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LAB 4

BALL CONTROL: IR PROXIMITY SENSOR

Adolfo Tec
Undergraduate Student
Mechanical Engineering
University of California
Berkeley, California 94720

Cozmo Nakamura
Undergraduate Student
Mechanical Engineering
University of California
Berkeley, California 94720

Katherine Hom
Undergraduate Student
Mechanical Engineering
University of California
Berkeley, California 94720

ABSTRACT

This lab explores a system using an infrared (IR) sensor and fan to control the position of a ping pong ball. The output voltage of the IR sensor and ball position were characterized by measuring the voltage using a custom LabVIEW VI and half-inch marks on the sides of the tube. These values were fit to a 3rd order polynomial using MATLAB. LabVIEW's built in Proportional Integral Derivative (PID) control block was used to implement feedback control, with gains determined by trial and error. Noise, lack of significant figures, and faulty equipment initially led to high degrees of error in our system. After resolving these issues, the feedback control implemented in our VI worked very well, with accurate steady state responses. The average height at steady state was within a half-inch of the desired height, with less than a half-inch standard deviation. Thus, PID control with an IR sensor to measure the displacement of the ball was sufficient to control the system relatively accurately.

INTRODUCTION

Given a sensor, a control system can be developed to control the variable measured. A control system for the position of the ping pong ball can be created using a test stand consisting of a hollow tube with multiple airflow holes, a fan, and an IR sensor.

Before testing, the IR sensor should be calibrated by manually positioning the ball to a set position and measuring the IR voltage at that position. Following calibration, a LabVIEW VI can be created to control the position of the ball by measuring the position of the ball and adjusting the fan voltage using a PID control. Considering the inaccuracies of the IR sensor from the previous lab, it was predicted that the system would not be able to accurately control the desired position of the ball.

Contrary to our initial assumptions, the feedback control system had accurate steady state responses, with less than a half-inch differences between the average heights and desired heights. The standard deviations were also less than a half-inch. The PID control was able to reduce the overshoot, settling time, and stabilize the position, creating a system with fast response times and accurate steady-state responses.

THEORY

1. Infrared and Filtering

An infrared sensor consists of an emitter, optical component, detector, and signal processor. An IR LED can be used to emit the IR radiation, which is then focused by an optical component such as a quartz lens. The IR light deflected off the target is then captured by an IR photodiode detector, usually a semiconductor. The magnitude of the captured IR is then transformed into a signal and amplified, since the captured signals are usually small [3].

As determined previously, IR sensors do not have a linear voltage-position relationship. A polynomial function was used to convert the position values to corresponding voltage values derived from the calibration. This lab will re-verify the appropriate fit according to the collected data for calibration.

Because a fan is used to control the position of a ping pong ball in this lab, the system itself is naturally noisy. In order to have a robust position controller, noise in the system must be reduced as much as possible. One way to reduce noise in this system is to reduce the noise recorded by the measurement devices, namely, the IR sensor. Noise of an IR sensor can be reduced by applying a filter that cuts off frequencies above the sampling frequency of the sensor [2]. An appropriate filter that does this is a low-pass filter, as depicted in Fig. (1).

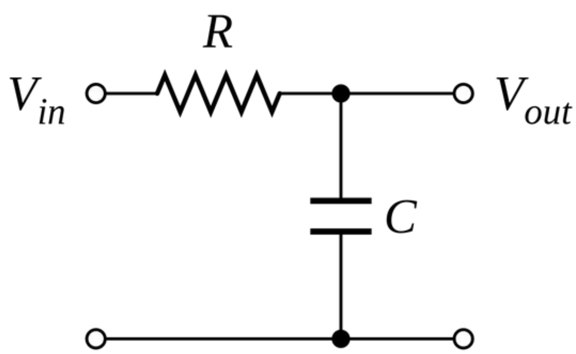

FIGURE 1: A SIMPLE RC LOW PASS FILTER CIRCUIT

A low-pass filter passes low-frequency signals below a certain cutoff frequency and attenuates signals with frequencies above the cutoff frequency, hence the name. The cutoff frequency of an RC circuit can be found by:

$$f_{cutoff} = \frac{1}{2\pi RC} \tag{1}$$

2. Proportional Integral Derivative (PID) Control

PID control is the most common control algorithm due to its robustness and wide range of operating conditions. It consists of three different coefficients: proportional, integral, and derivative.

Proportional gain (K_c) determines the ratio of the output response to the error signal. Generally, increasing this improves the response of the control system. However, a K_c that is too high can cause instabilities. [4]

The integral control sums the error over time, driving the steady state error to zero. Large integral time (T_i) can result in windup, where the system continues to overshoot. [4]

Derivative control reduces the output proportional to the rate of change of the variable. Increasing derivative time (T_d) causes the system to react more strongly to changes in the error term, increasing the overall control response speed. Because T_d is highly sensitive to noise, T_d values tend to be small. Particularly high values of T_d can lead to instabilities if the feedback system is noisy or if the control loop rate is too slow. [4]

The proper PID values can be obtained by trial and error, though many tuning methods exist. The Ziegler-Nichols method, also applicable for P (only proportional gain) and PI (proportional and integral gain only), involves the following steps:

1. Start with all PID coefficients at 0
2. Increase the proportional gain until the loop starts to oscillate
3. Record the critical K_c and period of oscillations P_c
4. Adjust the other variables according to the following Table. (1):

TABLE 1: ZIELER-NICHOLS METHOD TABLE

Control	P	T_i	T_d
P	$0.500K_c$	-	-
PI	$0.450K_c$	$0.833P_c$	-
PID	$0.600K_c$	$0.500P_c$	$0.125P_c$

Caption for ZN table

These values can then be input to the PID control block in LabVIEW.

3. Uncertainties

Statistical analysis of error shows that there are multiple ways of estimating a measurement errors based on using different probability distributions, the number of samples taken on a measurement, and the level of confidence, among other things [1]. Uncertainties for each sensor were found using the T-distribution uncertainty model given by Eqn. (2):

$$P_x = t_{\frac{\alpha}{2},\nu} \frac{S_x}{\sqrt{n}} \tag{2}$$

Where P_x is the precision uncertainty, α is the level of significance, S_x is the estimate for the mean of the data sets, n is the number of data sets, and t is the probability density function coefficient specific to the number of measurements taken [1].

This uncertainty model was employed due to the fact that not a large number of experiments were ran (i.e. greater than 30 experiments).

PROCEDURES

1. Equipment

- ☐ PXI-4110 controllable DC power supply
- ☐ PXI-4070 digital multimeter (DMM)
- ☐ National Instruments LabVIEW
- ☐ Test Stand
    - ☐ SHARP GP2Y0A41SK0F IR sensor
    - ☐ Fan
    - ☐ Tube with Airflow holes
    - ☐ Ping pong ball
    - ☐ Half-Inch Increment Tape Ruler
    - ☐ Breadboard
- ☐ Low Pass Filter (Optional)
    - ☐ 5k Resistor
    - ☐ .47 μF Capacitor
- ☐ Screwdriver set or any thin tool

2. Testing

First, the fan and the SHARP GP2Y0A41SK0F IR sensor are connected to the PXI-4110 controllable DC power supply on the breadboard, beginning the low-pass filter shown in Fig. (1) as the signal V_{in}. The PXI-4070 digital multimeter (DMM) is then connected to read the IR sensor voltage after the low-pass filter circuit, V_{out}. Values for the resistance and capacitor values were found using Eqn. (1), where the cutoff frequency was found to be around 60Hz [5]. A resistance of 5000ω was arbitrarily chosen, to yield a capacitance value of about 0.5μF. To simplify the physical circuit, a readily available 0.47μF capacitor was used instead.

Once the circuit is built, the IR sensor is calibrated. The IR sensor and fan are powered on with 5V and 20V respectively, and the the ball is moved to its maximum height, and held there with screwdrivers. To calibrate the sensor, the IR sensor voltage is read at multiple ball positions fixed by the screwdrivers. The position measurements for our tests were measured from the top of the ball.

With these measurements, a calibration curve can be created in MATLAB using the measured voltage and position readings. MATLABs built in polyfit can be used to create fit equations of varying polynomial orders. Once a sufficient polynomial is generated, the resulting fit equation can be used in a LabVIEW VI to convert voltage values to position values and vice versa.

Finally, a simple control algorithm is created. One option is to use the PID control block, built into LabVIEW. By adjusting the PID gains a simple, stable system can created. The PID gain values can either be determined by trial and error or by using theory.

3. Precautions

- ☐ Don't forget to turn on (and later off) all of the equipment. Make sure to power all of the needed sensors before attempting to take measurements.
- ☐ When creating fits with MATLAB code, remember to copy as many decimal points as possible. This especially applies when the coefficients are small, as the significant figures become important.
- ☐ Verify that each piece of equipment functions, and does so with reasonable accuracy, before proceeding with the lab. This should be done for every different sitting and every piece of equipment, to debug which pieces of equipment are damaged.

RESULTS AND DISCUSSION

Using a measuring tool on the tubes surface, the IR sensors voltage was measured at various positions. The tool ranged from 0 to 30 half-inches. The data is displayed in Fig. (2) with an overlaid second and third order fit. A fourth order polyfit on MATLAB resulted in a coefficient of 0.0000 associated with the fourth degree term. The value was not significant enough to be considered a fourth order equation. Thus, it was not included in the plot.

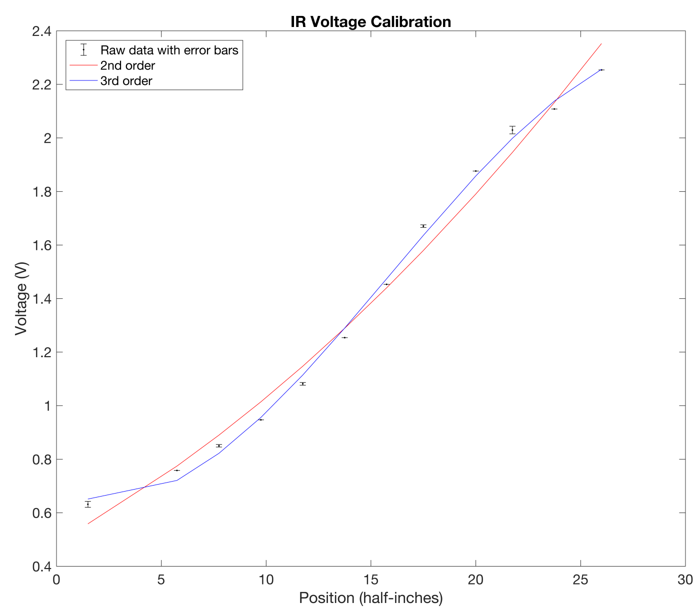

FIGURE 2: VOLTAGES MEASURED AT VARIOUS POSITIONS. ERROR BARS, ALONG WITH 2ND AND 3RD ORDER FITS

This data was taken after implementing a low pass filter. It was previously done without one, but large visual errors inhibited further data analysis.

As portrayed in the figure, a third order fit was most appropriate. The third order fit was found to be:

$$y = -1.66735 * 10^{-4}x^3 + 7.97000 * 10^{-3}x^2 - 0.0340690x + 0.684706 \quad (3)$$

Originally, this equation was not recorded with as many significant figures. However, large errors in our control even after implementing a low pass filter led us to return to the equation and check for errors. The first coefficient had originally been approximated as $2.00 * 10^{-4}$, but this value varied too greatly from the actual value.

Eqn. (3) was then used in our VI to calculate the expected voltage for the desired height, and is inverted to convert the measured voltage into position readings. A screenshot of the VI block diagram is shown in Fig. (3). The leftmost group of orange blocks convert the indicated height into volts, which is then compared to the measured voltage. The difference passes through a PID control, and then is used to alter the fan strength as needed to reach the desired height. The topmost group of orange blocks converts the voltage data into height, to generate position versus time data.

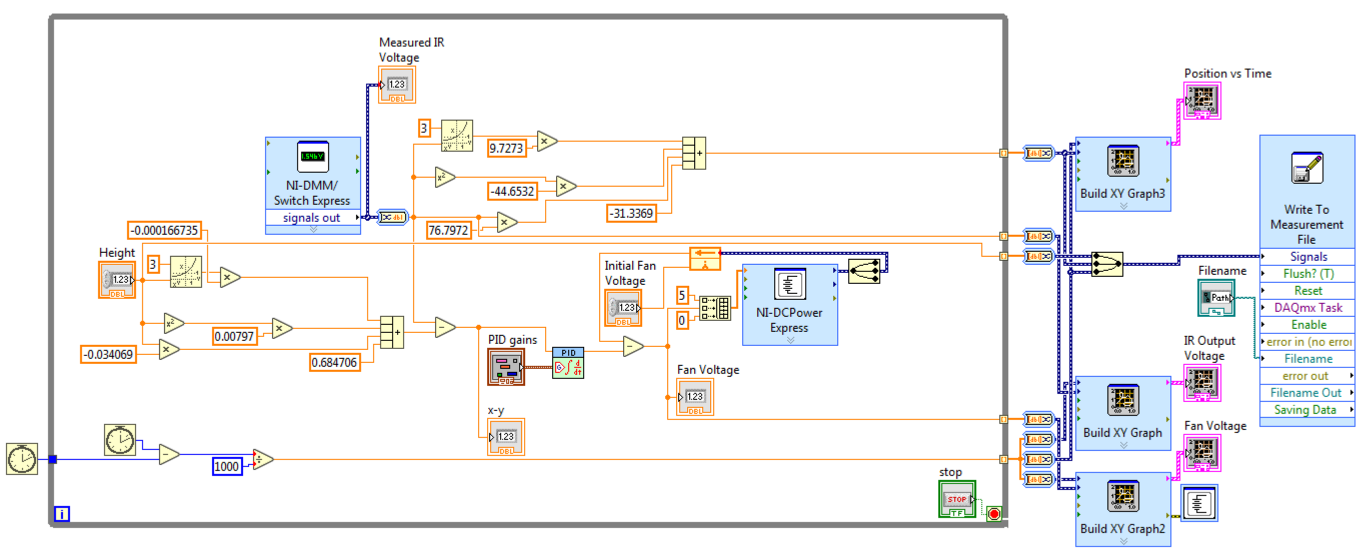

FIGURE 3: FINAL LABVIEW VI BLOCK DIAGRAM USED TO REACH DESIRED HEIGHT

Using trial and error, the PID gains are set to optimize the amount of overshoot relative to time required to reach desired height as indicated in Table. (2), the ball was able to reach the desired height with relatively small error. The results of our feedback can be seen in Fig. (4). The steady state responses to each of the positions is fairly accurate and close to our target positions as seen in Fig. (5). The peaks in error occur when the target position is changed. Other than the transition errors, the error centers approximately around zero.

TABLE 2: PID GAINS TABLE

Proportional Gain (K_c)	0.800
Integral Time (T_i, min)	0.500
Derivative Time (T_d, min)	0.100

Details on the time intervals in Fig.(4).

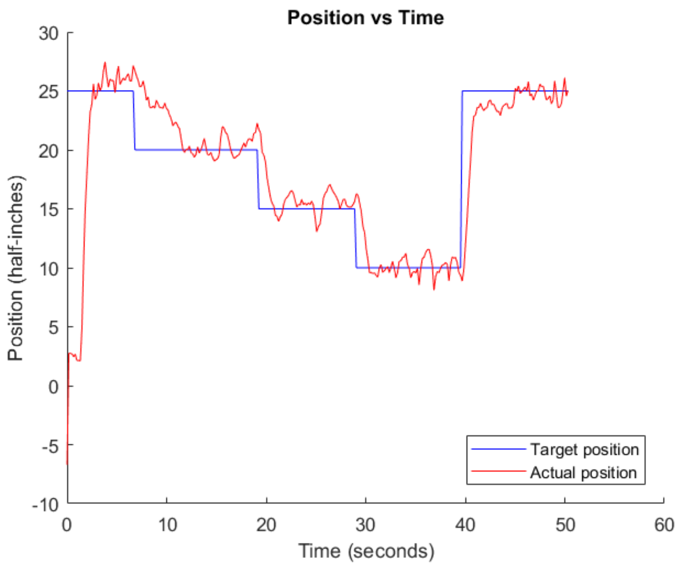

FIGURE 4: MEASURED FEEDBACK RESULTS. TARGET POSITION WAS CHANGED FROM 0 TO 25,20,15,10 AND 25 (1/2 IN)

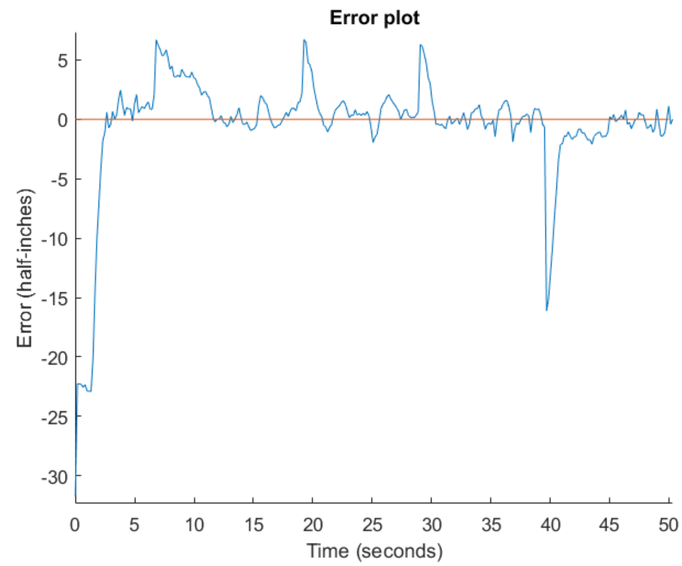

FIGURE 5: THE CALCULATED ERROR OF THE BALL POSITION

Table. (3) shows calculated time and position details from the data shown in Fig. (4). The ball was able to reach and stabilize less than half an inch from the designated height for each target change, as indicated by the listed average positions after first reach. In addition, the standard deviation is less than a half inch as well, which is also fairly low.

TABLE 3: TIME AND POSITION ANALYSIS OF FEEDBACK RESULTS

Target Position (1/2 in)	Average Height (1/2 in)	STD (1/2 in)	Time Interval (s)	Rise Time (s)
25.0	25.9	0.762	0-2.59	2.59
20.0	20.2	0.767	6.73-11.7	4.94
15.0	15.4	0.875	19.1-20.8	1.72
10.0	10.1	0.726	28.9-30.3	1.43
25.0	24.8	0.616	39.5-45.0	5.47

Details on the time intervals in Fig.(4).

CONCLUSION

After fixing errors with significant figures, noise, and faulty tools, the implemented control system was able to reach a level of accuracy and stability predicted in the hypothesis. The process of debugging and optimizing the control system was tedious, but resulted in a more stable and fast control system than originally predicted. However, results from this lab do not verify that the model used to relate the relationship between the IR voltage and position is valid.

The testing process could be improved by being more aware of possible error causes that are common in control system setups and general experiments. Significant figures and equipment functionality checks should be of high emphasis to reduce error. Equipment checks should be done for every test sitting in case of equipment damages or failures between sittings. This can remove sources of error before they become more difficult to locate. With large magnitude of error, even the most optimal control system cannot produce accurate results.

Appendix A: Extra Data

TABLE 4: IR VOLTAGE UNCERTAINTY VALUES AT DIFFERENT POSITIONS

Position (1/2 in)	Uncertainty (mV)
1.50	11.2
5.75	0
7.75	4.97
9.75	0
11.8	5.17
13.8	0
15.8	0
17.5	5.17
20.0	0
21.8	14.1
23.8	0
26.0	0

Details on the time intervals in Fig.(4).

REFERENCES

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[5] SHARP, *GP2Y0A41SK0F Distance Measuring Sensor Unit*, Sheet No. OP13008EN