

# MAE 106: Precision, High Speed Nerf Ball Shooting Final Project

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## Section I: Summary of Design Strategy

The purpose of this project was to design a robot that reads a random input signal ranging from one to five volts and projects a ball using a pneumatic cannon toward one of five targets. Key components of the system consist of a computer controlled motor, potentiometer, amplifier, and coupler, which is connected to the shaft of the shooter shaft as shown in Figure 1.1. The robotic system was designed to be detachable and easily configurable.

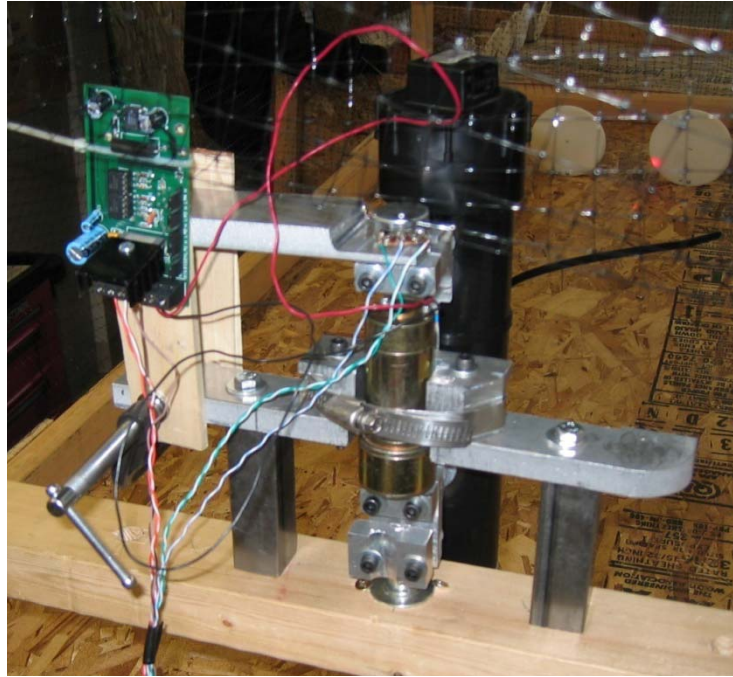


Figure 1.1 Photograph of Mounted Control System

For this project, emphasis was placed on the design of the mounting of the system onto the shooter shaft. The coupler was designed to minimize error in measurement of the angular position and angular velocities of all shafts. Measurement error was believed to lead to the least control over the response of the system. To ensure that measurement error was minimized, more effort was made to simplify the connection of the shafts, rather than exploring complicated linkage, pulley, or gear systems. The resulting coupling design is illustrated in Figure 1.2.

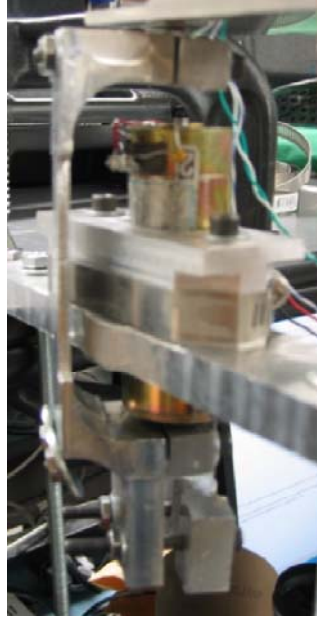


Figure 1.2 Coupling Assembly Used in Control System

The coupling assembly is made up of 3 sections. The bottom portion of the coupler directly links the shaft of the shooter and the motor together, and connects to the potentiometer directly above the shooter and motor shafts. All shaft bores were designed to be collinear to ensure a 1:1 ratio of angular displacement amongst all shafts. The coupler was fabricated using 6061 aluminum to allow easy machinability. It features the ability to couple a 3/16" diameter shaft to a 1/2" diameter shaft, which is not easily found in commercial-off-the-shelf components.

The mounting assembly was designed for ease of manufacturability, reliability, ease of assembly, and maintenance. Components were designed to allow for adjustability in position in case of interferences. For example, the height of the motor shaft relative to the height of the shaft of the shooter could be changed loosening the hose clamp and shifting the motor. Also, the distances between the coupler around the shaft of the shooter, motor, and potentiometer can be adjusted by the bolts. In order to allow for simple adjustment of the potentiometer, a notch was removed in the potentiometer mount. The program generated to control the motor implemented a proportional plus derivative control law managed by National Instrument's LabView software, a block diagram based integrated development environment. LabView was chosen as the controller for the system since it was advertised with the ability of achieving sampling rates up to 200 Hz, while a MATLAB run LabJack controller program is limited to sampling frequencies of about 30 Hz. A proportional plus derivative control system was implemented to control the position of the robot. The control law is characterized by the equation,  $u = -K_p(V - V_d) - K_d(\dot{V} - \dot{V}_d)$ , where  $u$  = motor torque,  $K_p$  = the proportional gain error,  $K_d$  = the voltage gain error,  $V$  = the actual voltage,  $V_d$  = the desired voltage. This form of control was selected because it was believed to result in better control of position than a proportional control system,  $u = -K_p(V - V_d)$ . It adjusts the control variable for the error in velocity, the  $-K_d(\dot{V} - \dot{V}_d)$  term, as well as the positional error.

Other than simply implementing the control law, the LabView code generated included logic capabilities which output a 5 volt trigger signal to a pneumatic valve for different error cases in position and velocity. Two output ports on the National Instruments D/A converter were set to constant voltages to be used as voltage sources for the potentiometer. This eliminated the need to wire the potentiometer positive and negative leads to the trainer kit and centralized the wires into the A/D and D/A converters. It also allowed for ease of assembly during competition day.

## Section II: System Description

Since this robot requires the potentiometer, motor, and cannon shafts to be collinear, the mount assembly in Figure 2.1 was designed.

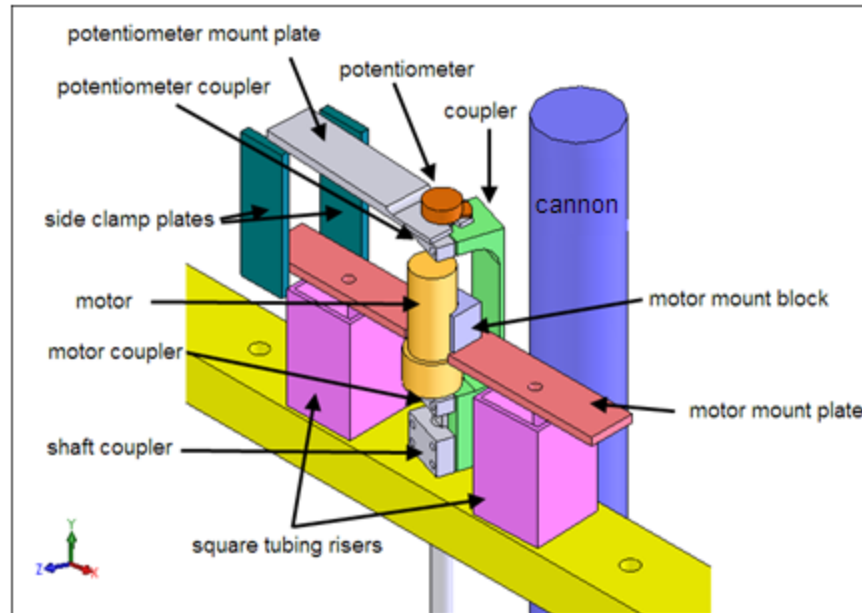


Figure 2.1 Mount Assembly

The most critical component in this assembly is the coupler because it joins the main components: potentiometer, cannon shaft, and motor shaft. The shaft coupler, motor coupler, and the potentiometer coupler make up the opposite side of the coupler to ensure that the shafts held will not slip. All of the other components in the assembly just support the coupler. Since the housing of the motor should not move relative to the base, it is stabilized by bolting the motor mount block into the motor mount plate, wrapping a hose clamp around that block and motor, and by the bolting of the same motor mount plate through the top of the square tubing risers to the bottom of the base; securing the motor this way, lifts the motor above the shaft of the shooter. Since the positioning of the potentiometer is also important, the mount plate and the side clamp plates are secured by a C-clamp to constrain the potentiometer correctly so that it remains collinear with the shaft and motor. The mount assembly is connected to the computer controlled system through many wires, and a schematic representation of how each of the components interacts with one another electronically is shown in Figure 2.2 on the following page.

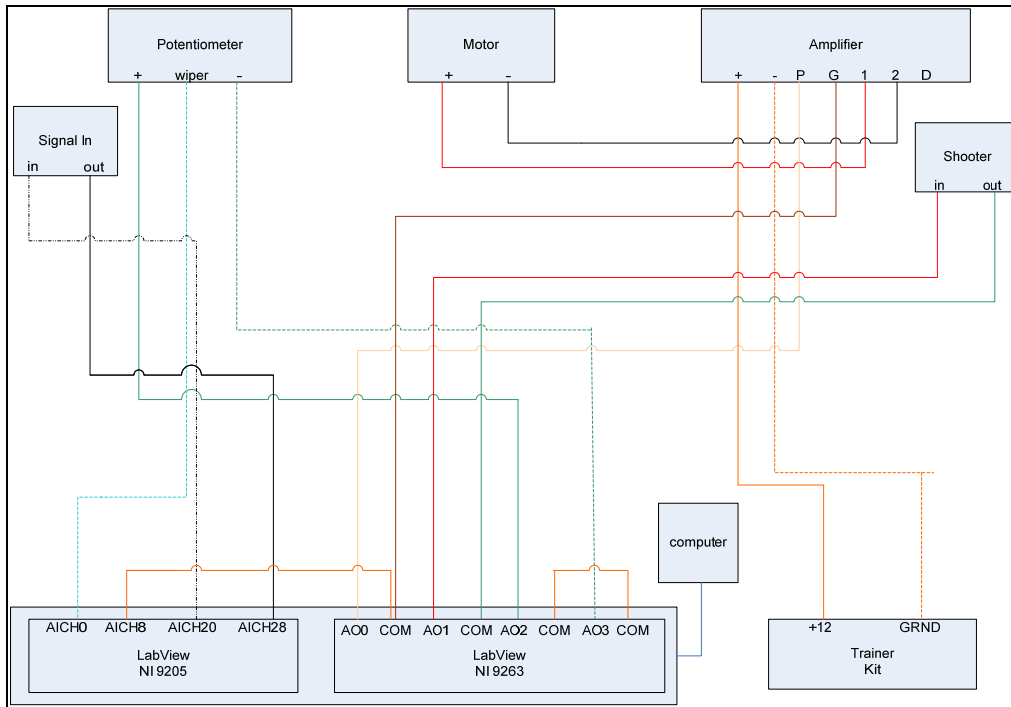


Figure 2.2 Circuit Diagram

As shown in this circuit schematic, the computer generates a signal to the National Instrument housing modules to implement the control law to the rest of the system. The control law outputted into the National Instrument's software, LabView, is a proportional plus derivative feedback system, as depicted in the Simulink diagram in Figure 2.3.

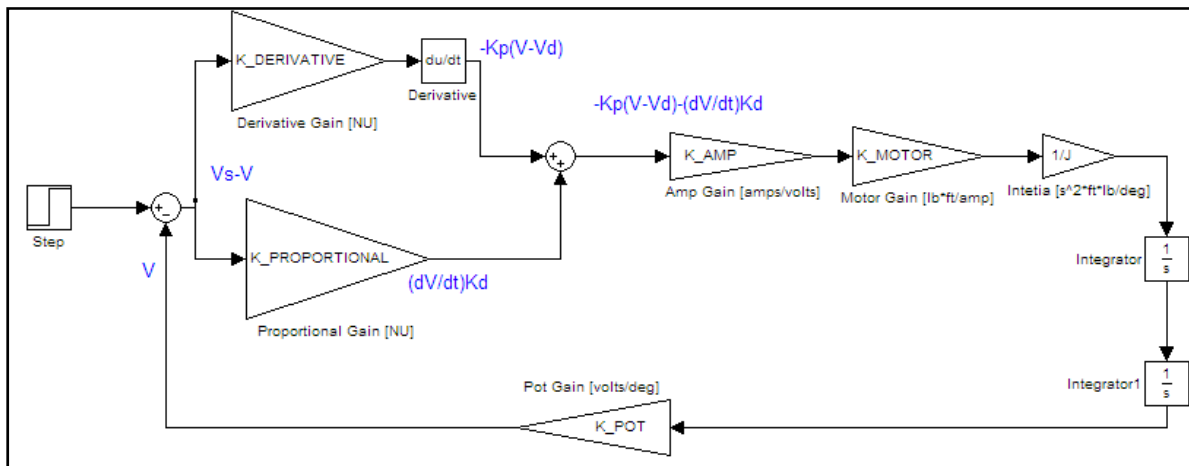


Figure 2.3 Simulink Diagram of Proportional Plus Derivative Control System

The Simulink diagram of the proportional plus derivative control system in Figure 2.3 can be applied to the automatic cannon. First the input into the system is a step function, which is just like the constant voltage input into our system. Then the system adds together a proportional plus a derivative control to implement the control law. Then the Amplifier gain,

Amp\_Gain, and Motor Gain,  $K_{\text{Motor}}$ , and the potentiometer gain,  $K_{\text{Pot}}$ , are added into the diagram by being gains which are inherently determined by the specifications of the amplifier and the motor itself. The inertia term,  $J$ , can be estimated by determining the geometry and density of the cannon and the distance from the pivoting axis. For this simulation, however, since inertia is very difficult to find, a constant value was set in its place. The other two gains, the  $K_{\text{DERIVATIVE}}$  and the  $K_{\text{PROPORTIONAL}}$ , the derivative gain and the proportional gain respectively, can be changed by modifying values in the control program code. Running this model gives an estimation of the relationship between the  $K_{\text{DERIVATIVE}}$  and the  $K_{\text{PROPORTIONAL}}$  terms.

The National Instrument's LabView software, coded in a block diagramming format, has the ability to take advantage of a proportional plus integral plus derivative control system. Through testing the code, it was determined that integral control was not necessary for this application. Integral control is usually used to eliminate steady state error, which does not affect our system because the bandwidth is very high. Instead the code uses the same type of proportional derivative control system as shown in Figure 2.1; in addition, it also includes code that adjusts many other aspects of the robot.

The LabView code first reads in an input voltage from the LabView NI9205, and converts this analog signal into a digital signal. Then, the input voltage is converted to the corresponding voltage of the potentiometer wiper at the desired position which is set by the user through the calibration of the potentiometer. After the system finds the desired position, the control law is implemented so that the actual input will constantly try to match the desired output. The LabView code also determines the desired time and duration that the shot to hit the target would occur; this task is written into the code by firing a shot only if the steady-state error and the derivative error is lower than user-defined values. The code plots the waveforms of the measured, desired, and the control signal onto a voltage versus time graph onto the front panel as shown in Figure A.3 in the Appendix.

### Section III: Testing

Because table time was very limited, to test our system, the assembly without the cannon shaft was clamped to the edge of a workbench. A MATLAB simulation, shown in Appendix A.1, was generated to output analog signals of 1, 2, 3, 4, 5, and 0 volts through LabJack by a user input. The sensitivity of the system to step responses was observed as the voltages changed. The proportional and derivative gains were adjusted so that the shortest settling time was achieved. Upper limits of proportional gain and derivative gain were observed at which the response would oscillate uncontrollably. The settling time of the response seemed to decrease with increasing proportional gain and increasing derivative gain. When the LabView program was set to save data to a file, the response oscillated uncontrollably due to an increase of loop execution time from ~9 to 110 milliseconds. The “bench tests” were not used to determine values to be used on competition day because they did not reflect the true response of the system.

When the table was available for testing, our system was attached to the support beam and the control signal along with the trigger input was connected. Data was recorded using an oscilloscope to observe the response of the system against the desired position. The optimal gain values were found experimentally to be  $K_p = 60.1$  and  $K_d = 2$  for proportional gain and derivative gain, respectively. These values resulted in an underdamped but close to critically damped system. It allowed for overshoot which resulted in lower settling time. The response of the system was not recorded in data tables because no oscilloscope was close enough to the tables to probe for the response of the system. Also, saving the data using LabView would be inaccurate because the save process decreases the sampling rate of the program, which could cause the response to be unstable.

To ensure that the cannon would not fire twice at the same target consecutively, balls were shot with different trigger time values until a critical value which differentiated a single shot versus a multiple shot was determined. We chose the optimal trigger time to be approximately 10% less than the critical value for the trigger time. In practice, the optimal trigger time was found to depend upon the pressure available for use in the cannon. When the feed pressure for the cannon was 20 psi, 350 milliseconds was the optimal trigger time value. When the feed pressure was at 40 psi, the optimal trigger time value was 140 milliseconds. From our observations, this pair of time values prevented “double shots” and “no shots” which refers to two balls shot in one “open valve” command and no balls shot in one “open valve” command, respectively. To determine when the control system should be set to shoot, a filter was generated in the code of the LabView program. The program was set to send a 5 volt signal to the trigger when the absolute value of proportional error was below a set value and the absolute value of derivative error was below a set value. The optimal values were determined by running the table program and trying different values which result in 12 of 12 targets being hit. The optimal values of proportional and derivative error used to filter shooting was found to be 0.06 and 0.02, respectively. A table of recorded values for each run of the test is included in the appendix of this report in Figure A.1.

**Section IV: Parts List**

Detail	Nomenclature	Description	Quantity	Made/Bought	Notes
1	Square Tubing Riser	1" x 1" x .0625" Steel Tube	2	Made	Machine as req'd
2	Motor Mount Plate	1.5" x 10" x .500" 6061-T6 Alum Block	1	Made	Machine as req'd
3	Motor Mount Block	3.5" x 1.25" x 1" 6061-T6 Alum Block	1	Made	Machine as req'd
4	Potentiometer Mount Plate	1.5" x 6.5" x .500" 6061-T6 Alum Plate	1	Made	Machine as req'd.
5	Shaft Coupler	2" x 2" x 7" 6061-T6 Alum Block	1	Made	Machine as req'd
6	Motor Coupler	1"x 2" x 1" 6061-T6 Alum Block	1	Made	Machine as req'd
7	Potentiometer Coupler	1"x 2" x 1" 6061-T6 Alum Block	1	Made	Machine as req'd
8	Shaft Mounting Plates	2" x .5" x .75" 6061-T6 Alum Flat	3	Made	Ball End Mill Bit Machine as req'd
9	Hose Clamp	3.25" DIA, .5" Width Hose Clamp	1	Bought	Ace Hardware OTS
10	Motor	24V Geared DC Motor	1	Bought	Pitman/GM8714F560
11	Motor Amplifier	Switching Motor Amplifier	1	Bought	UCI/Dave Hartwig
12	Potentiometer	50KOhm 24mm Potentiometer	1	Bought	ALPHA/31VA405-F
13	Bolt	1/4"-20 UNC BOLT, 6" LGTH	2	Bought	Ace Hardware OTS
14	Washer	1/4" ID, 3/4" OD WASHER	4	Bought	Ace Hardware OTS
15	Nut	1/4"-20 UNC STEEL NUT	2	Bought	Ace Hardware OTS
16	Socket Head Cap Screw	10-32 UNF SHCS, 2.5" LGTH	8	Bought	Ace Hardware OTS
17	Washer	TO FIT 10-32 HOLE	16	Bought	Ace Hardware OTS
18	Side Clamp Plates	1.5" x 5.5" x .25" Birch Wood Flat	2	Made	Cut as req'd
19	Clamp	2" ID Clamping Length	1	Bought	Ace Hardware OTS

## Section V: Summary of Contributions from Each Group Member

Amelia Halim:

- Designed components for coupling assembly
- Designed mounting assembly
- Generated Simulink simulation
- Wrote report
- Tested supplied components for functionality
- Tested, assembled, and wired complete assembly
- Coded LabView control program

Alex Yang:

- Designed components for coupling assembly
- Designed mounting assembly
- Wrote report
- Tested supplied components for functionality
- Tested, assembled, and wired complete assembly
- Coded LabView control program
- Fabricated custom components of assembly

Randy Ting:

- Designed components for coupling assembly
- Designed mounting assembly
- Wrote report
- Tested supplied components for functionality
- Tested, assembled, and wired complete assembly
- Coded LabView control program
- Fabricated custom components of assembly
- Investigated different options for controllers

## Section VI: Appendices

Table A.1 Recorded Values and Comments for Test Runs

Run Number	Prop Gain (Kp)	Deriv Gain (Kd)	Shot Max Prop Error	Shot Max Deriv Error	Shot Time Delay	Score	Comment
1	10.35	0.095	0.05	0.0037	500	----	continuous double shot
2	10.35	0.095	0.05	0.003	250	5-1	1 double shot
3	10.35	0.095	0.05	0.003	250	7-3	1 double shot and 2 misses
4	11	0.095	0.04	0.003	200	9-3	1 miss at steady state
5	11.14	0.095	0.045	0.003	200	9-3	1 double shot
6	11.15	0.1	0.043	0.003	175	-----	1st shot delay then stopped
7	11.15	0.1	0.044	0.003	175	4-8	2 double shot, miss due to broken target
8	11.15	0.1	0.044	0.003	125	10-2	triple shot, stuck at steady state
9	11.15	0.1	0.045	0.003	100	10-2	1 double shot, doesn't shoot at all
10	11.15	0.1	0.045	0.003	115	----	0 shots fired, got stuck
11	11.5	0.1	0.045	0.004	125	----	bad target, shoots w/o ball, stopped midways
12	11.5	0.1	0.045	0.004	125	----	bad calibration

```
clear
clc
close all
user_entry = 0;
while user_entry ~= 9
    user_entry=input("Target Number?");
    EAnalogOut(0, 0, user_entry,0);
end
```

Figure A.1 Target Program Simulation MATLAB code

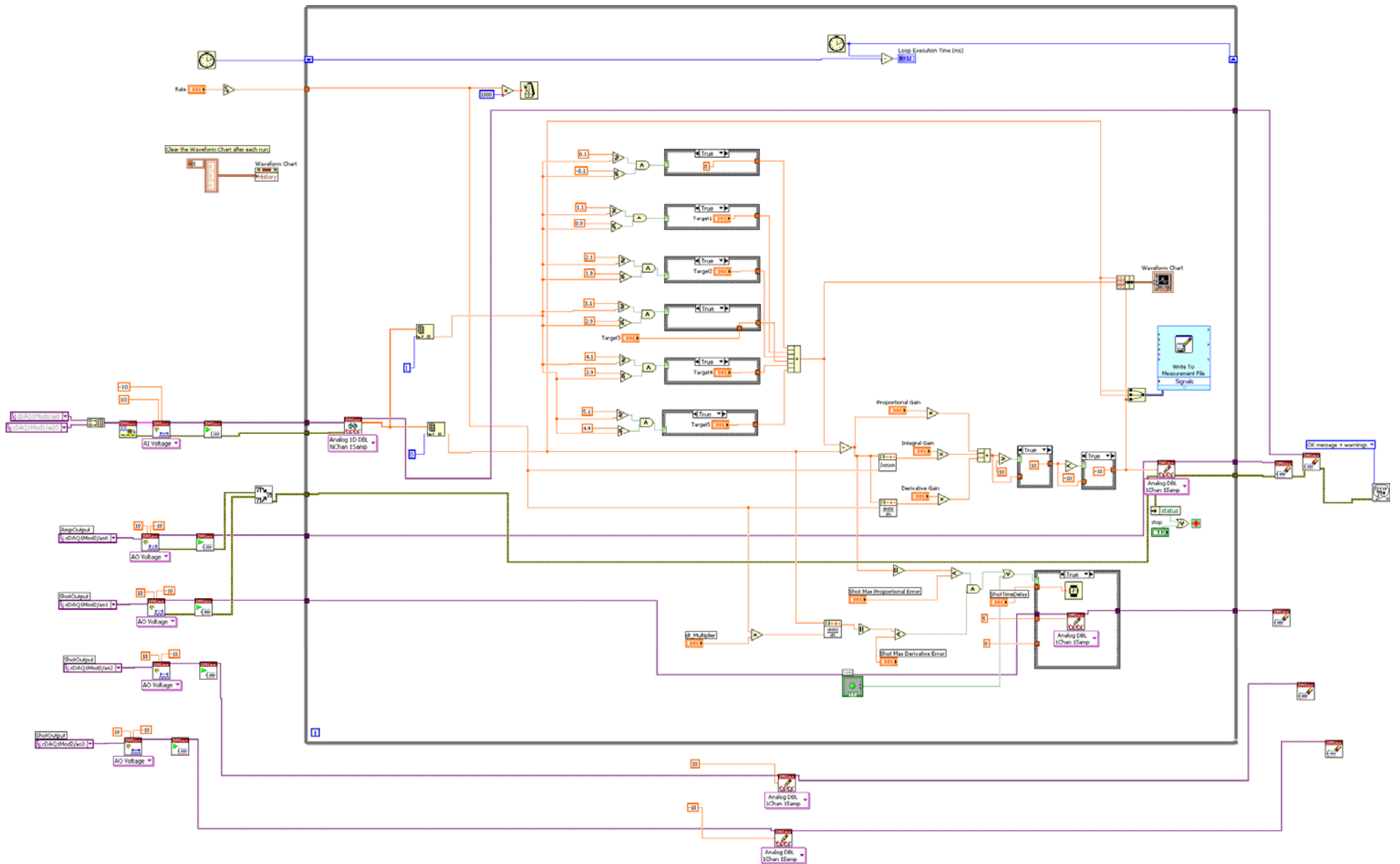


Figure A.2 Block Diagram of LabView Program



Figure A.3 Front Panel of LabView Program