RYERSON UNIVERSITY

Faculty of Engineering and Architectural Science

Department of Mechanical and Industrial Engineering

Program: Mechanical Engineering

Course Number	**MEC751**
Course Title	**Measurements, Instruments, and Sensors**
Semester/Year	Fall 2016
Instructor	**Dr. Ghasempoor**

PROJECT NO.	**1**

Report Title	**Final Report – Linear Fume Tracker**

Section No.	
Group No.	
Submission Date	
Due Date	**November 28, 2016**

Name	Student ID	Signature*
Victor Callisto		
Wilson Chu		
Herman Woo		
Kirollos Elmasry		

(Note: remove the first 4 digits from your student ID)

**By signing above you attest that you have contributed to this submission and confirm that all work you have contributed to this submission is your own work. Any suspicion of copying or plagiarism in this work <u>will result in an investigation of Academic Misconduct and may result in a "0" on the work,</u> an "F" in the course, or possibly more severe penalties, as well as a Disciplinary Notice on your academic record under the Student Code of Academic Conduct, which can be found online at: http://www.ryerson.ca/senate/policies/pol60.pdf.*

Executive Summary

In this design project, a prototype of a Linear Fume Tracker was created. This system consisted of two blocks representing components of a typical linear tracker: a fume extractor hood, and a welding gun. In normal operation, the welding gun is user-controlled and moves along a work piece. The fume extractor hood follows the welding gun in order to maintain clean air around the welder. In this project, the fume extractor hood was represented with a miniature car (follower) and the welding gun was represented with a movable solid surface mounted on a linear rail. As the solid surface was moved along the track, the follower moved with the surface in order to maintain a 100 mm (10.0 cm) distance between the two objects. The welding gun model was limited in movement to 50 mm (5.0 cm) in each direction on the rail. A Sharp IR Sensor, 4-speed high torque Tamiya motor kit, motor driver, and 5VDC power supply were provided for the fabrication of this project. Using these devices and other building materials, a mechanical design was made for the entire Linear Fume Tracker model. A DAQ board and LabVIEW was used to control the motion of the follower, so that its movements behaved in a manner that resulted in minimal response time, settling time, and overshoot. Eventually, through several iterations, a final design and prototype were developed that satisfied all the project requirements. A complete analysis of the performance of the follower system was then completed.

Table of Contents

1.0 Introduction

This design project purpose was familiarizing us with the behavior of sensor/control system and to create a model of the Linear Fume Tracker. A small-scale car was to symbolize the fume extractor, while the movable welding gun was represented by a simple solid surface mounted on a track. LabVIEW is used to program the DAQ board to control the motor and sensor on the car. The goal was to keep both bodies at a constant distance of 10 cm. A Sharp Infrared Proximity Sensor was used to detect the distance between the two bodies. And a motor driver (ModelDVR8833) was used to maneuver the car to keep the required distance. Our motor gear ratio was set to 74:1 (torque of 876 gf·cm), which we, as group felt was the appropriate and needed torque to reach acceptable results. There were several modifications made to our original design that will be thoroughly discussed in this paper. This report will also provide detailed analysis on various components and designs of our project.

2.0 Description of Mechanical System

The design of the prototype of the Linear Fume Tracker somewhat resembled a miniature car on a track. The fume extractor hood (follower) was represented by the miniature car, while the movable welding gun was represented by a simple solid surface mounted on a track. For the follower, the motor and gearbox were enclosed in a case made of rigid foam board, connected together with screws, glue, and electrical tape. Wheels were directly attached to the axle of the motor box. A small breadboard was used to neatly group all the connecting wires from the DAQ board to the motor driver and sensor on the follower. The motor driver was placed on top of the car, behind the motor. A Sharp Infrared Proximity Sensor was used to detect the distance between the follower and the movable solid block. The sensor was connected to the front of the car by mounting it against the foam board gearbox casing with screws. The second movable block was simply a plane of wood, with small supports behind it to keep it upright. This is what will be user-controlled during the demonstration of the Fume Tracker model. Both the follower and movable block are mounted on top of a linear track, which is itself placed on top of a flat wooden surface. Both the follower and moving block slide on top of the track to ensure that all movement will be linear during the demonstration of this system. All loose wires between the DAQ board and the motor were grouped together with electrical tape and zip-ties in order to prevent any wire disconnections during the operation of the model. The DAQ board and breadboard were placed aside, away from the main Linear Fume Tracker setup, to prevent any possible interferences with any operations.

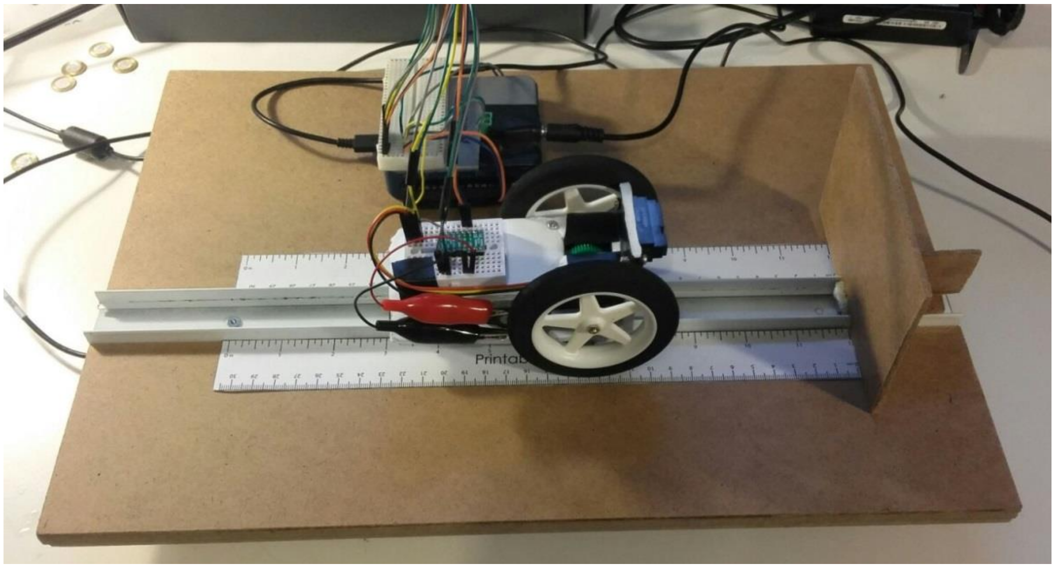

Figure 1: The final design of the Linear Fume Tracker model

The store-bought wheels attached to the follower had a diameter of 7.0 cm. It was determined that one revolution of the wheel would result in a movement of approximately 22.0 cm. The constraints of this project limits the maximum distance travelled to be 10.0 cm (a range of 5.0 cm each direction), so this wheel design was deemed to be sufficient for the project requirements. Given the size of the wheels, only about half of a revolution of each wheel was expected to be needed to satisfy the project requirements.

The gearbox of the follower was constructed from a 4-speed high torque Tamiya motor kit, which was provided for this project. The gear ratio used in the gearbox of the follower design was set to 74:1, which generated the maximum possible torque of 876 gf·cm or approximately 0.0859 N·m. This translated to a rotational speed of approximately 136 rpm. A much higher torque (or conversely, less rotational speed) would have been preferable for the purposes of this project but was not possible due to the capabilities of the provided motor system. Smaller, heavier wheels were considered for the follower design in order to reduce the effects of the high rotational speed, but this implementation was found to also increase the overshoot of the follower system. It was decided that the increased overshoot adversely affected the performance of the system too significantly, so the 7.0 cm wheels were kept.

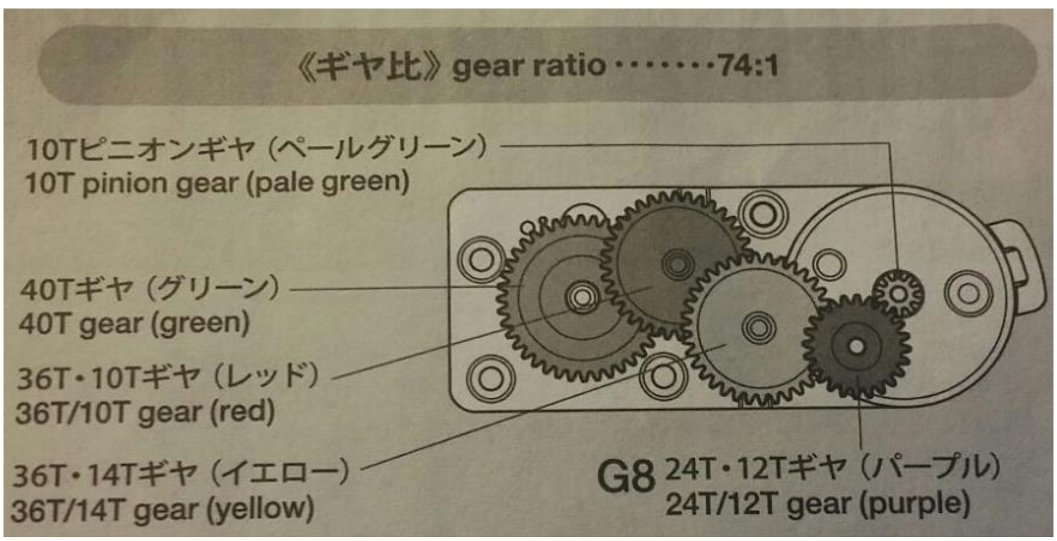

Figure 2: A diagram of the gearing used in the gearbox of the follower.

3.0 Description of Electrical System

All of the components in the electrical system were provided, and the program which runs the DAQ is available online for free. The following is a summary of the main function each component serves within the main setup, a block diagram of their wiring connections, and a flow chart detailing how the components communicate.

3.1 Description of Electrical Components

COMPUTER (LabVIEW 2016)

- The monitor provides a graphical display of data in the system
- The keyboard provides user input for desired values in the system
- The CPU generates the real time graphs and displays the response of the electrical system
- Power is provided to the DAQ, and data is transferred back and forth via USB connection
- Houses LabVIEW, the main function of directing how the DAQ handles electrical signals

DATA ACQUISITION (National Instruments USB-6001)

- Acquires a voltage signal and generates a numeric value to be seen on the front panel
- Provides 5V power to IR sensor
- Processes signal received from IR sensor through an analog in port and based on LabVIEW program that is implemented, sends square waves out of two analog out ports

Figure: Data Acquisition Board – National Instruments USB-6001(http://antronic.co.th/images/Products/Products/11-05-45-2.png)

.

DISTANCE SENSOR (Sharp IR Sensor)

- Send out an IR signal and receives a signal back
- The quicker the signal comes back the closer the object is
- This corresponds to outputting a certain voltage in the range of 0-5v depending on the feedback
- The output signal is sent from the Vcc port to the Ai0 Port on the DAQ

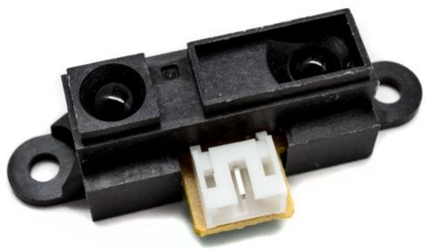

Figure : Distance Sensor (**https://www.upgradeindustries.com/media/img/hi_res/front_only_lg.jpg**)

MOTOR DRIVER (ModelDVR8833) + MOTOR (4-speed high torque Tamiya motor kit)

- If AIN1 receives a PWM signal from Ao0, it causes the 5v power supply to flow through AOUT1 to the motor and into AOUT2, which goes to the ground
- If AIN2 receives a PWM signal from Ao0, it causes the 5v power supply to flow instead through AOUT2 to the motor and into AOUT1, which goes to the ground
- The motor is able to spin in opposite directions based on these two actions, causing the electricity to flow in both ways through the motor's terminals
- If neither AIN1 or AIN2 receive a signal, the 5V power is blocked from entering either terminal of the motor, and as such the motor does not spin

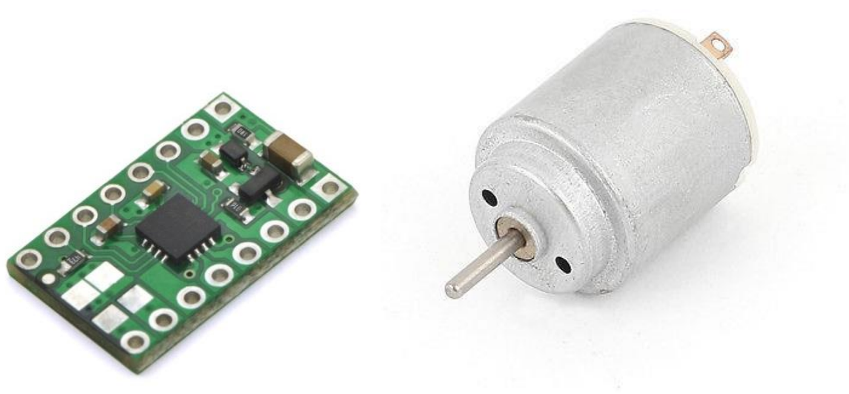

Figure: ModelDVR8833 and Type 140 DC motor

DC 5V POWER SUPPLY

- Receives electricity from wall outlet
- Supplies main power to the motor

Figure: 5V DC power supply

3.2 Block Diagram of Electrical System

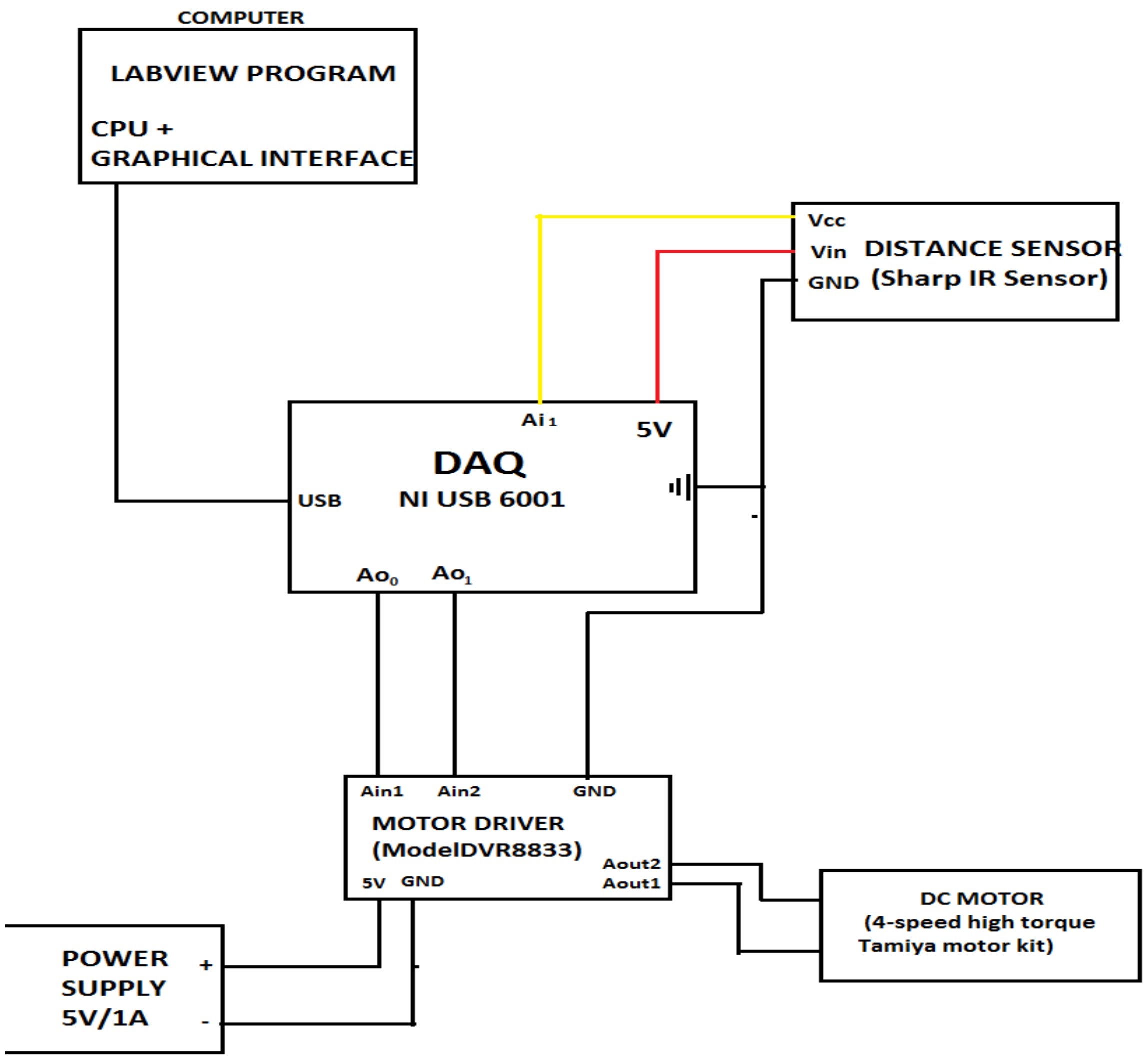

Figure 3: Block diagram of electrical system

3.3 Flowchart of Electrical System

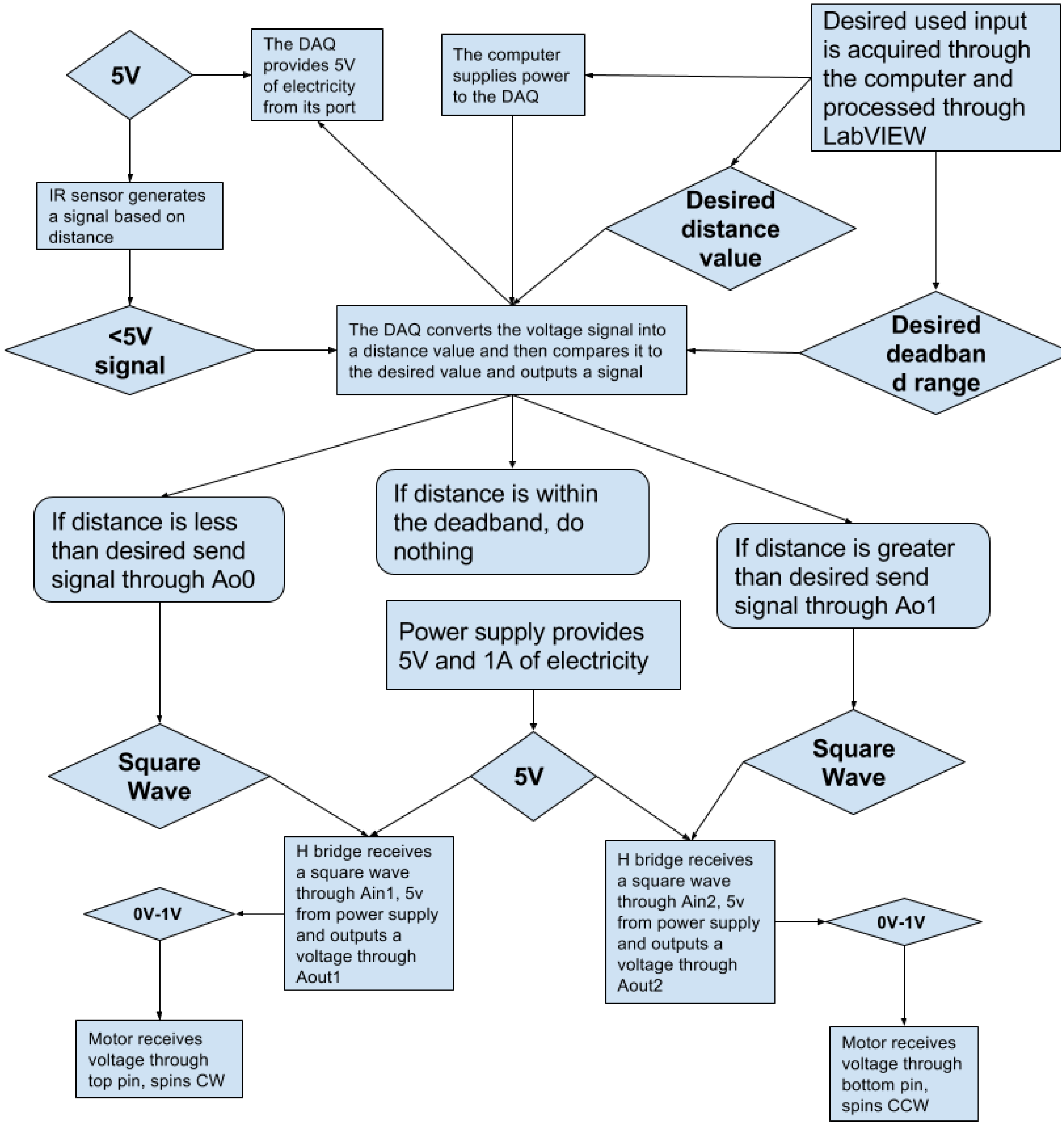

Figure 4: Flowchart of general electrical system setup

4.0 Description of Control System and LabVIEW Program

The motor of this system is controlled using PWM (Pulse Width Modulation). A duty cycle is inputted into the Simulate Signal block so that a range of power can be controlled for the motor. The duty cycle is dependent on the PID system implemented in the LabVIEW program. PID control was used to increase precision and accuracy in the system. Firstly, the proportional control was implemented by multiplying the error read from the sensor by the proportional gain K_p and added that value to the duty cycle. This control decreases the rise time and therefore has a quicker response. The issue is that the P gain also increases the overshoot of the system and therefore needs a derivative controller to adjust for that. The integral control was implemented by using shift registers to add the initial I control to the error at after each response and multiply it by the integral gain K_I. Similar to the proportional control, the integral control increase the overshoot and decreases the rise time of the control system. The integral control will significantly decrease the steady state error, and is why it is implemented into the LabVIEW program. Lastly, the derivative control was designed into the program using shift registers by subtracting the current error by the previous error and then multiplying that by a derivative gain K_D. By inputting a small gain for the derivative, the program is able to decrease the overshoot whilst insignificantly affecting the other aspects of the control system. Therefore, the final design of the control system was made to give the best response time without overshooting the designated target too much. This was determined through testing different values for the PID. The group first started by adjusting the P value until a fair response was made. After that, I value was tested because it was found that the Integral gain would sometimes make the system worse over time, but in the cases tested, only a momentary action was used so would improve the response time a little bit. Lastly, D gain value was tested to improve overshoot to finalize the controller. These observations can be seen the PID graphs located in the Appendix.

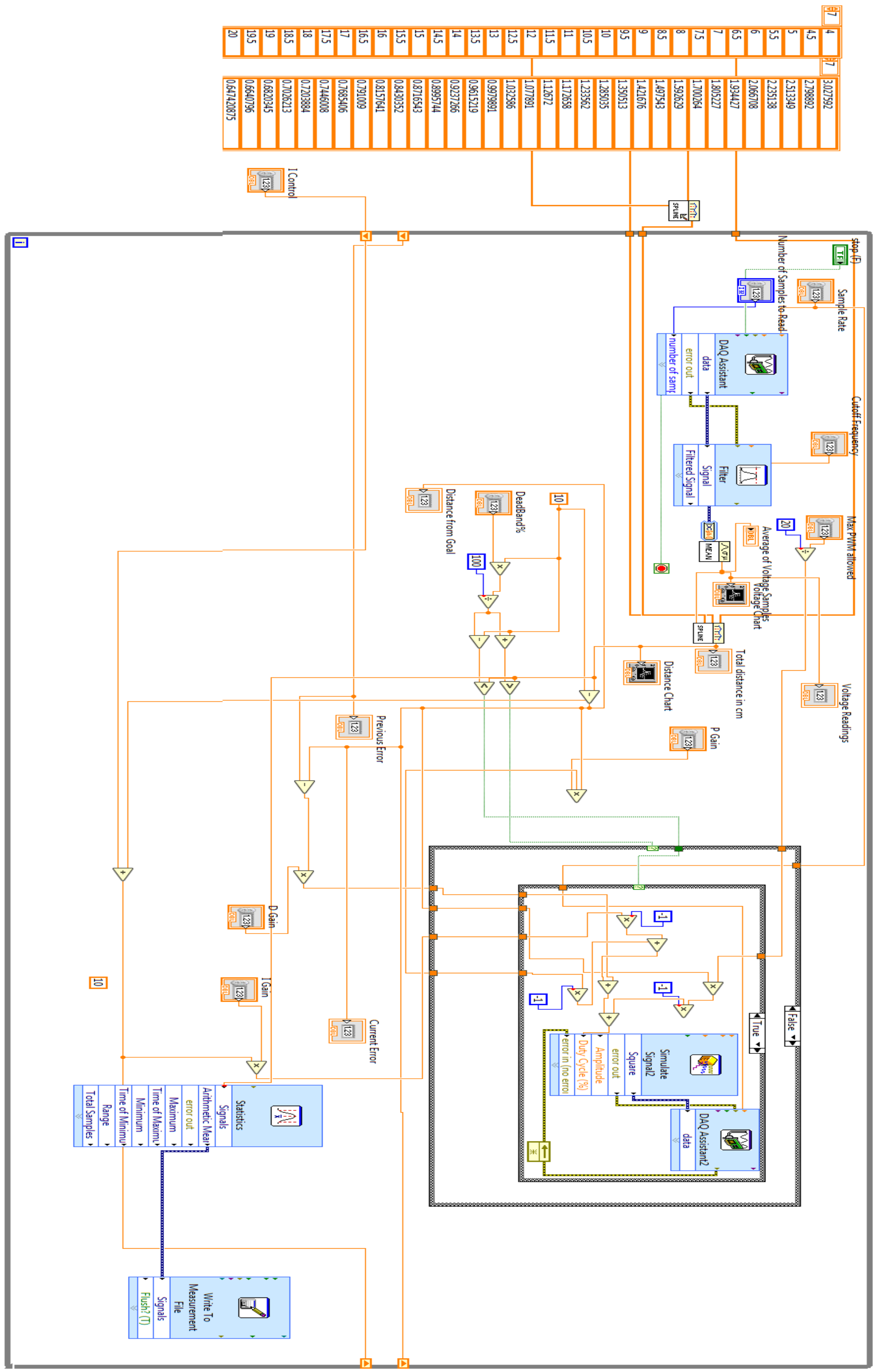

Figure 5: Block Diagram of Final Program

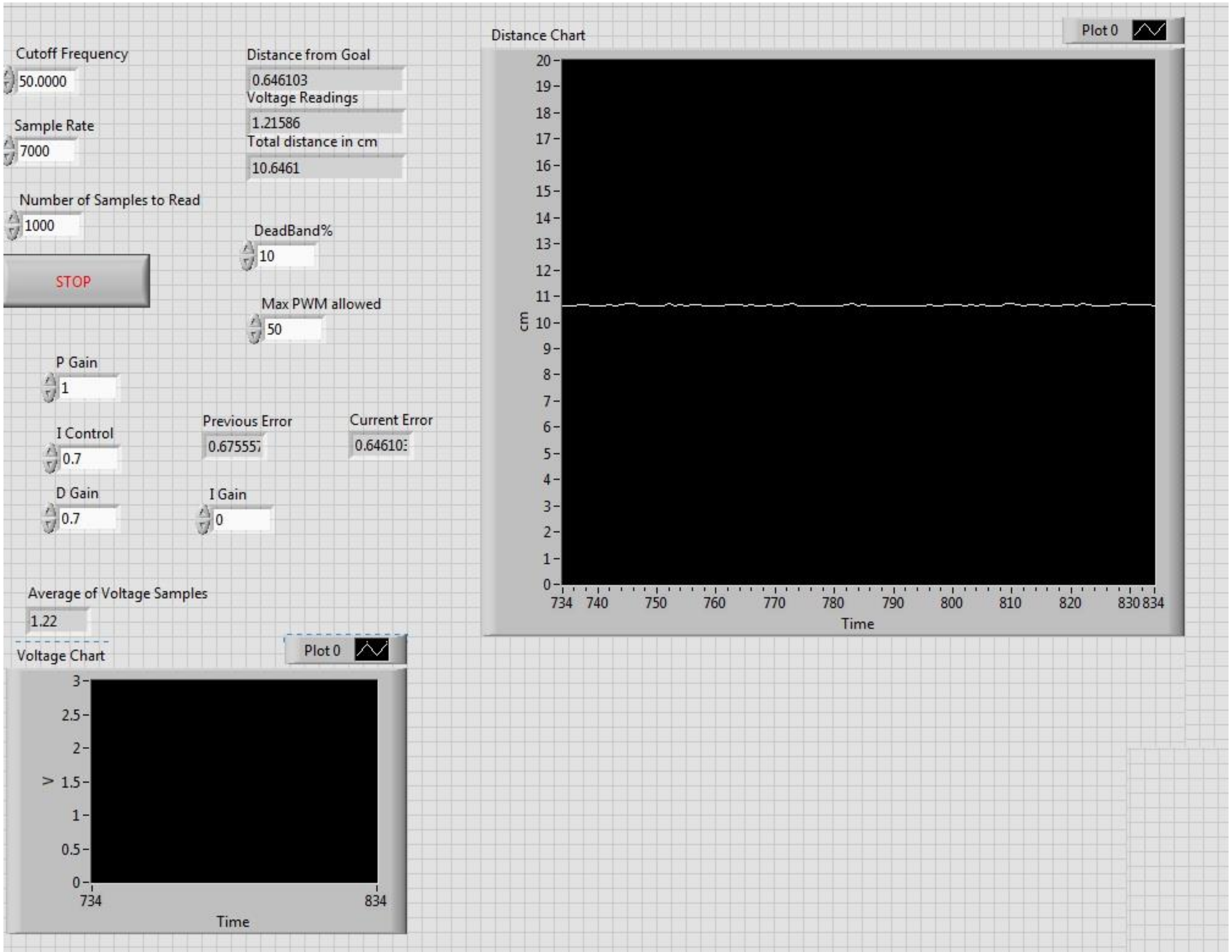

Figure 6: Front Panel of Final Program

5.0 Results

Below is the table used to store the calibration data which was used in the LabVIEW program to calibrate the sensor to the best of its ability.

Table 1: Calibration Data

Distance (cm)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10	Avg
1.00	1.37	1.36	1.32	1.32	1.34	1.35	1.34	1.34	1.34	1.34	1.34
1.50	1.60	1.63	1.67	1.68	1.74	1.83	1.97	1.87	1.89	1.85	1.77
2.00	2.18	2.18	2.18	2.18	2.11	2.11	2.03	2.03	2.00	2.08	2.11
2.50	1.96	1.96	1.98	2.00	2.00	2.00	2.11	2.05	2.07	2.04	2.02
3.00	2.41	2.42	2.58	2.51	2.59	2.77	2.74	2.82	2.79	2.79	2.64
3.50	3.05	3.05	3.08	3.07	3.08	3.08	3.09	3.09	3.09	3.09	3.08
4.00	3.05	3.08	3.06	3.05	3.03	3.02	3.00	2.99	2.99	3.00	3.03
4.50	2.88	2.84	2.82	2.83	2.82	2.79	2.74	2.77	2.74	2.75	2.80
5.00	2.60	2.54	2.58	2.48	2.55	2.48	2.49	2.42	2.56	2.43	2.51
5.50	2.32	2.28	2.24	2.25	2.27	2.22	2.20	2.20	2.20	2.19	2.24
6.00	2.12	2.11	2.08	2.08	2.04	2.05	2.05	2.05	2.03	2.05	2.07
6.50	1.99	1.98	1.96	1.94	1.92	1.93	1.91	1.91	1.91	1.91	1.93
7.00	1.85	1.85	1.81	1.81	1.79	1.80	1.79	1.78	1.78	1.79	1.81
7.50	1.72	1.74	1.70	1.79	1.68	1.69	1.68	1.67	1.67	1.66	1.70
8.00	1.63	1.64	1.59	1.61	1.58	1.58	1.57	1.57	1.58	1.57	1.59
8.50	1.48	1.54	1.52	1.52	1.50	1.48	1.50	1.48	1.49	1.48	1.50
9.00	1.45	1.45	1.42	1.42	1.42	1.43	1.41	1.41	1.41	1.41	1.42
9.50	1.38	1.38	1.35	1.37	1.35	1.35	1.33	1.33	1.33	1.33	1.35
10.00	1.31	1.31	1.29	1.29	1.27	1.28	1.27	1.27	1.28	1.27	1.29
10.50	1.28	1.25	1.24	1.24	1.24	1.22	1.22	1.22	1.22	1.22	1.23
11.00	1.19	1.19	1.17	1.18	1.18	1.18	1.16	1.16	1.16	1.16	1.17
11.50	1.15	1.14	1.13	1.13	1.12	1.12	1.11	1.11	1.12	1.12	1.13
12.00	1.10	1.10	1.08	1.08	1.08	1.08	1.06	1.06	1.06	1.06	1.08
12.50	1.06	1.04	1.04	1.04	1.01	1.03	1.03	1.03	1.02	1.03	1.03
13.00	1.02	1.01	1.01	1.01	0.99	0.99	0.99	0.99	0.99	0.99	1.00
13.50	0.99	0.97	0.97	0.99	0.95	0.95	0.95	0.95	0.95	0.95	0.96
14.00	0.94	0.93	0.93	0.93	0.93	0.91	0.91	0.91	0.91	0.91	0.92
14.50	0.91	0.91	0.90	0.90	0.90	0.91	0.90	0.89	0.88	0.89	0.90
15.00	0.88	0.88	0.88	0.88	0.86	0.87	0.87	0.86	0.87	0.86	0.87
15.50	0.86	0.86	0.84	0.85	0.85	0.85	0.83	0.83	0.83	0.83	0.84
16.00	0.83	0.84	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81	0.82
16.50	0.80	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
17.00	0.79	0.79	0.77	0.77	0.77	0.77	0.76	0.75	0.76	0.77	0.77

17.50	0.77	0.77	0.75	0.75	0.74	0.75	0.73	0.73	0.73	0.73	0.74
18.00	0.75	0.73	0.73	0.73	0.71	0.71	0.71	0.71	0.71	0.71	0.72
18.50	0.73	0.73	0.71	0.71	0.69	0.69	0.69	0.69	0.69	0.69	0.70
19.00	0.71	0.69	0.69	0.69	0.67	0.68	0.67	0.67	0.67	0.67	0.68
19.50	0.69	0.69	0.67	0.67	0.65	0.66	0.65	0.65	0.65	0.65	0.66

The following graphs represent the final system for the follower demonstrating a step response, varying the position three times to see the difference between forwards and backwards motion, and to also see how distance affects the response as well.

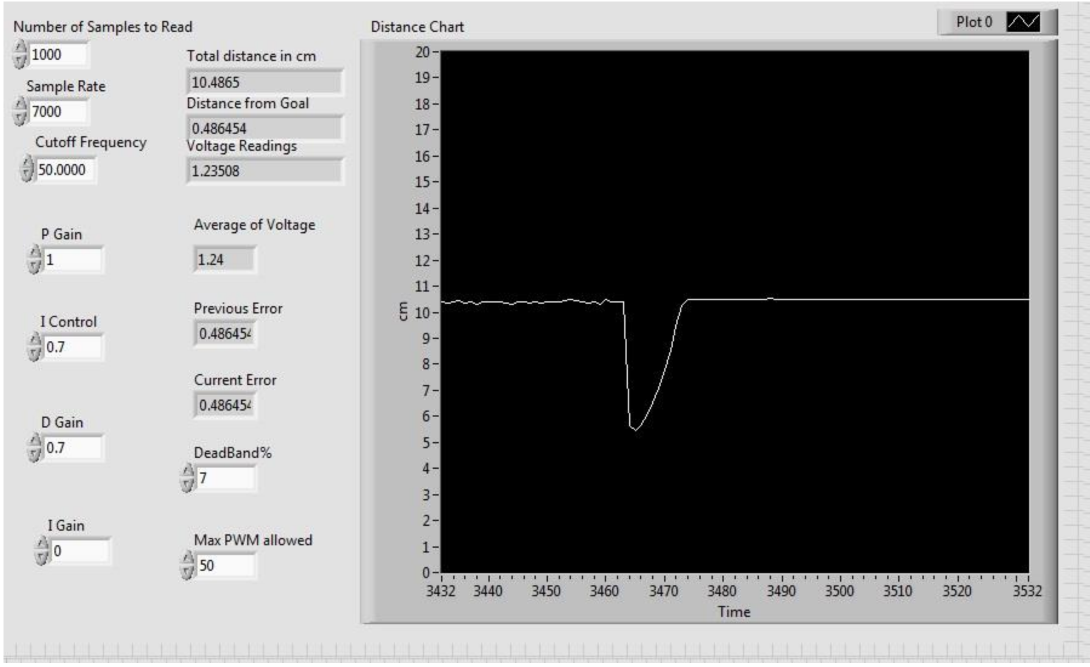

Figure 7: Final Program (5-10cm)

It is important to note that the time taken from LabVIEW did not start from 0 every time, so adjustments were made for calculations.

D is distance for the following calculations.

deltaD = maxD – minD

delatD = 10.48853 cm- 5.43579 cm = 5.05274 cm

.63deltaD = (.63*deltaD) + minD = (.63*5.05274 cm) + 5.43579 cm

.63deltaD = 8.619 cm

The correlating time with this distance is roughly .868 seconds.

Time Constant ≈ .868 seconds

Rise Time ≈ 1.571 seconds

Settling Time ≈ 4*Time Constant ≈ 3.472 seconds

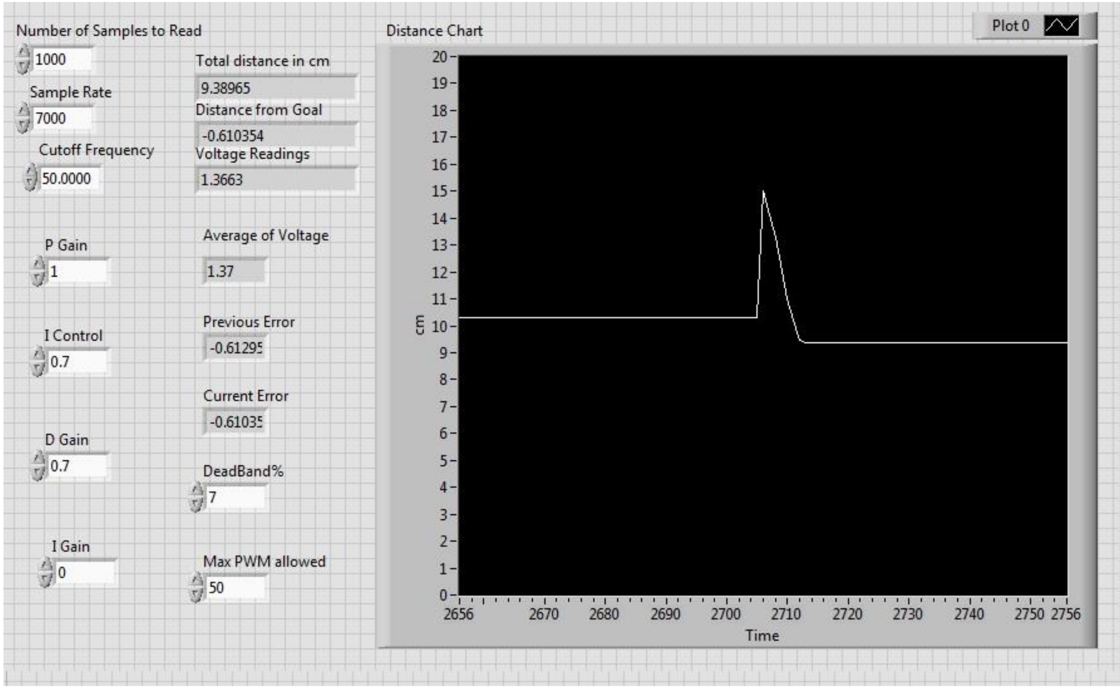

Figure 8: Final Program (15-10cm)

.63deltaD = 12.931 cm

The correlating time with this distance is roughly .317 seconds.

Time Constant ≈ .317 seconds

Rise Time ≈ 1.00 second

Settling Time ≈ 1.268 seconds

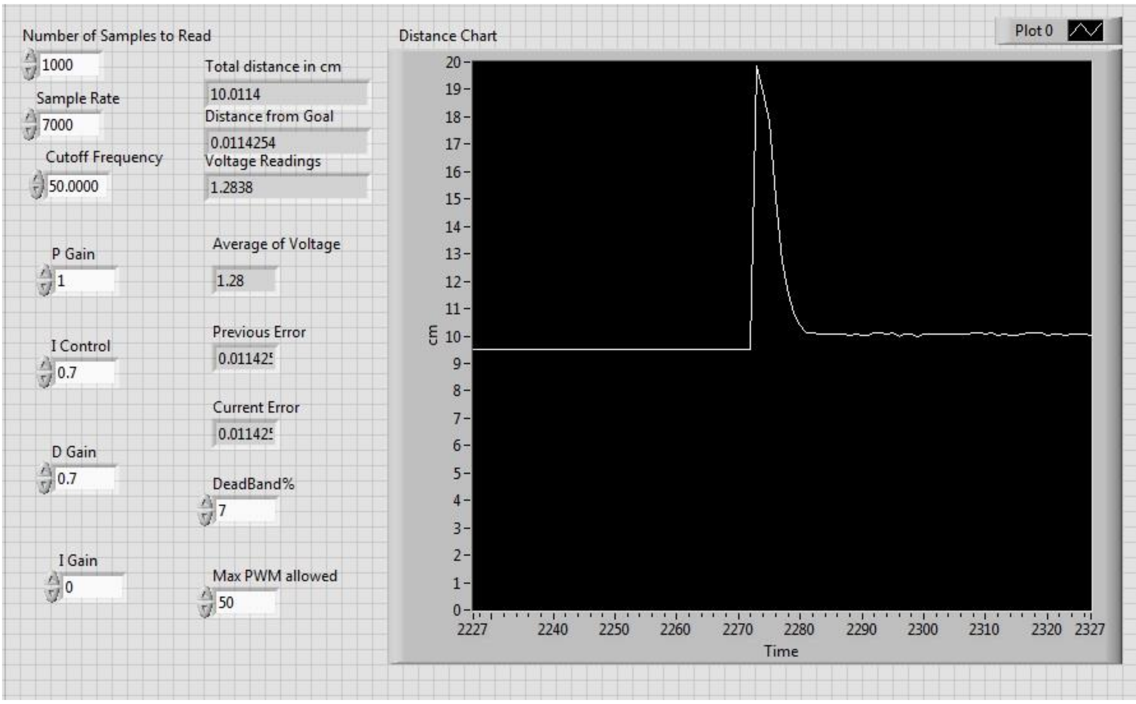

Figure 9: Final Program (20-10cm)

.63deltaD = 16.19319 cm

The correlating time with this distance is roughly .405 seconds.

Time Constant ≈ .405 seconds

Rise Time ≈ 2.001 seconds

Settling Time ≈ 1.62 seconds

6.0 Discussion

The most obvious discrepancy in all the data taken is the difference between when the follower moves forward and when it moves backwards. The final program for moving from 5 cm to 10 cm (backwards) yielded a rise time of roughly 1.571 seconds. Whereas the program for moving from 15 cm to 10 cm yielded a rise time of roughly 1 second. Clearly there was error in either the program or in the mechanical design of the follower since it was evident that the response time in every test was greater when the follower had to move forward rather than back. Another observation can be made that in most cases that backwards motion also gave less overshoot and a more stable system. Evidently, it was easier for the mechanism to move forward and because of it, created more overshoot and had to adjust for it.

The implementation of the LabVIEW program consisted of many variables to output the best results. Sample rates were tested to see which one outputted the most accurate response, which ended up being 7000. It was noticed that 9000 created too much overshoot and would not stay on target, whereas 5000 had a very slow response time and followed much slower. The second portion of testing was for the PID controller. For the proportional control, it was noticed that it should not exceed 1.0 since then the overshoot gets out of control and changes the duty cycle of the system too much. The integral control was tricky since it continuously added on to the duty cycle so only momentary tests were taken for it, in which it did improve the system. The control for this had to be kept low in the decimals or else overshoot would occur, but adding a 0.7 control increased the response time of the system. Lastly, the derivative control was used to compensate for overshoot, but it was very important that it was kept low as to not vary the response too much. By observing the graphs in the Appendix, one can see that the best response happened to be the 0.7 gain value, since 0.5 did not help much and anything higher than 0.7 would create more error in the control system. Overall, the tests done for the sample rate and for the PID controller created a satisfactory response time and overshoot value which helped yield good results for the final design values.

The first design initially was that the system would have the two moving bodies, each of them attached to four wheels; essentially two moving cars. The rail would also simply be one “fence” that was mounted perpendicular to the main floor. The two cars would then guide along this rail due to an opening that creates a passage for the fence and keeps the cars in a linear motion. The main car would simply be an empty box that would move along the track, where the follower car would have the distance sensor, the DAQ, the motor driver, and the gear box all sitting in its body. Allowing the only moving wires to be the USB cord and the power supply cord.

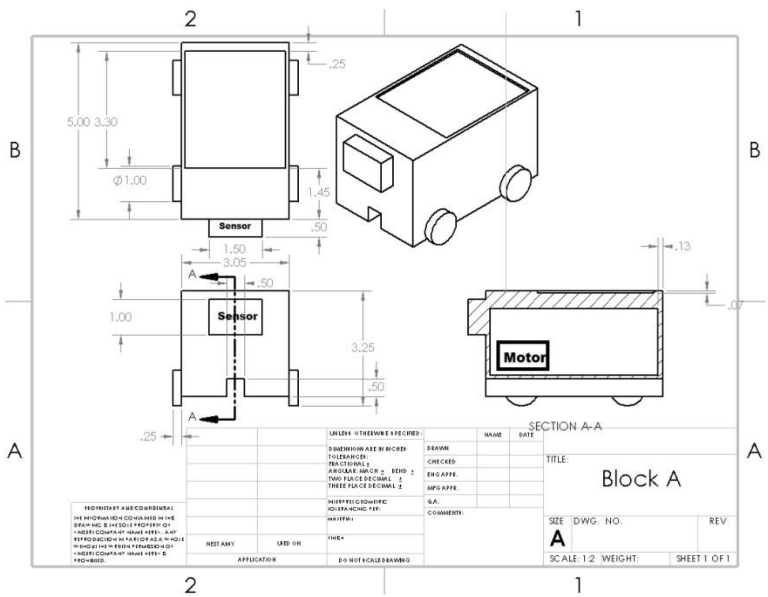

Figure 10: Initial follower design

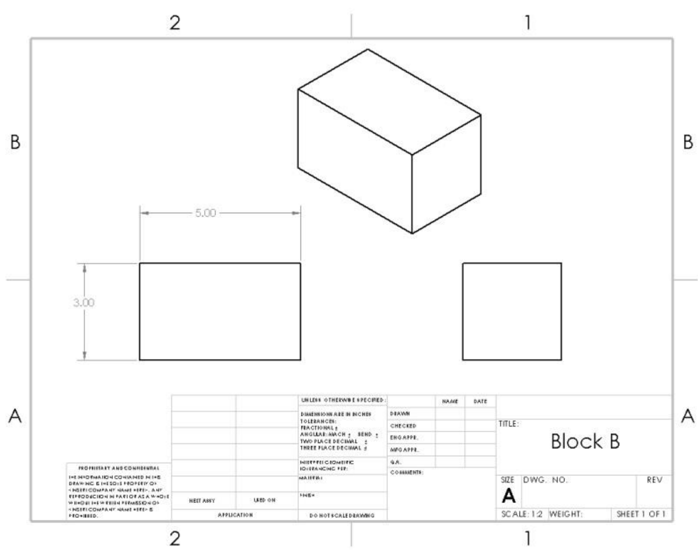

Figure 11: Initial user block design

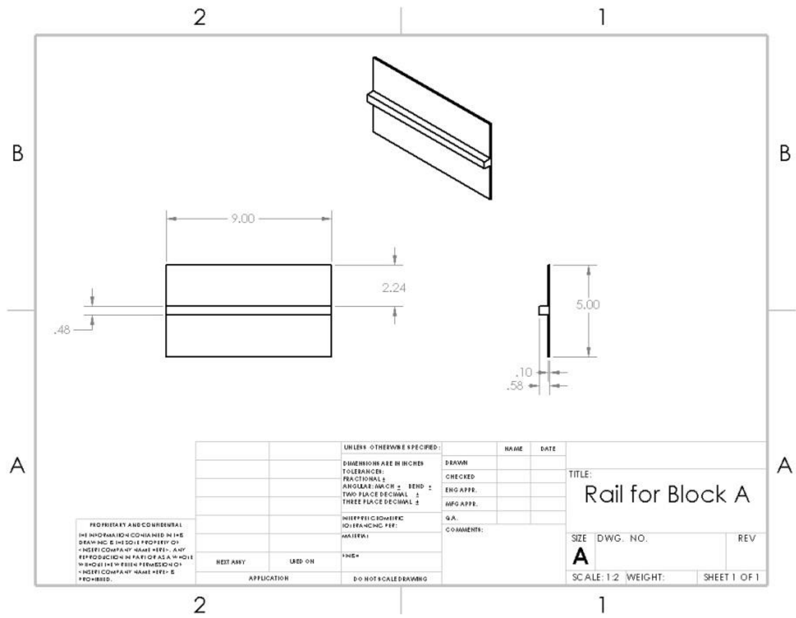

Figure 12: Original design of the rail

However, doubting the stability of a fence that simply stood perpendicularly to the car, another method was thought of in how to make the car drive in one dimension: a rack and pinion system. This method was considered for a long period of time due to its perceived advantages; stable 1D following and that the distance could be perfectly calculated based on the teeth of the gears involved. This idea was ultimately abandoned due to finding a simpler system in a more stable rail.

The final rail was acquired from a sliding door track, as such, instead of the rail going in to the car, a piece of the car would act as a guide as it moves back and forth. A piece of metal that was used to guide the door the system was originally from was also retrieved, and it was decided that this would be attached to the moving car.

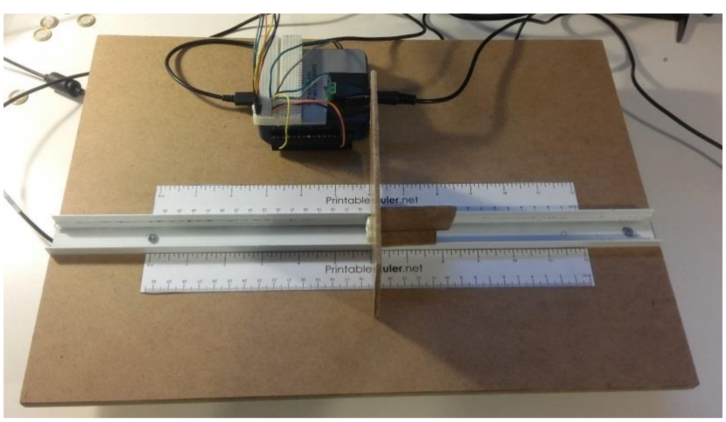

Figure 13: Final design of the rail

The design of the follower was changed when it was decided that the DAQ would be unnecessary weight, and that constantly tugging on the USB cable was undesirable. The DAQ was then decided to be placed close by on the side of the rail, out of the way of the follower, yet close enough to feed the jumper wires coming out of the DAQ. These jumper wires would all flow in to the breadboard on which the motor driver was attached to. The wires for the distance sensor would also be placed on the breadboard and from there extended via jumper cables back to the DAQ. Eventually, another breadboard was attached on top of the DAQ so that all jumper wires from the DAQ, along with a connection from the DC power source, would flow into this breadboard, which would then have the connections extended from longer connected wires via the breadboard, to be sent to motor driver, and in the case of the distance sensor, from the first breadboard to the second. This allowed for a more efficient system, as only one batch of wires would be compressed and stretched, close to the intent of the initial design that had only two moving wires.

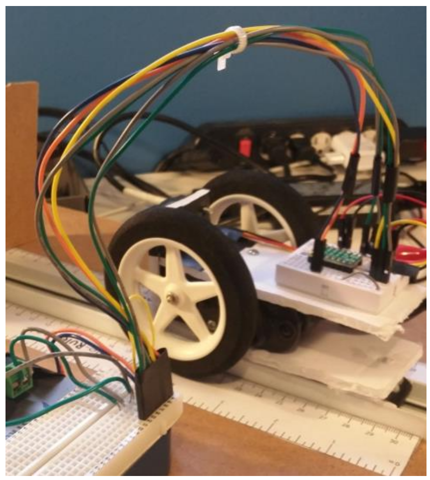

Figure 14: solution for cable management

It was decided that a body would be constructed out of foam boards, chosen for their decent durability and light weight. Two pieces, which were measured to the size of the gear box, were attached to its top and bottom. The shaft side of the gear box was considered to be the front, and so a third piece was attached, linking the top and bottom pieces together. This third piece would also allow the distance sensor to be mounted to the front of the entire body in a stable manner. The motor driver breadboard would then be attached to the foam board on top of the gear box, completing the wiring system of the project, as the wire from the motor, and distance sensor would wire into the breadboard of the motor driver, longer jumper wires would connect from the motor driver breadboard to the DAQ breadboard, which would then have shorter wires connecting to the ports of the DAQ and the DC power supply. A follower, made up of a stack of 3 foam board pieces, was created and mounted to the bottom of the body to allow for it to move within the rail. Wheels were directed attached to both sides of the shaft, secured through the usage of nut and the threads on the ends of the shaft.

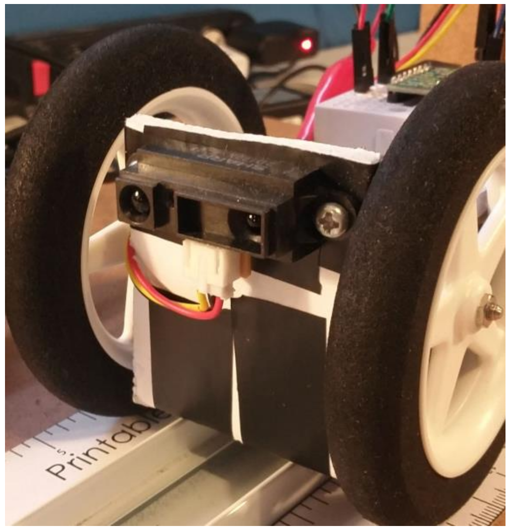

Figure 15: Final design of the follower with the camera mounted in front

Finally it was decided that an extra "car" would be extraneous, after simply testing the how the follower moves along a flat piece of foam in front of it. A wooden board was decided to replace the testing foam board and it was glued to the metal follower initially attached to a door. A handle close to the base and metal follower was then also glued to the back so that it would allow for greater maneuverability from a user.

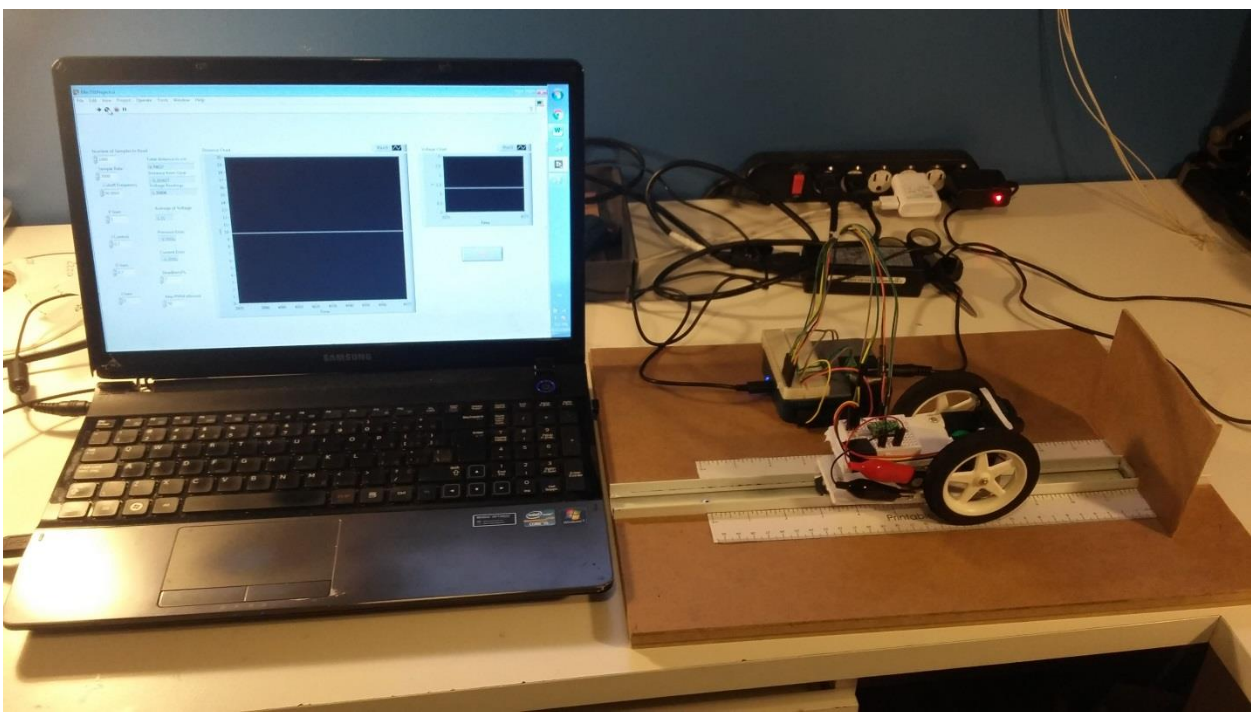

Figure 16: The complete final setup

The strengths in the final design are that the system is simple, cost effective, and lightweight. It effectively executes the main requirement of project; a follower that will maintain a distance of 10cm from the user.

However some issues this design encountered is that due to its light weight, the wheels will slip under the lowest outputs of the motor, causing the system to lose precision. This problem is more or less alleviated with a large enough dead band range, however as the dead band range shrinks, in an attempt to get the follower to be closer to an exact 10cm range, the slippage because an issue again.

7.0 Conclusion

Ultimately the final result of the project achieved its main purpose: the miniature car is able to follow the object in front and maintain a distance within the user's desired range.

This project allowed for a greater understanding of LabVIEW as there was no prior knowledge of the inner workings of the program. As familiarity with the program increased, due to repetitive trial and error, tutorials in the lab experiments, and reading though the online tutorials, ability to use the program to return a desired result also increased, allowing for a deeper understanding of analog to digital systems.

This project also required the manipulation of a dc motor to spin clockwise and counter clockwise according to the project requirement. Again, through trial and error and reading up on typical electrical systems, there became a greater adeptness towards small electrical systems. This also allowed for a deeper understanding of the sensitivity of modern sensors, and the necessity of proper digital control systems to skillfully handle the many requirements in today's world.

Finally, this project gave the team a greater insight into the industry, and automated processes. Automation is a large field and continues to grow, allowing for many opportunities in the future. Through the design of the car through SOLIDWORKS, the programming and setup of the electrical system through the motor driver and LabVIEW, and finally, the opportunity to work in a group, insight into future career as an engineer in today's world is gained.

8.0 Appendix

8.1 Final Design of Linear Fume Tracker

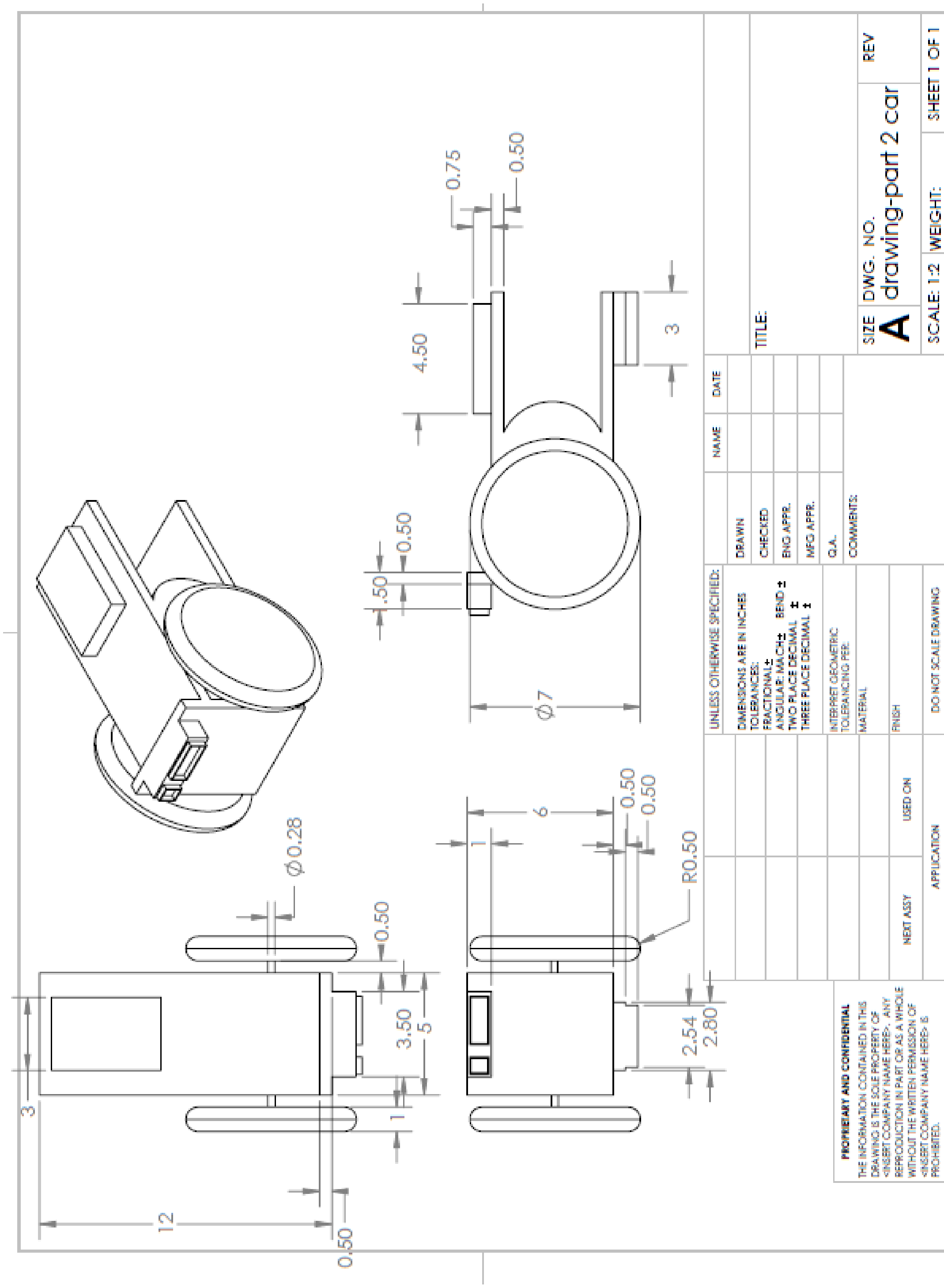

Figure 17: The final design of the follower

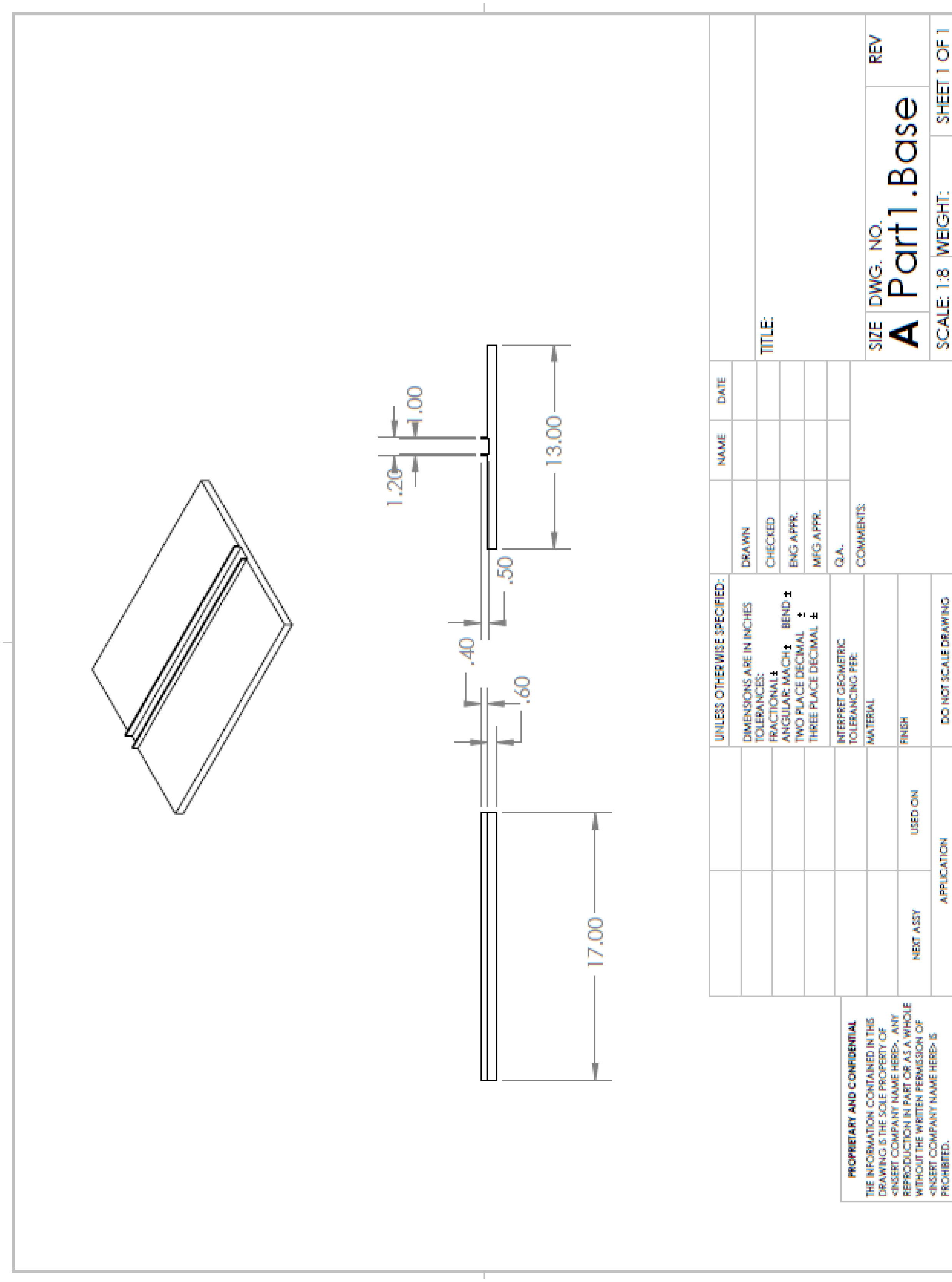

Figure 18: The final design of the track and base

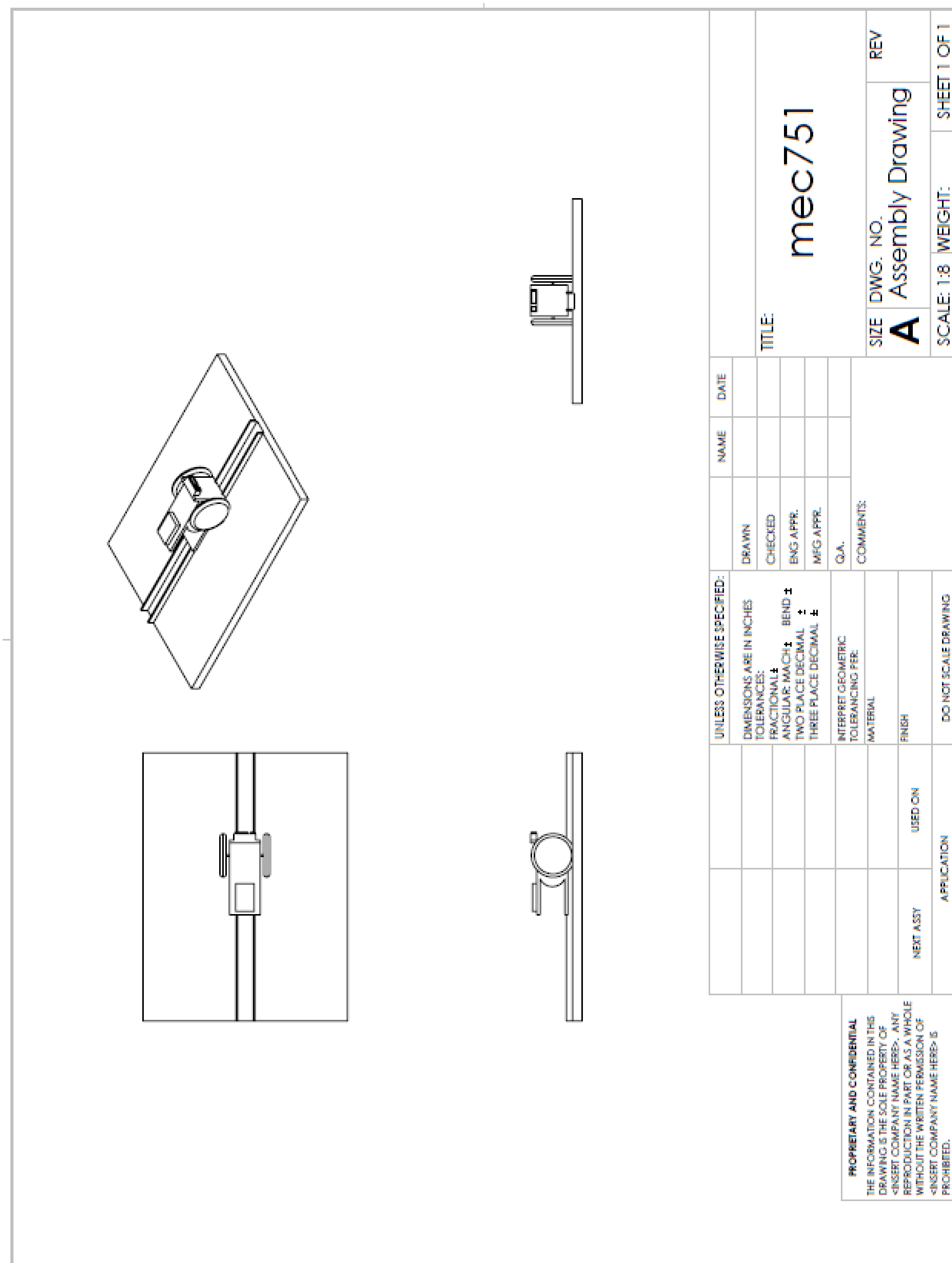

Figure 19: The final assembly of the linear fume tracker

8.2 Results from Sample Rate Tests

The following graphs show the data taken from altering the sample rate:

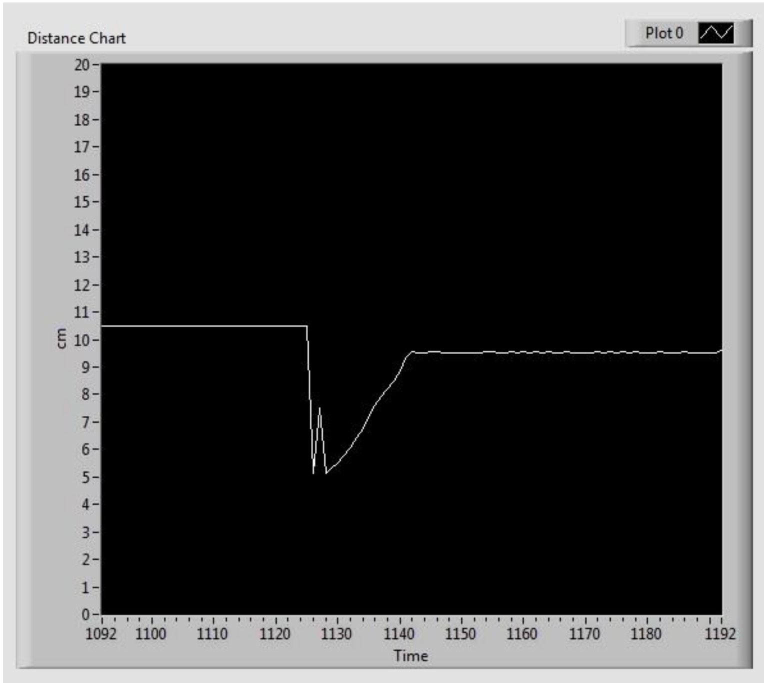

Figure 20: Sample Rate of 5000 (5-10cm)

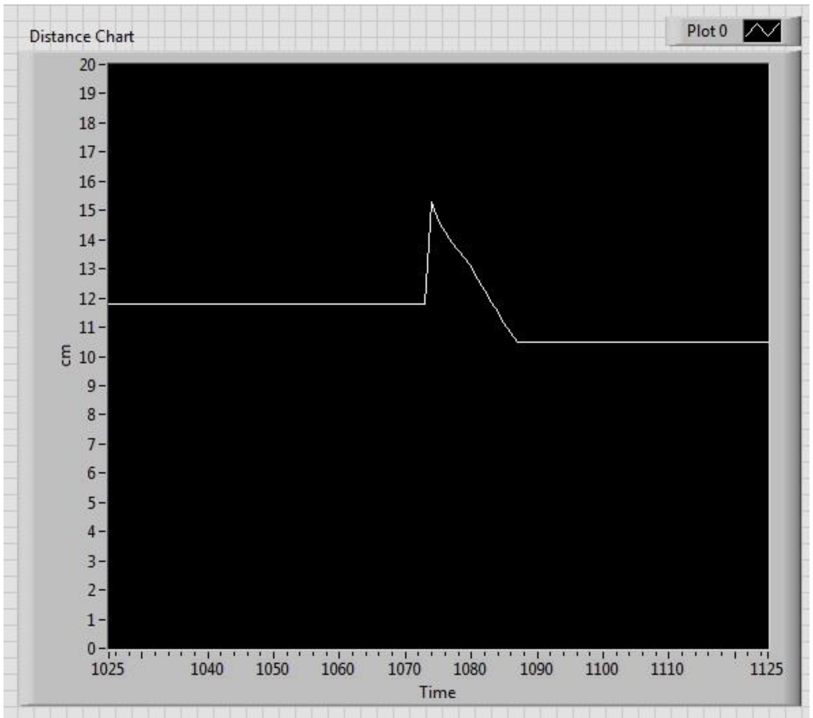

Figure 21: Sample Rate of 5000 (15-10cm)

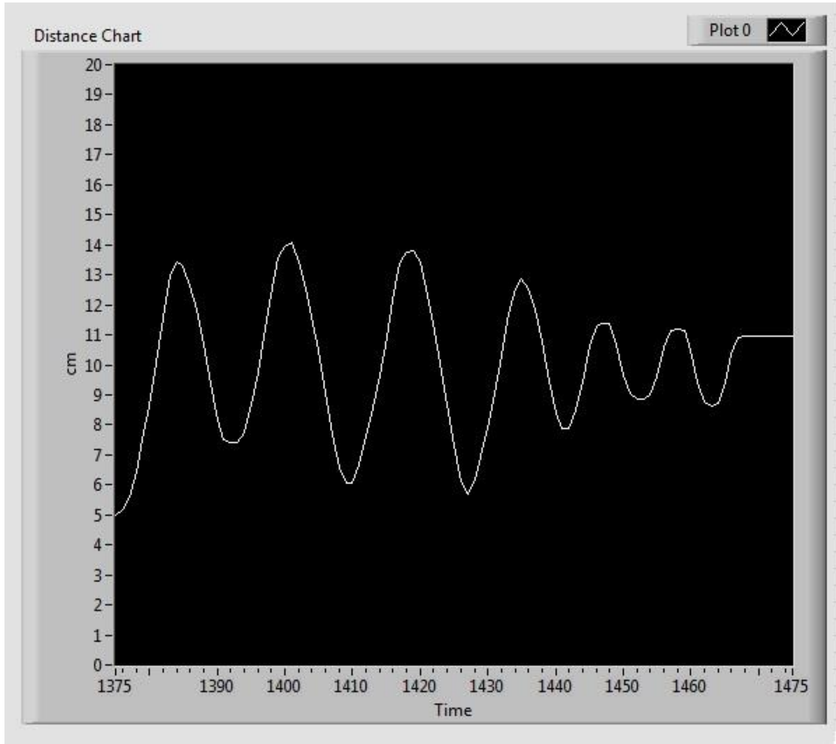

Figure 22: Sample Rate of 9000

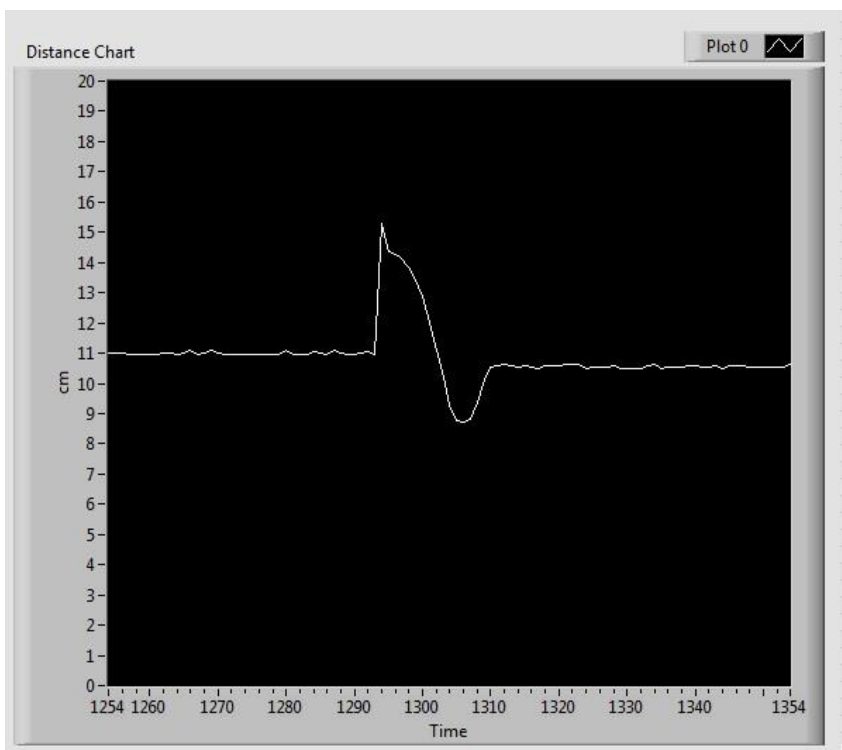

Figure 23: Sample Rate of 9000 (15-10cm)

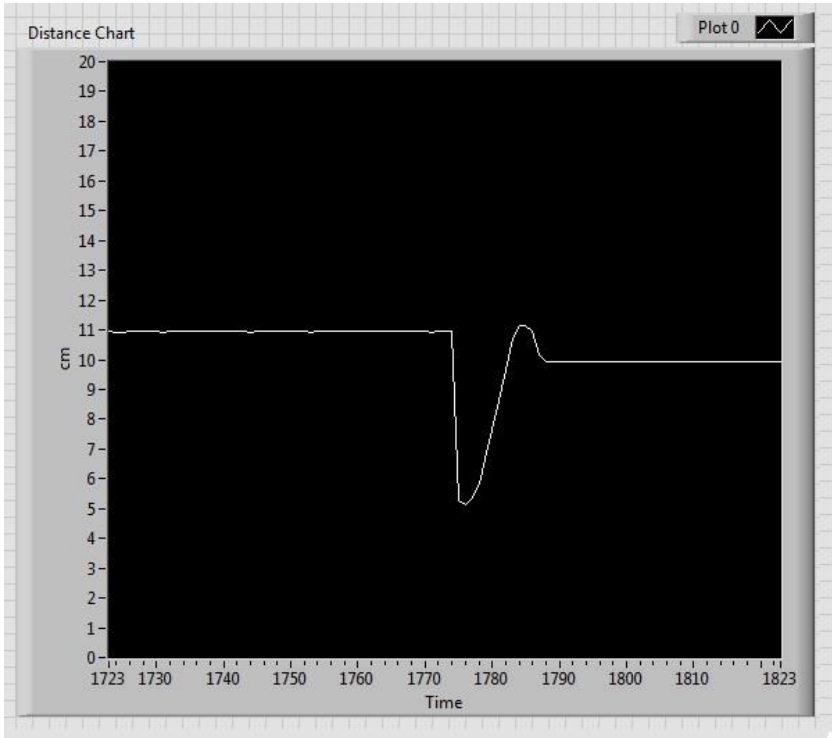

Figure 24: Sample Rate of 7000 (5-10cm)

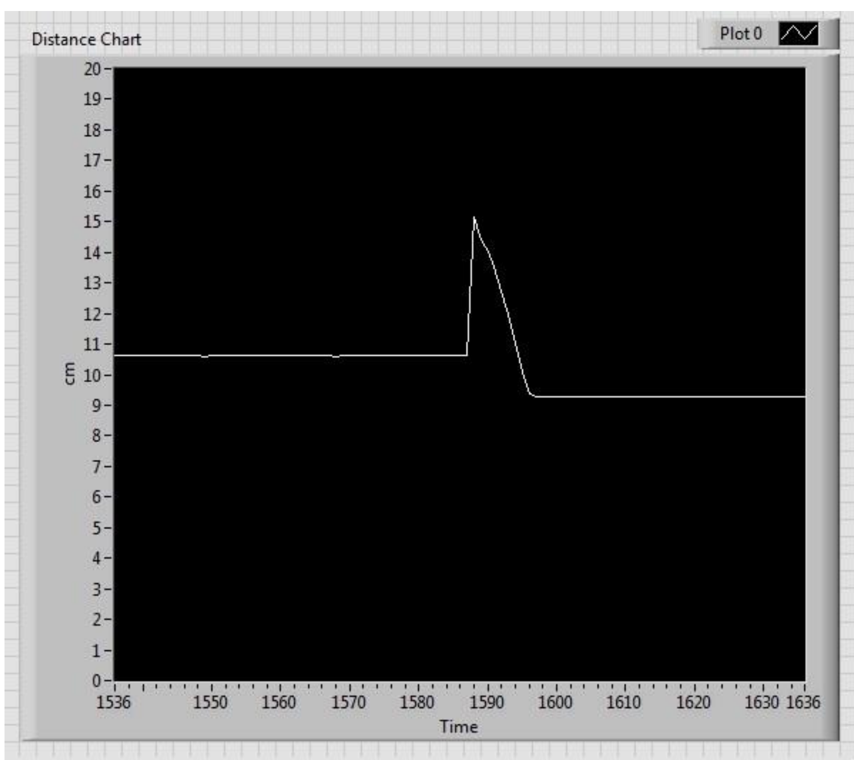

Figure 25: Sample Rate of 7000 (15-10cm)

8.3 Results from Proportional Gain Tests

The following graphs show the data taken from altering the Proportional Gain value:

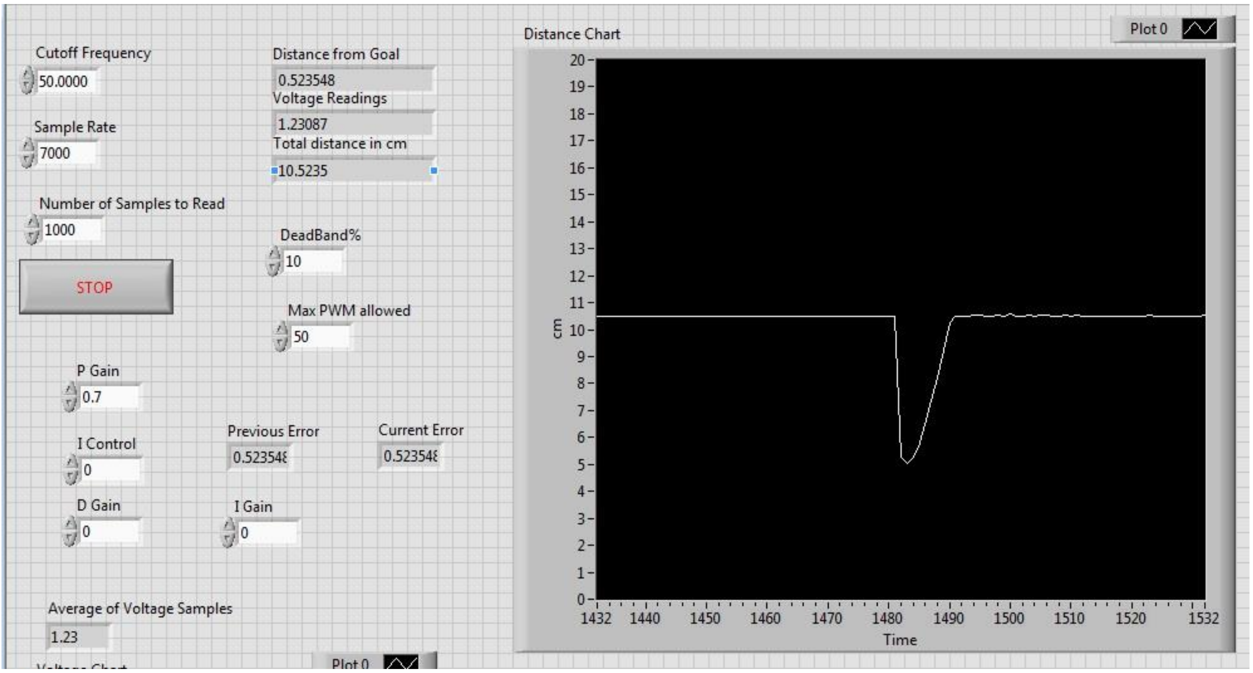

Figure 26: P Gain of 0.7 (5-10cm)

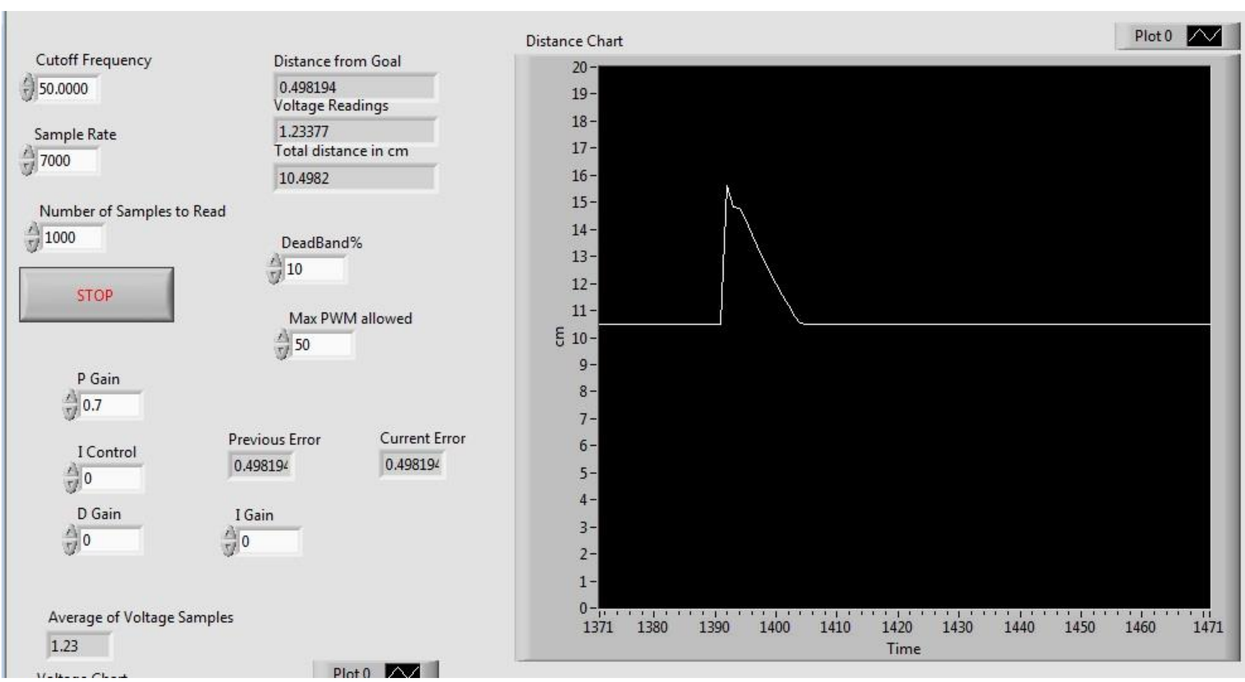

Figure 27: P Gain of 0.7 (15-10cm)

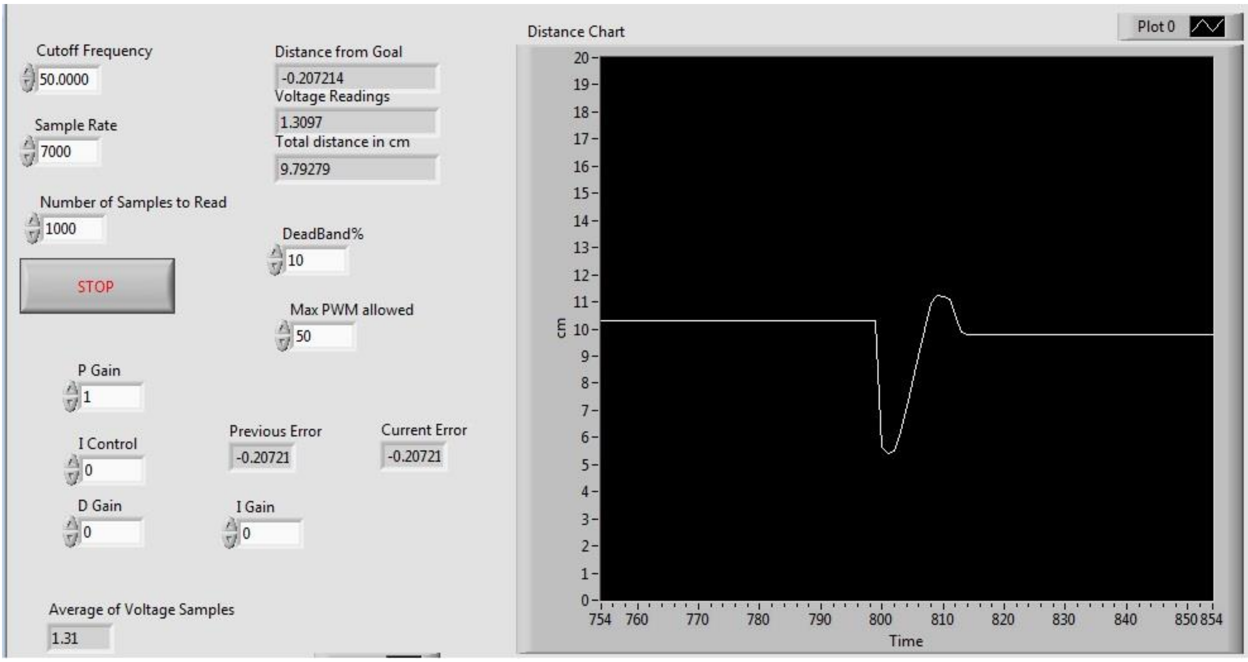

Figure 28: P Gain of 1.0 (5-10cm)

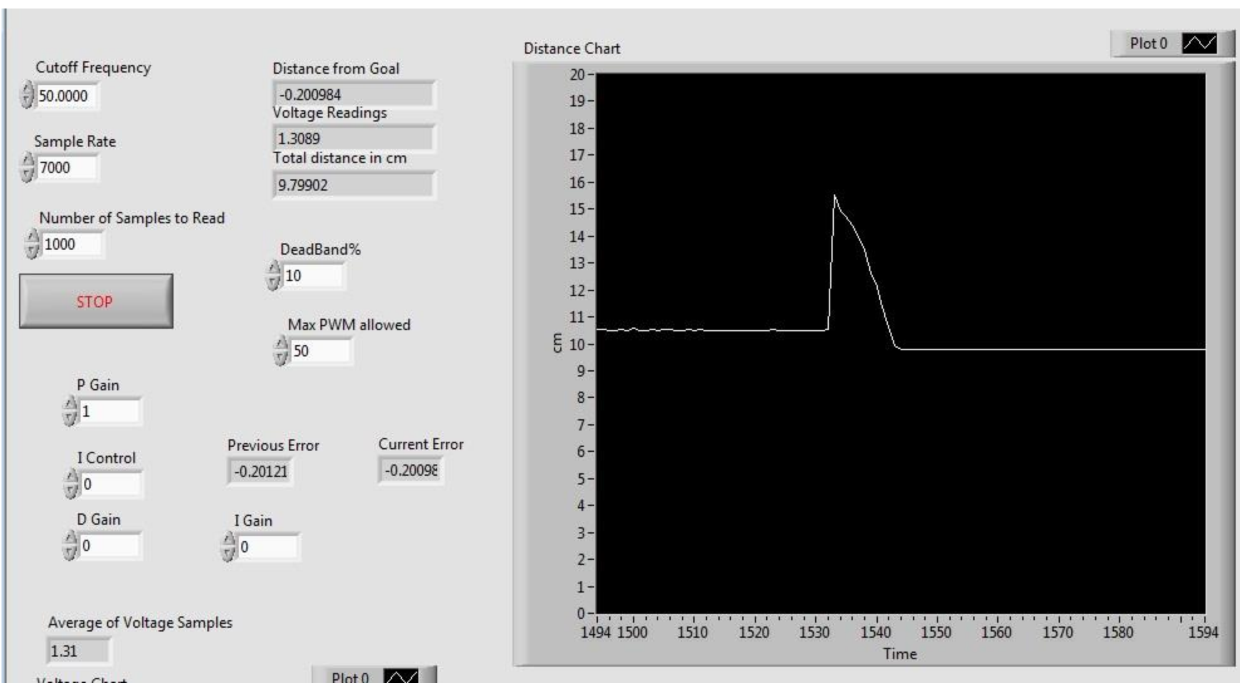

Figure 29: P Gain of 1.0 (15-10cm)

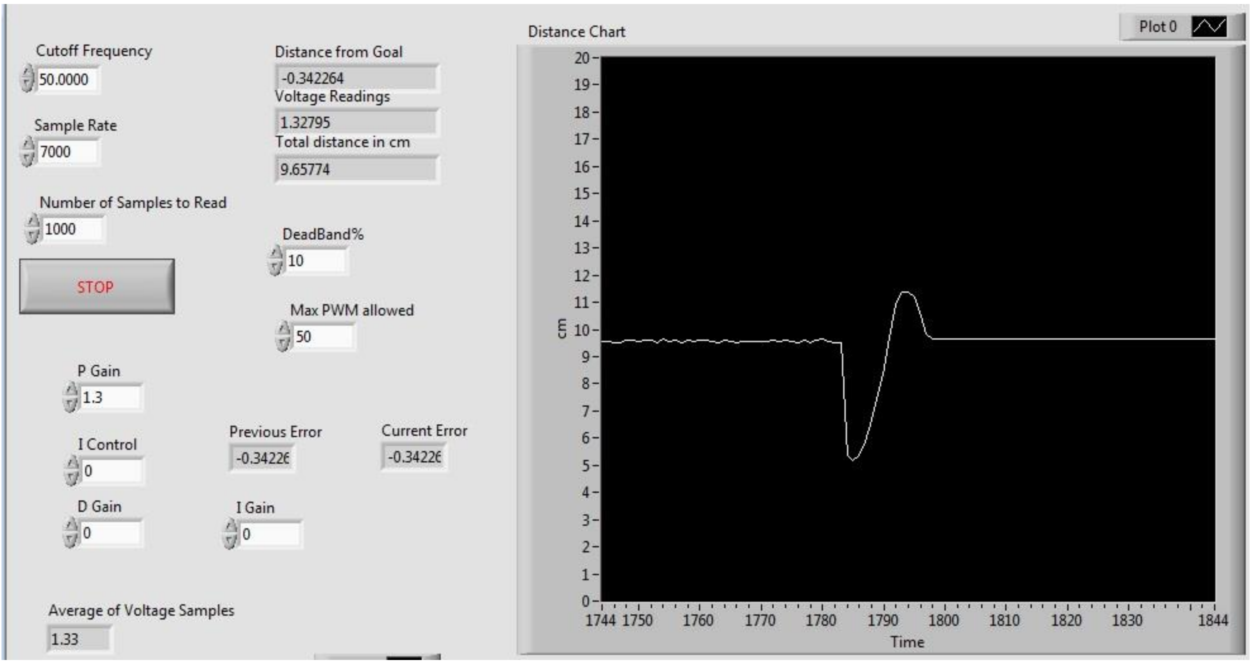

Figure 30: P Gain of 1.3 (5-10cm)

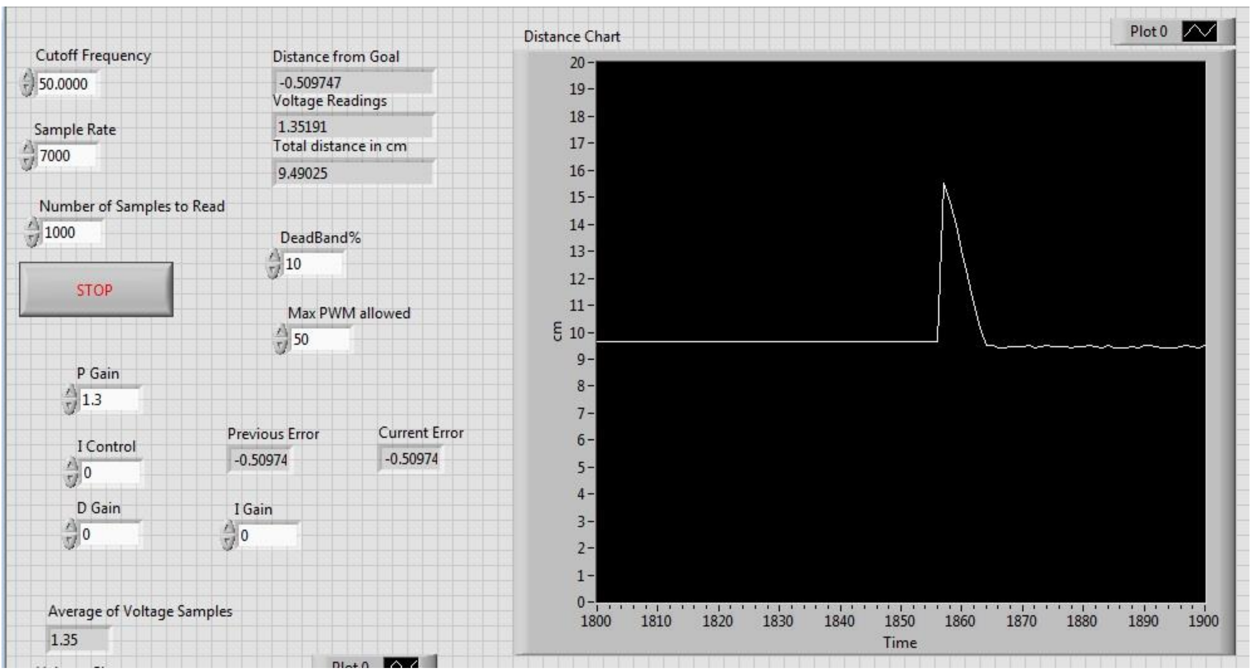

Figure 31: P Gain of 1.3 (15-10cm)

8.4 Results from Integral Gain Tests

The following graphs show the data taken from altering the Integral Control value:

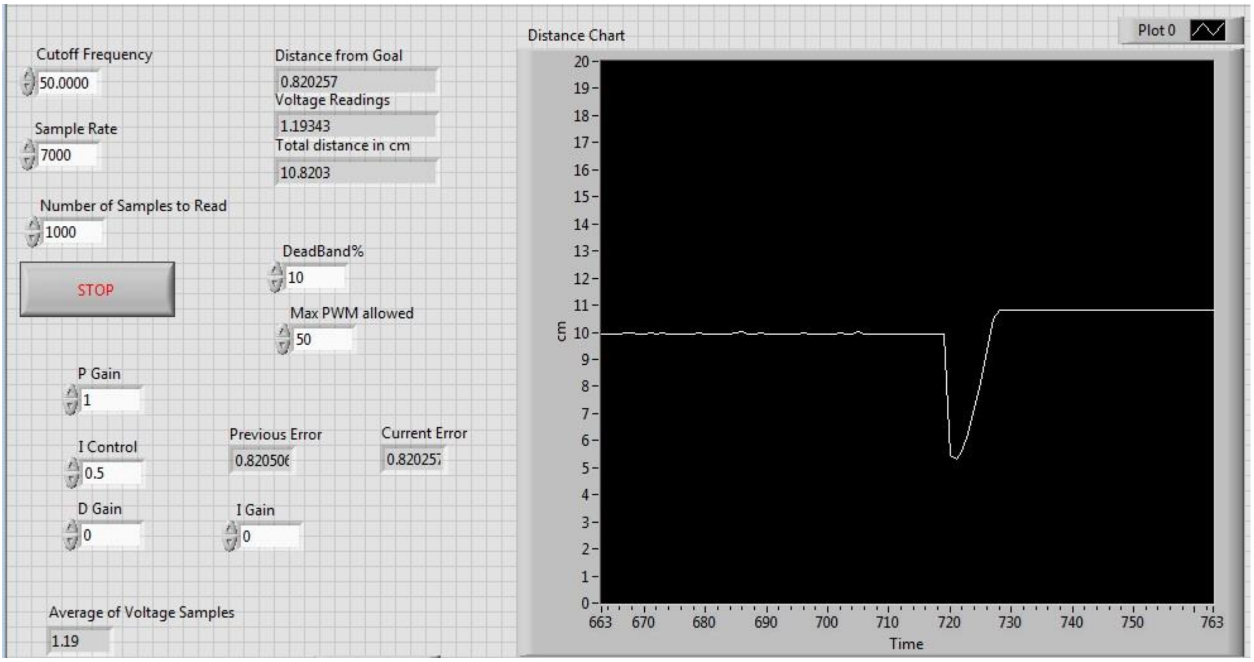

Figure 1: I Control of 0.5 (5-10cm)

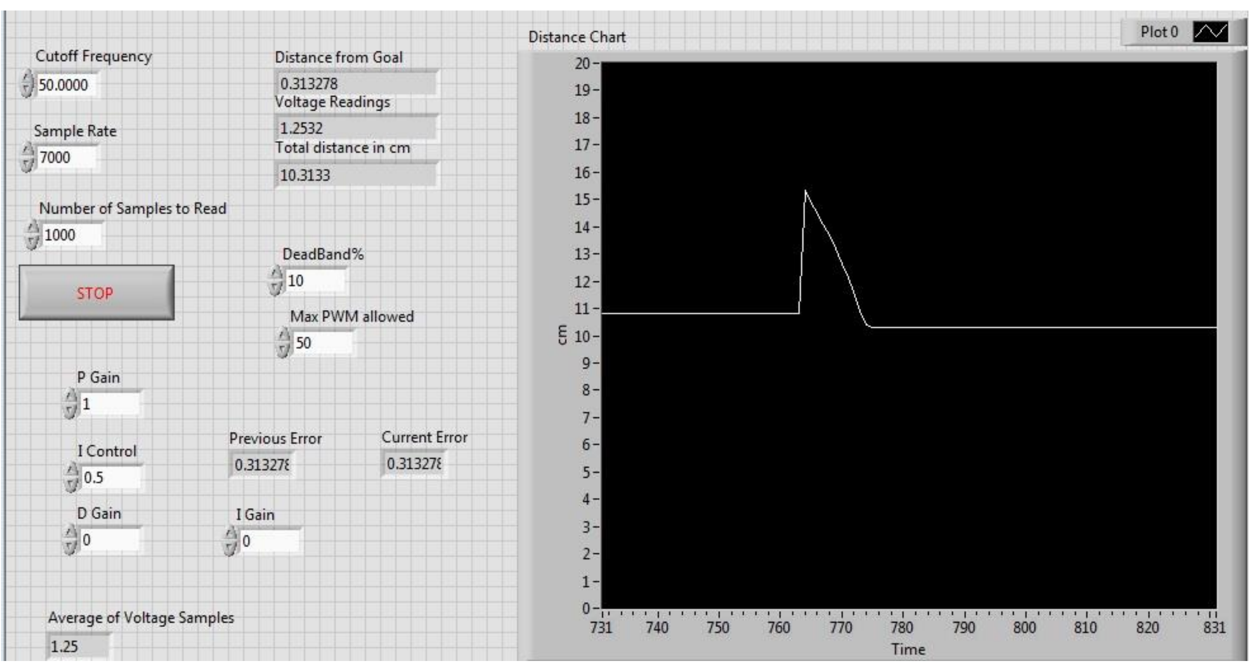

Figure 2: I Control of 0.5 (15-10cm)

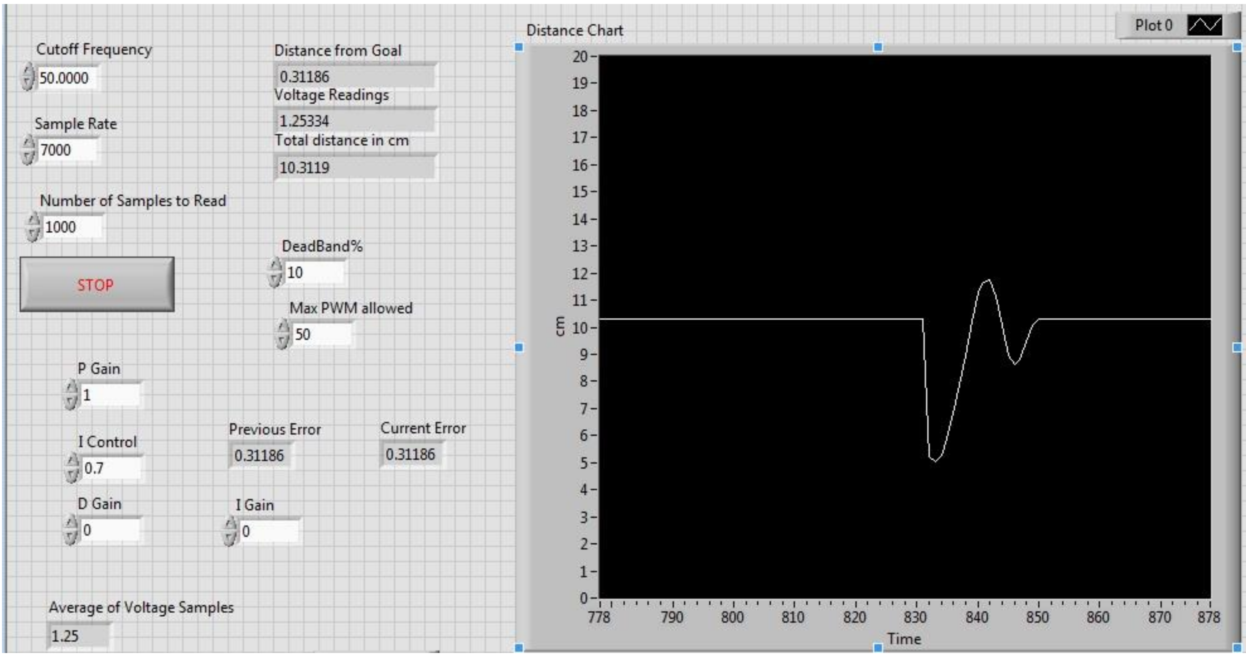

Figure 34: I Control of 0.7 (5-10cm)

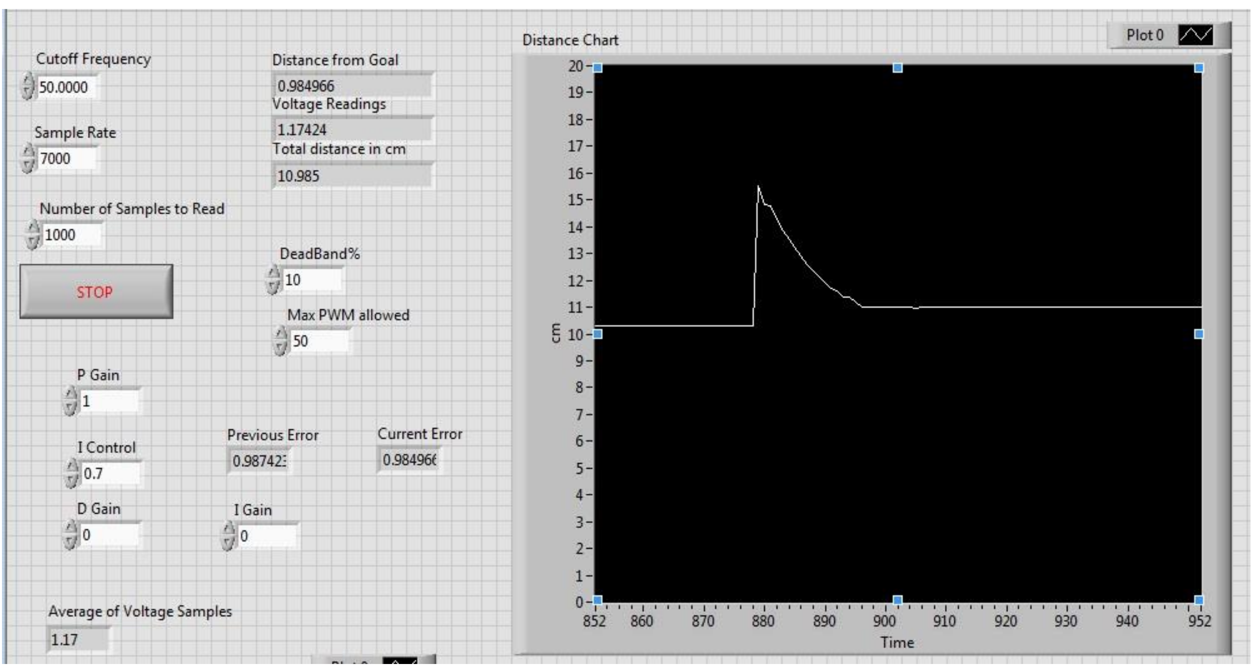

Figure 35: I Control of 0.7 (15-10cm)

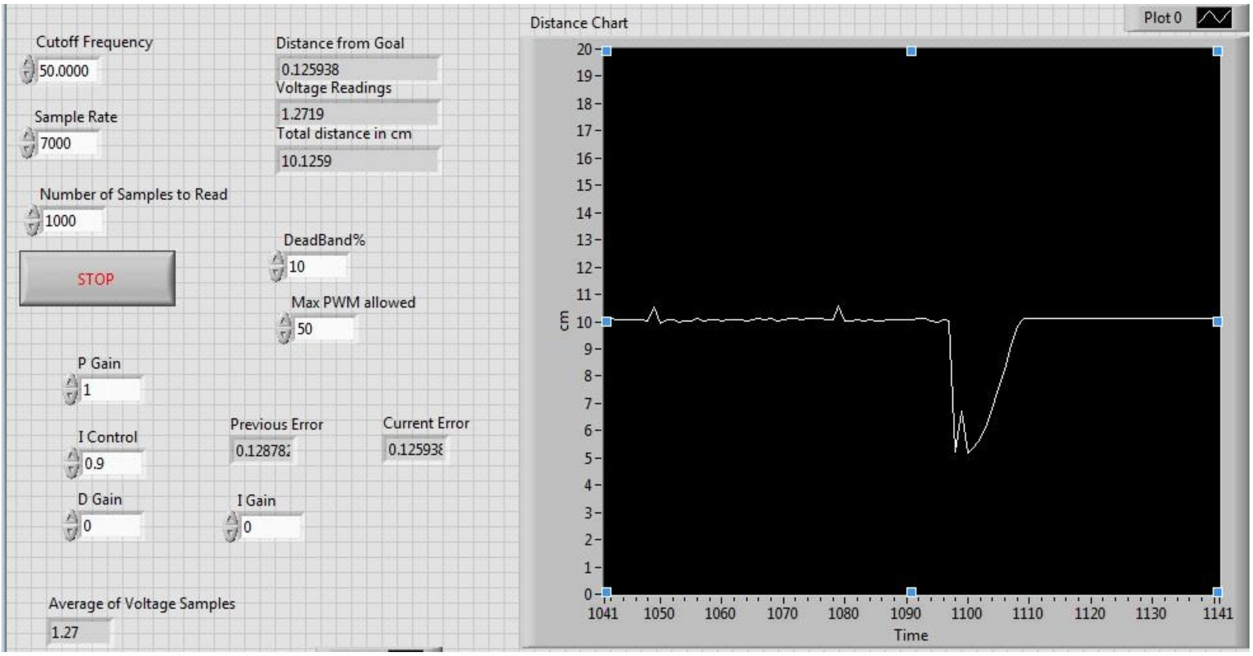

Figure 36: I Control of 0.9 (5-10cm)

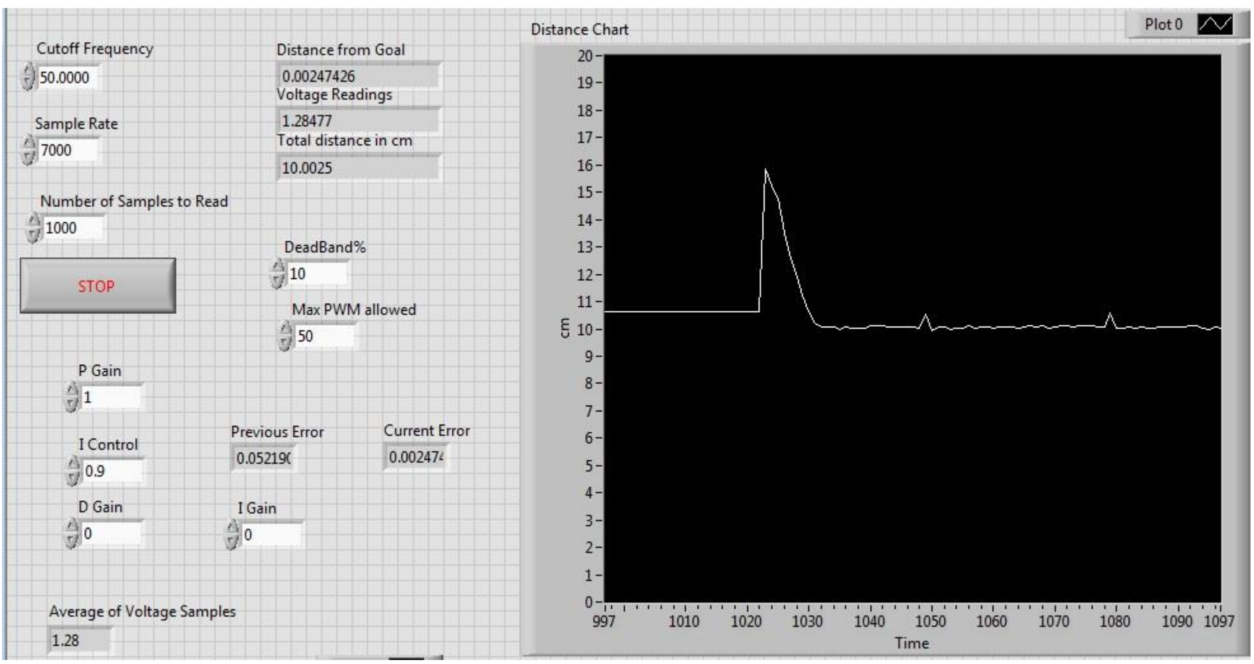

Figure 37: I Control of 0.9 (15-10cm)

8.5 Results from Derivative Gain Tests

The following graphs show the data taken from altering the Derivative Gain value:

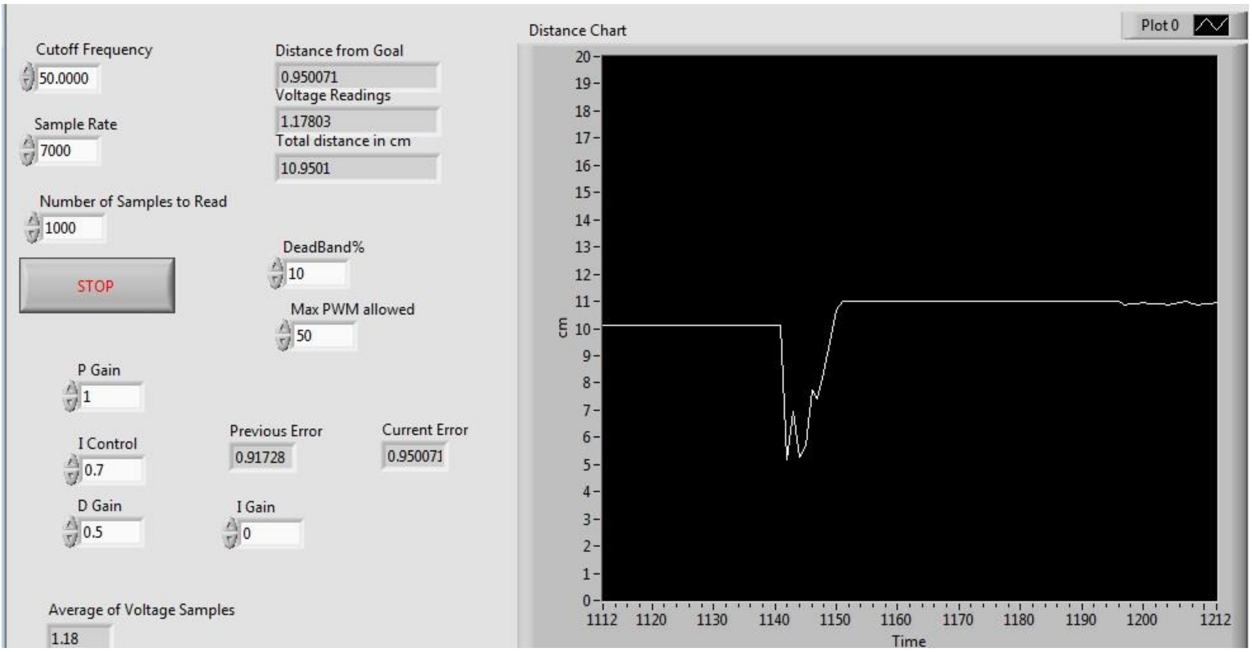

Figure 38: Derivative Gain of 0.5 (5-10cm)

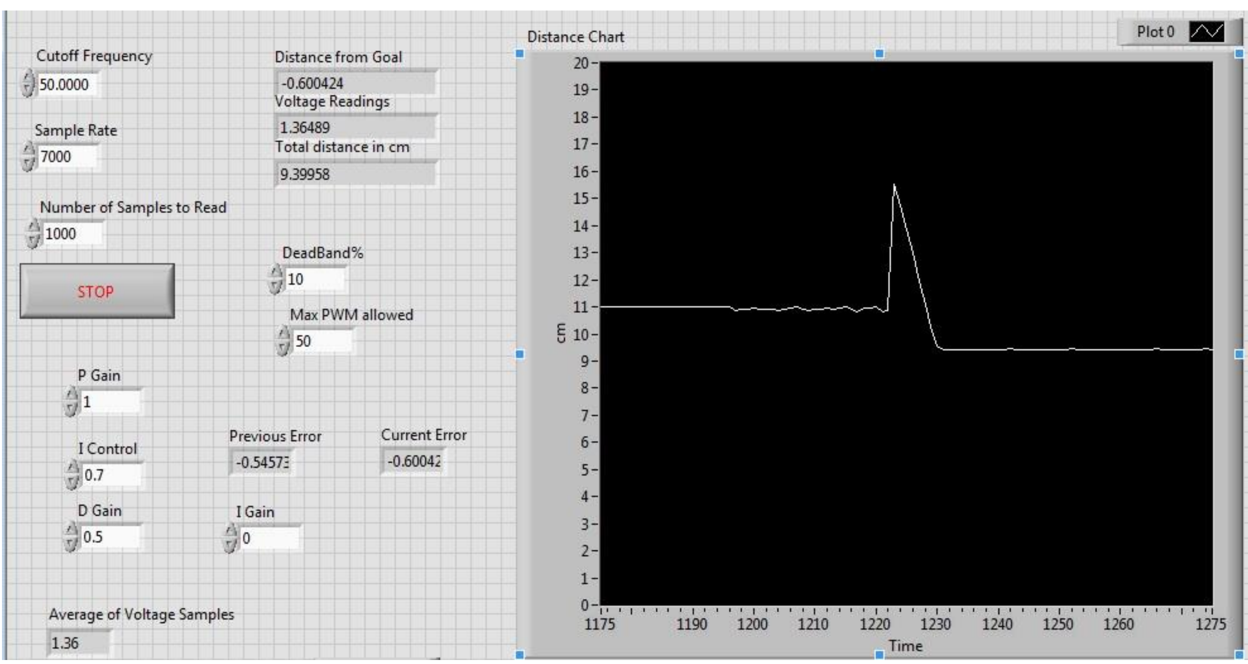

Figure 39: Derivative Gain of 0.5 (15-10cm)

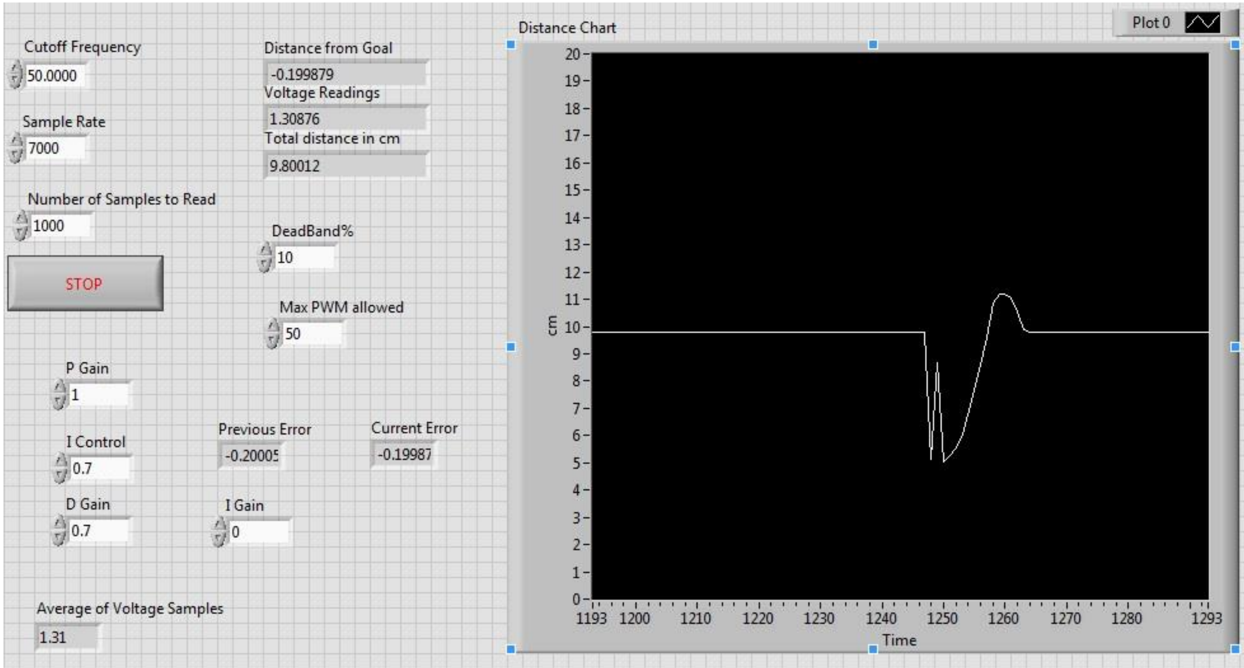

Figure 40: Derivative Gain of 0.7 (5-10cm)

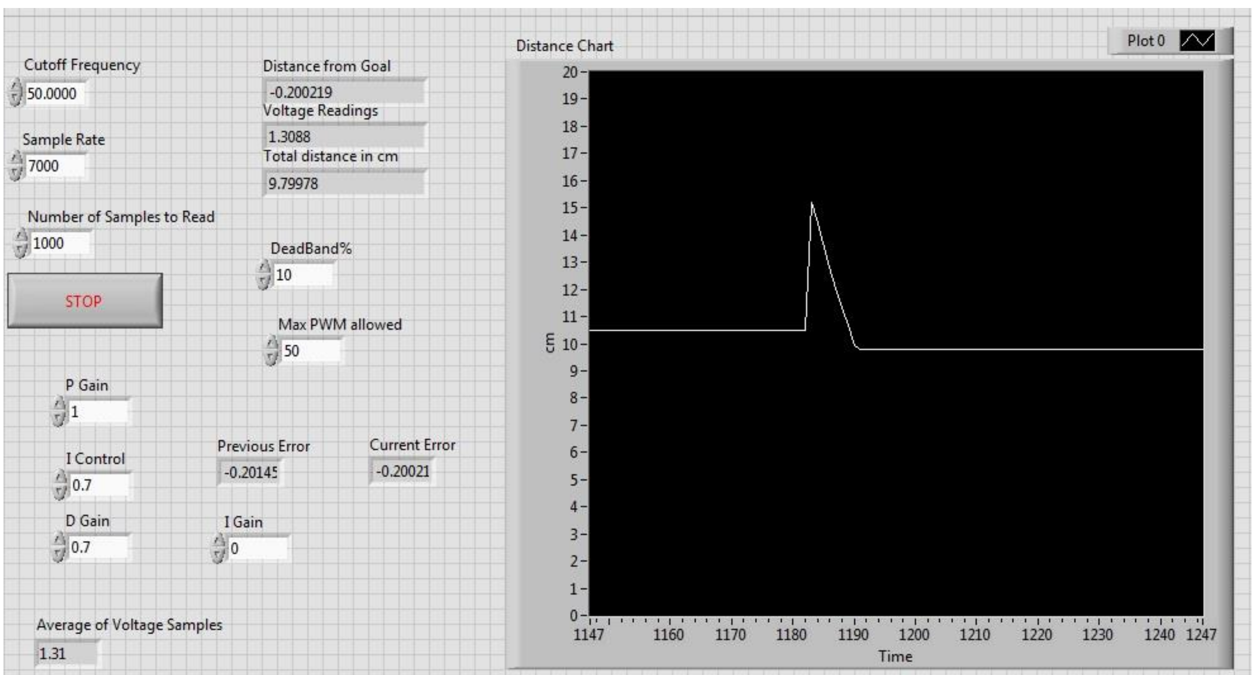

Figure 41: Derivative Gain of 0.7 (15-10cm)

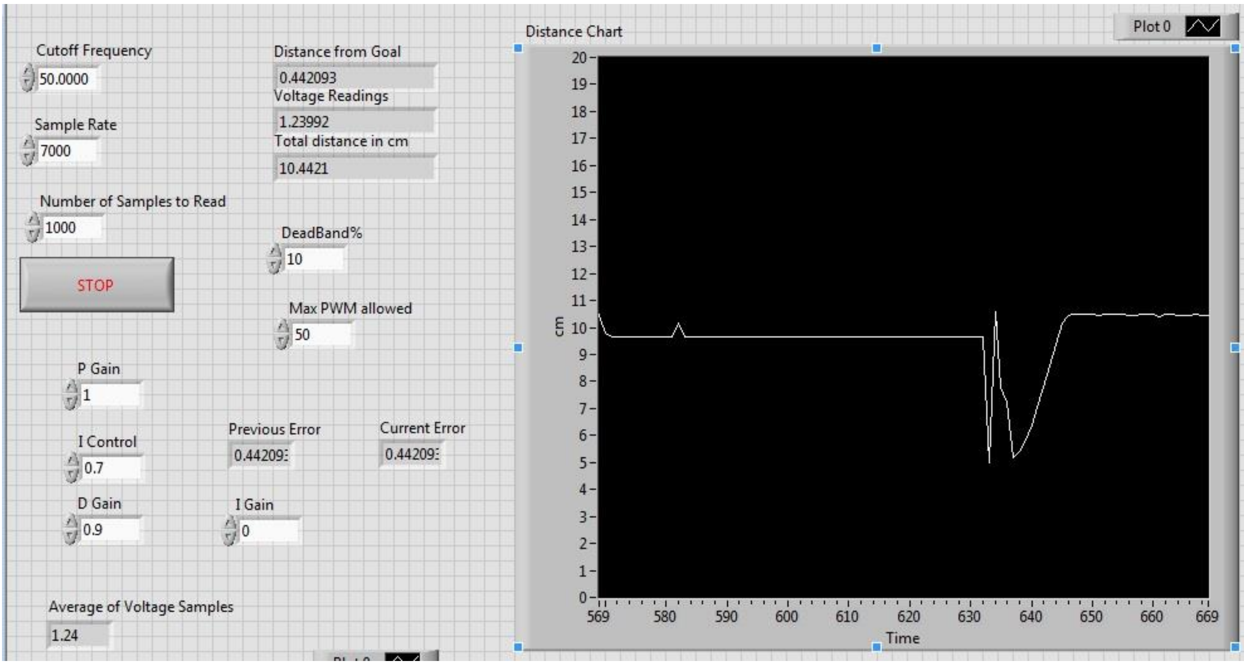

Figure 42: Derivative Gain of 0.9 (5-10cm)

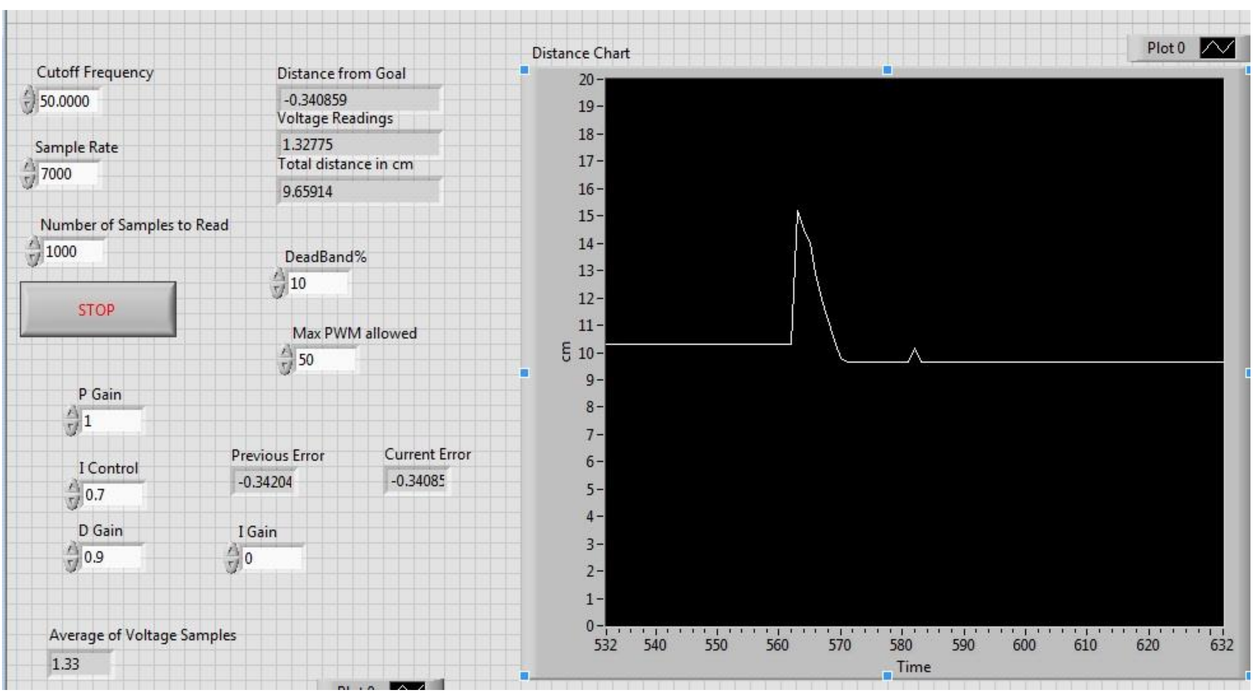

Figure 43: Derivative Gain of 0.9 (15-10cm)