Indian Institute of Technology Gandhinagar

Balancing of Ball on a Beam System

ME 352 : Mechanical Engineering Lab 2

Lab Report - Experiment 3

Group - 8

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OBJECTIVE

Design and implement a control algorithm that controls the motor in such a way that the ball is stabilized at the desired position on the beam.

ABSTRACT

The ball balancing system measures the ball's position using sensors and the PID algorithm to adjust the servo motor's position to maintain balance. When an electrical control signal is applied to the motor, the beam can be tilted about its horizontal axis, and the ball will roll on the top of the beam. The ball may fall from the beam if the system cannot be controlled properly. PID controller Algorithm based on Arduino microcontroller, which depends on the feedback signal, is used to control the ball position using an ultrasonic sensor. The ultrasonic sensor measures the distance between the ball and the sensor and the information used to calculate the error signal for the PID controller. The PID algorithm then adjusts the system's output to bring the error signal to zero and keep the ball balanced. The servo motor adjusts the rods' position based on the PID controller's output.

EXPERIMENTAL DESIGN

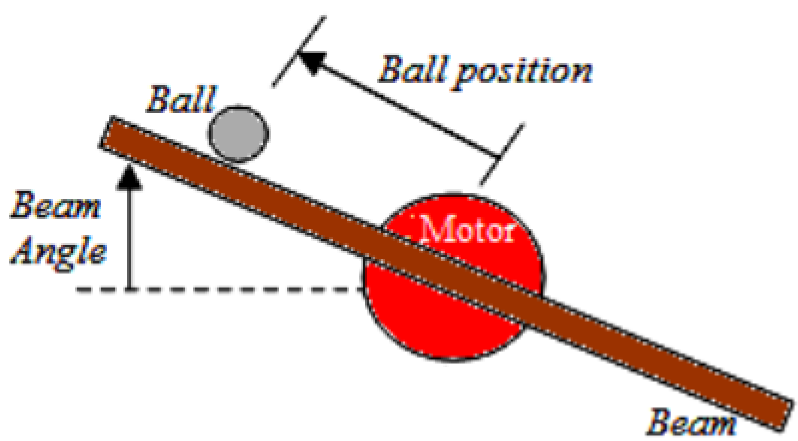


Figure 1 : Schematic of Setup

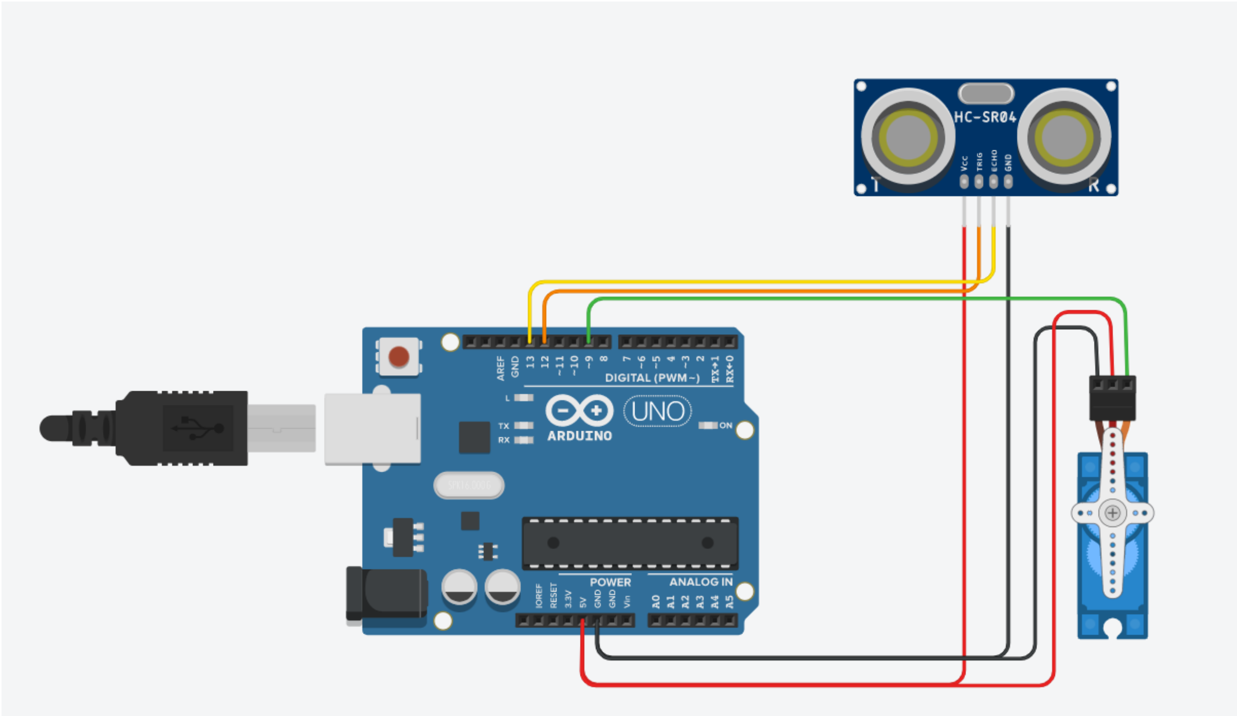


Figure 2 : Circuit Diagram

FABRICATION DETAILS

The beam was fabricated using two 3D printed end supports and 5 mm Aluminium rod between them for the ball to roll on. A slot was made for the center to be joined to the servo motor. The whole beam was joined with the servo motor.

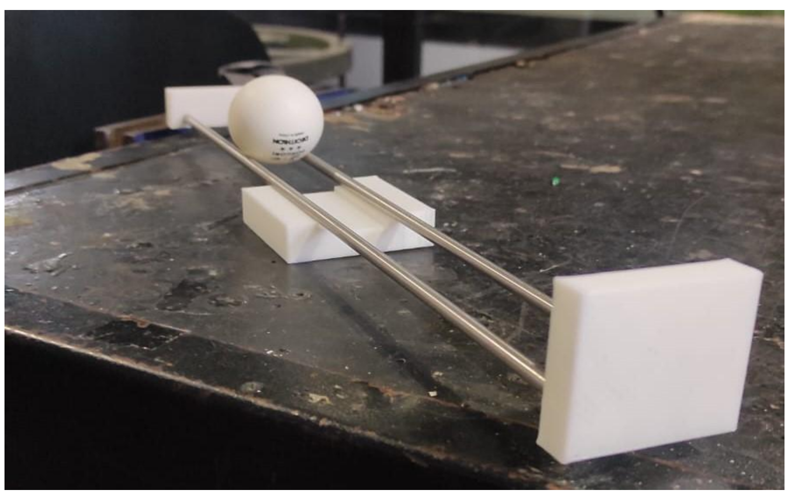


Figure 3 : Beam Setup

3 MDF strips were used to minimize the sensors measurment error as well as ensure that the ball does not fall off from the ramp. The whole setup was attached to a wooden base for stability to avoid toppling. The sensor was attached using a laser cut MDF cutout.

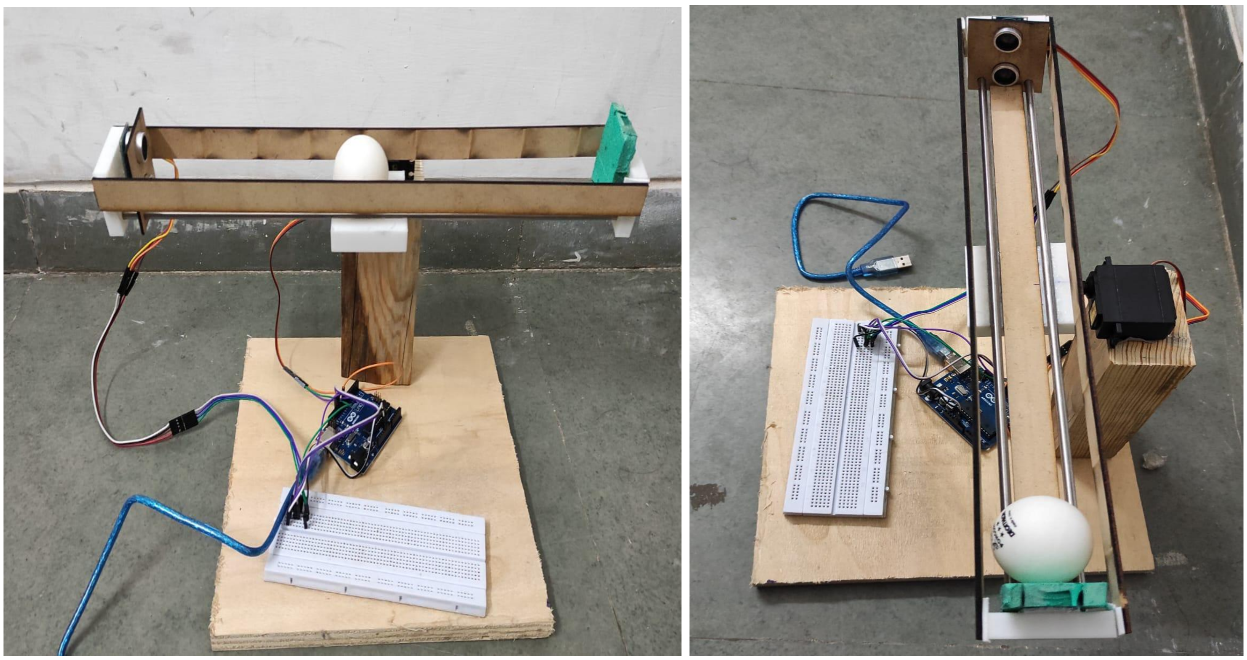


Figure 4 : Final Experimental Setup

MATHEMATICAL MODELLING

A Proportional-Integral-Derivative(PID) controller is a feedback control mechanism widely used in industrial, engineering, and robotic applications to regulate a system's behavior. It continuously monitors the system's output, compares it to a desired reference or setpoint value, and generates an error signal that adjusts the system's input. A PID controller can be an effective tool for balancing a ball on a beam, as it can provide precise and responsive control of the beam's angle in real time based on the ball's position.

The PID controller consists of three control terms: proportional, integral, and derivative.

Proportional term: Computes an output that is proportional to the error signal. The larger the error, the larger the correction signal. It would adjust the beam's angle in proportion to the ball's position with respect to the center of the beam. This term provides a quick initial response to disturbances but may result in overshooting or instability.

$$P_{out} = K_p e(t)$$

where,

$K_p = proportional\ constant(tuned\ based\ on\ the\ system\ to\ move\ the\ ball\ at\ center) = 0.01$

$and\ e(t) = distance\ between\ the\ ball's\ position\ and\ beam's\ center\ at\ a\ particular\ time$

Integral term: Integrates the error over time, which can help eliminate steady-state errors by gradually adjusting the beam's angle over time. It reduces the system's error over time but may also introduce overshoots or oscillations.

$$I_{out} = K_i \int_0^t e(t)dt$$

where,

$K_i = integral\ constant(tuned\ based\ on\ the\ system\ to\ get\ the\ ball\ at\ center) = 0.005$

$and,\ \int_0^t e(t)dt = Integration\ of\ e(t)\ over\ time$

Derivative term: Computes the rate of change of the error signal, which can help predict the future trend and dampen oscillations. It would predict the future trend of the ball's position and help prevent oscillations. It provides a correction signal that is proportional to the rate of change of the error, helping to reduce overshoot and improve stability.

$$D_{out} = K_d \frac{de(t)}{dt}$$

where,

$K_d = derivative\ constant(tuned\ based\ on\ the\ system\ to\ stop\ the\ ball) = 6$

$and\ \frac{de(t)}{dt} = derivative\ of\ e(t)\ at\ a\ particular\ time$

The three control terms are combined to generate the final output of the controller, which is used to adjust the system's input. The relative weights of the terms are set by tuning the controller's parameters, which depend on the specific application and system.

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

An ultrasonic sensor was used to measure the ball's position and provide feedback to the controller to implement the PID controller in the ball-on-beam system. The controller compared the ball's position to a desired setpoint(center of the beam) and generated an error signal, which adjusted the beam's angle. The controller's parameters were tuned to optimize the system's performance and stability to keep the ball at the center of the beam.

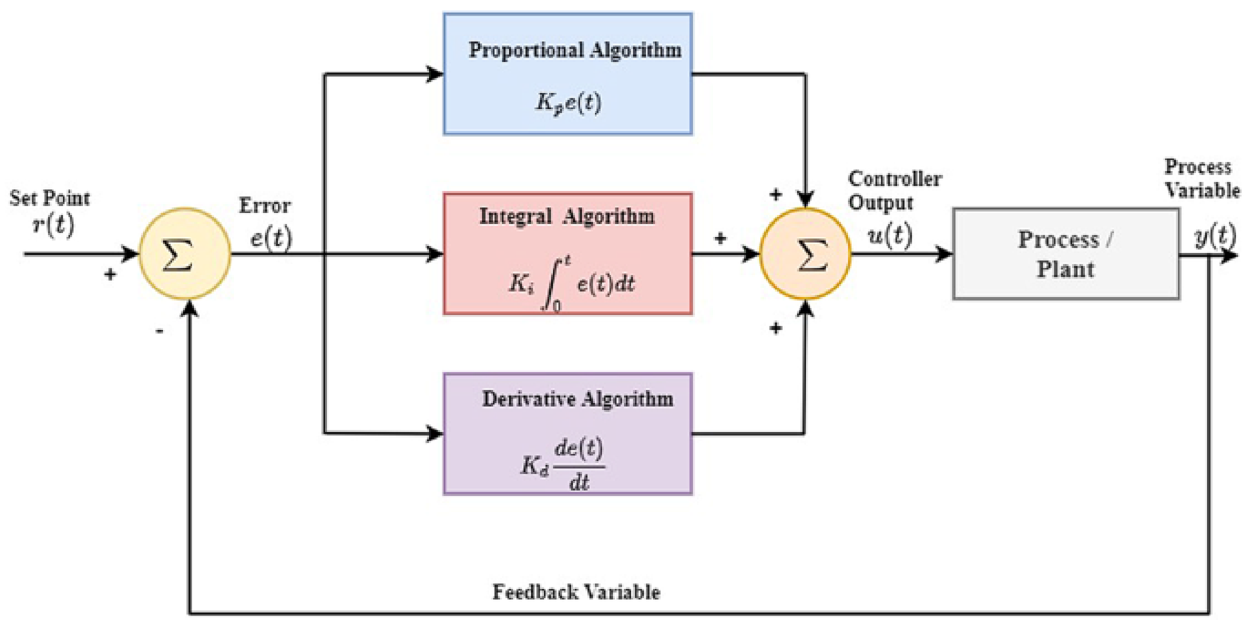


Figure 5 : PID Controller

CODE

```
#include <Servo.h>
#include <Ultrasonic.h>

// Define constants
const int setpoint = 16;  // desired distance for the ball from the sensor
const int servo_center = 88;  // servo center position

const double kp = 0.01;  // proportional gain
const double ki = 0.005;  // integral gain
const double kd = 6;  // derivative gain

// Define variables
int distance = 0;
double error, last_error, total_error, P, I, D, pid_value;

// Create objects
Servo myservo;
Ultrasonic ultrasonic(12, 13);

void setup() {
  myservo.attach(9);  // attach servo to pin 9
  myservo.write(servo_center);  // set initial position to the center
  Serial.begin(9600);   // initialize serial communication
}

void loop() {
  // Read distance from ultrasonic sensor
  distance = ultrasonic.read();
  if(distance<35){
```

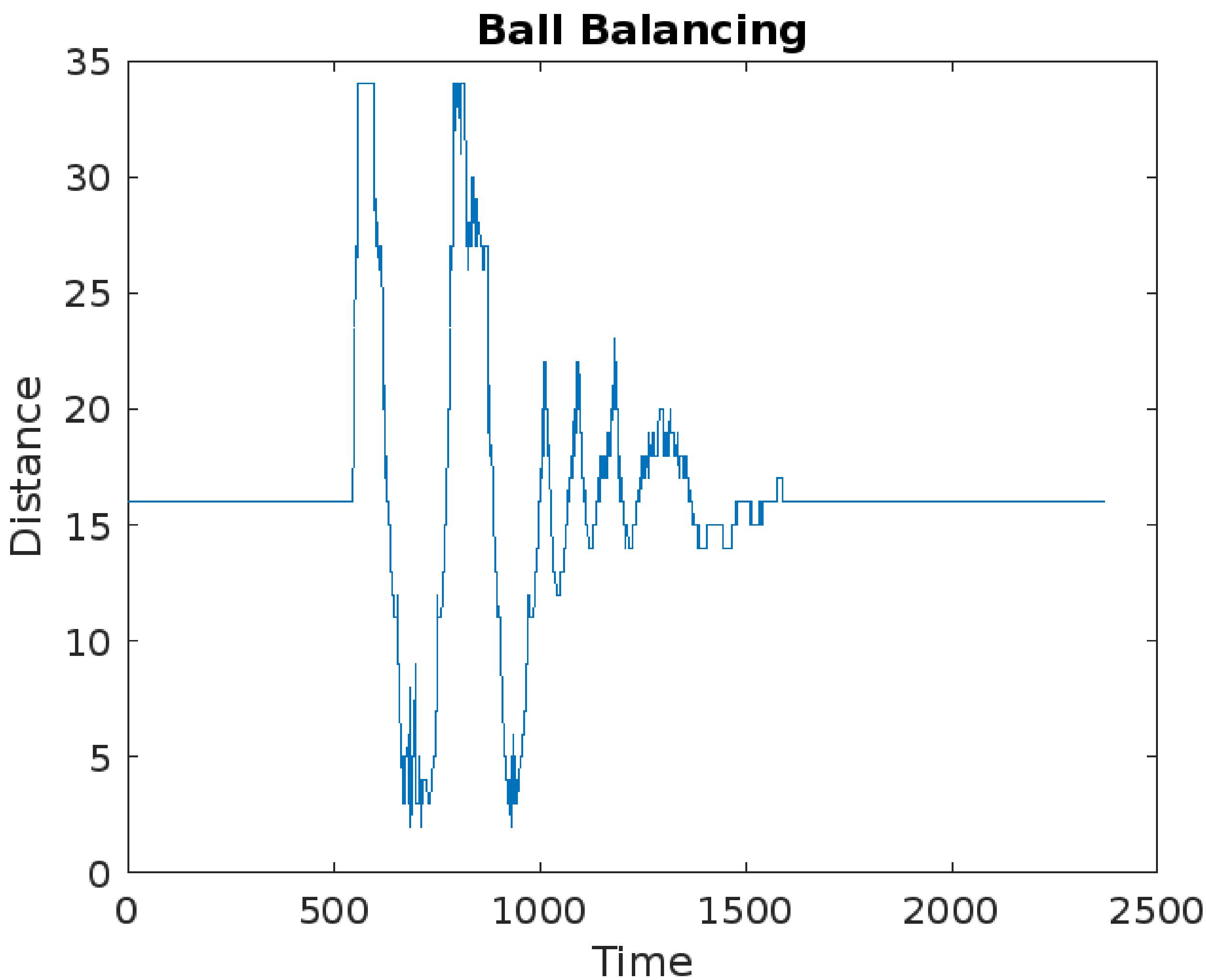
```
  Serial.print("Distance in CM: ");
  Serial.println(distance);

  // Calculate error
  error = setpoint - distance;
  P = kp * error;  // calculate proportional term
  total_error += error;  // update integral term
  I = ki * total_error;  // calculate integral term
  D = kd * (error - last_error);  // calculate derivative term, Note: the time division
factor is removed since the time gap is constant (10ms) and it gets compensated in
the value of kd.
  last_error = error;  // update last error
  pid_value = P + I + D;  // calculate PID value

  myservo.write(servo_center - pid_value); // move servo towards the desired position

  delay(10);  // wait for servo to move
}
}
```

RESULTS

The total length of the rod taken was 32cm. The ball was made to balance at the at 16 cm. The desired location was provided in the code.

The time gap between two readings is 10ms. Since this time gap is constant, the time term in the differential term of the code was removed. The differential constant K_d gets scaled correspondingly.

By trial and error optimisation, the PID constants were found to be $K_p = 0.01$, $K_i = 0.005$, $K_d = 6$, we get a ball balancing system which provides a graph which corresponds to the one below,



REASONS FOR MISMATCHING

- The Ultrasonic sensor could not detect the exact location of ball. It had noise and random fluctuations at some points.
- Controlling the servo from the center rather than the end lead to high torque and sudden jerks.
- Errors while measurement.
- The ball on the beam may be affected by some external disturbances

SCOPE OF IMPROVEMENT

- Better ramp fabrication with slots for the sensors for accurate orientation of the sensor.
- Refining the constants
- Minimizing the jerk felt by the ball

REFERENCES

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- A review of PID control, tuning methods and applications | SpringerLink

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