create instability in the system.

- When there are sudden or quick changes derivative than is used in the end.
Proportional, Integral and derivative term are represent by constants $K_p$, $K_i$ and $K_d$ respectively all three are add together in a closed loop system as shown in Fig. 3.

An example of a feedback controller system is balancing a ball on a beam at desired point. Here in our system a closed loop system is activated by simultaneously measuring the distance of a ball on beam and it gives back the signals to motor which in the end change the angle of beam to stabilize the system by using a microcontroller. [1]

II. MECHANICAL STRUCTURE

This type of configuration is called ‘Ball and Beam Module’. The structure is designed in a manner that both sides of lever arm are supported as shown in Fig. 4; one is coupled with the motor and other works as a pivot point. [2]

This setup only contains two degree of freedom. First the moving of ball left and right by levitating the beam and second is beam; rotating at its central axis.

The ball balancing beam is a four bar mechanism which consists of three bars of aluminum and one ground bar for the support of the structure. Its primary function is to balance and stabilize a ball on a particular set point. The feedback system has been used in this mechanism for making it more stabilize as the balls keeps changing its position due to turbulence that can be air or human repositioning the ball. The position of ball is measured by an Ultrasonic sensor that is placed on starting point of beam and a motor is attached which rotates the beam. Both sensor and motor are connected with microcontroller (Arduino) for controlling the whole system. After comparing to its set point it sends the signal to motor to rotate from its initial angle to desired, so the ball can be balanced.

There can be another method to measure the position by using a conductive ball and a resistive material. [3][4]

A. Sonar Sensor:

A sensor which transmits and receives ultrasound waves. It basically works as transducers as it converts sound waves to electrical signals. This sensor can be used for different tasks but here it is used to measure the position of ball at every instance on the beam. The picture of embedded ultrasonic sensor is shown in Fig. 5.

B. Stepper Motor:

Stepper Motor, as shown in Fig 6, provides a controlled rotatory motion because of its precision in angular position it helps the system to be more stable. They have vast application in controlling and robotic field.

C. Microcontroller:

Microcontroller is single integrated circuits which work as a small computer. They are easily programmable having input/output pins. They are used in controlled system applications such as automated devices, remote controls, machines and other embedded systems. Here in our project ‘Arduino UNO’, as shown in Fig 7, is used as it is feasible to our project.
III. EXPERIMENTAL SETUP

A. Physical Setup:

According to the Fig 8, it can be seen that to change the position of ball first we have to change the angle of lever arm which can be done by using motor which cause the beam to change angle and due to gravity the ball starts to roll along the beam [5,6]. Position of ball can be traced and can be changed according to prescribed command using microcontroller.

To make it more stable we should calculate its result using mathematical equation as it helps to get more close results which are helpful to be easily applied to the system.

B. Mathematical Modelling:

As seen many research based works model used Lagrangian method to derive the equation of motion [2][7].

By applying Lagrangian method the equation of motion of the ball is following [6]

\[ 0 = \left( \frac{d}{d^2} + m \right) \ddot{\theta} + mg \sin \alpha - mr \ddot{d} \]

Transforming the above equation in linear form by substituting \( \alpha = 0 \)

\[ \left( \frac{d}{d^2} + m \right) \ddot{\theta} = -mr \ddot{d} \]

If the system is considered as linear angle \( \alpha \) is

\[ \alpha = \frac{\dot{d} \dot{\theta}}{2} \]

By substituting the parameters of \( \alpha \) we get

\[ \left( \frac{d}{d^2} + m \right) \ddot{\theta} = -mg \frac{\dot{d} \dot{\theta}}{2} \]

Applying Laplace transformation on above equation

\[ \left( \frac{d}{d^2} + m \right) \mathcal{L} \{ \ddot{\theta} \} = -mg \frac{\dot{d} \dot{\theta}}{2} \mathcal{L} \{ \dot{d} \dot{\theta} \} \]

Rearranging the terms with respect to the ratio of input to output

\[ \frac{\dot{d} \dot{\theta}}{\ddot{\theta}} = \frac{\mathcal{L} \{ \ddot{\theta} \}}{\mathcal{L} \{ \dot{d} \dot{\theta} \}} = \frac{mg \dot{d} \dot{\theta}}{L \left( \frac{d}{d^2} + m \right) \dot{d} \dot{\theta}} \]

As it can be seen transfer function, there is double integrator in above which makes the system marginally stable. The response of the original system is shown in Fig 9.

C. Closed Loop with PID implementation

We need to design our problem on criteria which can make our system to works fast and with minimum of error which includes settling time and overshoot. This problem can be overcome by implementing the PID controller.

Every plant even with a feedback controller works efficient by implementing a PID on the system

To overcome gain we need to consider derivative gain and tune the values according to our problem criteria. The results of tuning for PID gains is shown in Fig 10, 11 and 12.
In figure 11 there is remarkable change in overshoot but still settling time is too much for our system to decrease it we need to increase the value of our Proportional and Derivative gain.

It is seen that the output is not the same as it was expected from the software calculations, because they were calculated while taking suppositions such that there will be no error as friction of beam, air drag etc and delay of sensors and microcontrollers were also been supposed by us which makes the real time graph differ to the calculated graph [Fig 12].

V. CONCLUSION

Ball balancing is useful to learn controlled systems as many methods and techniques are used to stabilize the system [7,8]. There are many systems which works on their principles such as airplane or other aerodynamic object which tends to balance their position.

In our project we have shown with graphs how a simple change with a feedback can turn the output result. It is also seen that the mechanical structure plays an important role to fulfill the results. By completing and learning about this setup many things were understood and can be implemented on different structures and designs which contains the same idea.

REFERENCES


