Validation Document

ELEC 491 Capstone Proposal - Dynamic Projector Mount Project

Andy Kwan [redacted]
Smaran Karimbil [redacted]
Siamak Rahmanian [redacted]
Dante Ye [redacted]

Executive Summary:

The purpose of this document is to describe the tests we used to determine the structural integrity, reliability and scope of the various components in our design. We tested every subsystem in our design, documented the results and formed conclusions about the viability of using each component. In this report we will break down the three subsystems:- Mechanical, Electrical and Software and describe the process of their validation.

There are three main aspects to validating mechanical design: Assembly fitment, Stress/Strain, and Fabrication/Manufacturing feasibility, these are the bases of mechanisms to operate correctly. The fitment test passed in our simulations and we were able to construct our prototype. The secondary point is to make sure that the parts which form the assembly do not fail from the stresses and strains when under load. Our design was tested and capable of carrying the load with additional strength for safety. The final stage is to check that the designed parts are possible to manufacture for constraints such as cost and machine availability; it is a test to measure the practicality of manufacture. Most parts allow for fast prototyping, which means that the design is made by using commonly available parts, waterjet cutting and 3D printing.

For the electronics and software, there are four aspects to test, which are the motors, sensors, bluetooth communication and software control. Our primary requirement for our project is to accurately position the projector, and this is achieved by having precisely controlled motors and sensors to correct the positions of the motors. We were able to verify that our design For the motor we also test if the speed can be controlled, this is to ensure no damage is done to the projector. We then test the reliability of bluetooth communication to verify if it would be a viable option for wireless communication, which is also a requirement for our system. Finally, the overall power consumption must be measured, which is an important consideration while designing the power distribution circuit.

We were able to pass all the tests for our system, thus making it possible to meet all the requirements of this project.

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1. Mechanical

1.1 Assembly Fitment

1.1.1 Purpose

We perform the Interference Detection and Clearance Verification through Solidworks to validate and test the feasibility and fitment of the designed parts in the assembly. Running this these tools will show if any of the parts or design ends up not working in the mechanism. These two features work by measuring all the dimensions of all the parts relative to its mated position in the assembly. These tools will locate exactly where the problematic area is so that it can be re-engineered and fixed. Although not directly validating any of the requirements, this test is crucial for a successful assembly and mechanical design.

1.1.2 Test Set-up

Use generic set-up provided by Solidworks, no custom parameters required for this test set-up. To pass the test, the results must show No Interferences, otherwise it is a fail.

1.1.3 Results and Conclusion

The results/report for the two test tools are shown in Figure 1.2 validating that through many iterations of fixing the parts so that it fits, this designed part works and has no fitment issues and passes the test.

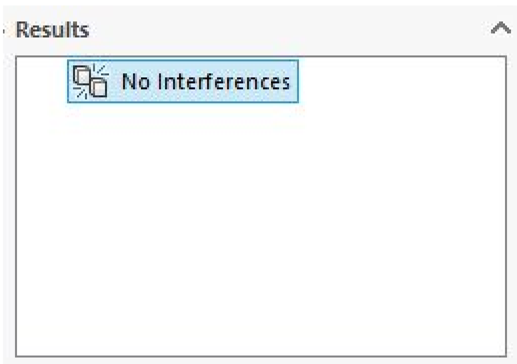

Figure 1.1 - Interference Detection Result

1.2 Materials Tensile/Stress

1.1.1 Purpose

To validate the tensile strength and stress on the mechanical components requires a simulation. SOLIDWORKS has an add-in tool to simulate force and pressure. This tool is called SimulationXpress and can be setup to show stress on a part.

1.1.2 Test Set-up

Use ¼" 6061 Aluminum Alloy in the materials parameters. The colors validates whether the part will support the payload, and the less red it shows the lower the chance of failure. The user of the tool can further read how much stress the part can take before it fails. To pass the test, each part has to go through simulation and read to determine if it can carry the payload with the required minimum safety factor of 2. If it can carry the payload it is a pass, otherwise a fail, which requires re-engineering.

1.1.3 Results and Conclusion

In this test for one of the pan tilt plate used in the structural frame, for a complete failure where payload is detached from the plate, it shows that the strength of 200kg which has a factor of safety of 4. This surpasses as per our requirement (Non-Functional Requirement 2). The other parts are not shown but the Solidworks files will be made available to our client Tim Herron.

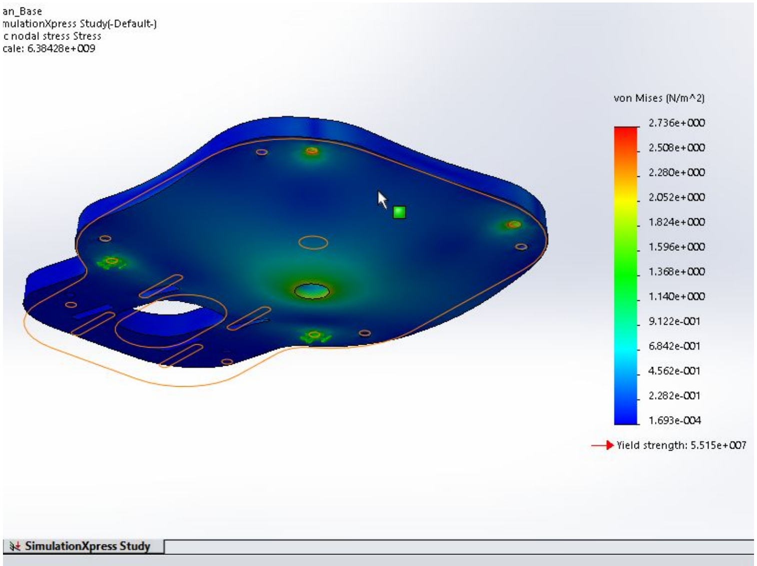

Figure 2 - Solidworks Stress Simulation Result

1.3 Ease of Fabrication/Manufacturing

To validate this component of the design will require an actual prototype to be fabricated. At this stage the design and engineering of the parts are still in progress so the testing has not been fully completed. However, the most precision and accuracy intensive part, which happens to be very critical to the design, has been tested to validate that it can be prototyped through a computer controlled waterjet machine. Figure 3 shows a pulley using the same timing belt tooth profile as the dynamic projector mount was cut to show the mesh quality with the timing belt. Visual inspection confirms that there are no significant difference between the two profiles.

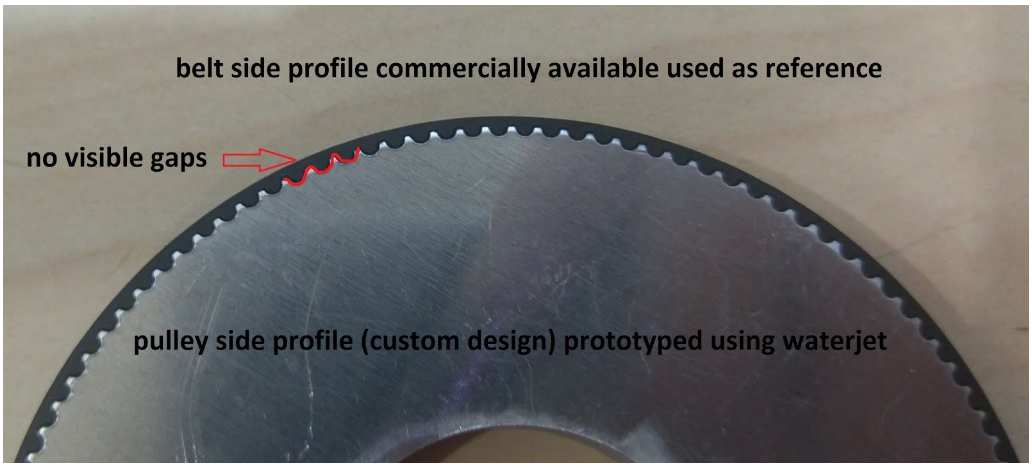

Figure 3 - Pulley and Belt Profile Comparison

Once the first version of the design is finalized the fabrication of the prototype parts will commence. Through actually fabricating the parts, the feasibility can be observed and any problems with designing for fabrication will be recorded. A new iteration of design will take these points into consideration. The waterjet test concludes that that most precise and accurate part of the dynamic projector mount can be prototyped, and that all parts requiring less precision and accuracy can be fabricated.

2. Electrical Circuit

2.1 Motor position Control Test

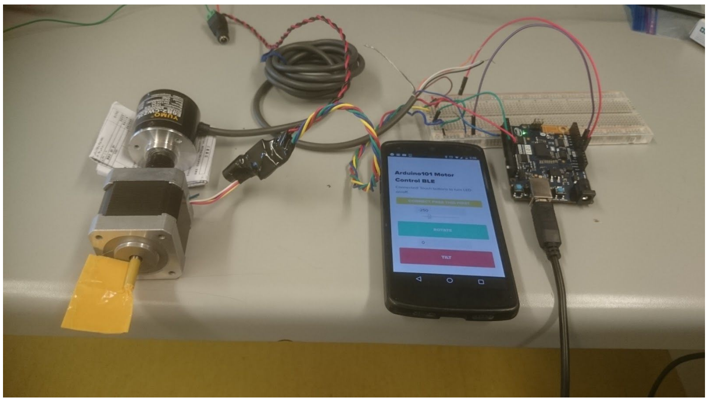

Figure 2.1 - Motor Control System

2.1.1 Purpose

The first test of the electronics section should be of the motors/ motor drivers, to see if that it can accurately be controlled and positioned. Doing this test will be useful for all subsequent tests of the system. To validate the control of the motors we will mainly be testing if the motor moves to the different positions based on the number of steps applied. The motors will be satisfactory for our use if we can move them for the desired range of 360° in any direction as well as move them with a precision of 0.1°.

2.1.2 Test Set-up

The motor driver is controlled by a square wave pulse and would move the stepper motor one step on every rising edge of the pulse. From our stepper motor specifications we knew that there are 200 steps with 16 microsteps giving us 3200 steps per rotation. This also means that every step of the motor will translate to 0.1125° per step. To calculate the number of steps needed to move for a desired angle in degrees we can calculate as follows:

$$Number\ of\ steps = (New\ Position - Old\ Position)^o * \frac{3200}{360}$$

To validate the functionality of the motor driver as well as test the microcontroller signal, one can easily probe our microcontroller output pins and view the results on an oscilloscope. Our first test was to see if we could move the motor by any desired number of steps, by using the above relation. Using the microcontroller we are able to output any number of square waves. This is done by using the serial monitor or a simple app as we can see in the figure 2.1 above. The output signals are observer as in figure 2.2

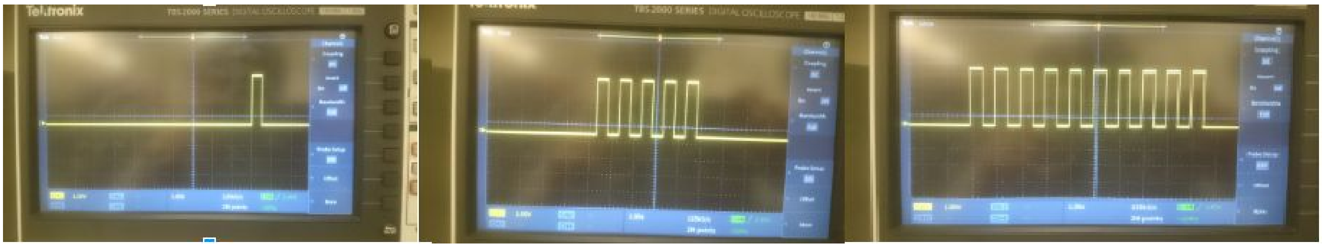

Figure 2.2 - Oscilloscope output for variable number of square waves

2.1.3 Results and Conclusion

The motor control test was very successful. We were control the position of the motor with 100% accuracy as seen in the Table 2.1. As we mentioned before, there will be a movement of 0.1125° per step. When we connect it to our belt and pulley system we will be able to calculate the movement per step by multiplying it by the gear ratio of 20:160 for pan and 20:200 for tilt. This gives us approximately 0.01° of movement. This allows us to meet our requirements of 0.1 degree movement.

Number of pulses	Angle Expected in degrees	Angle of rotation in degrees
800	90	90
1600	180	180
3200	360	360

Table 2.1 - Number of square waves and corresponding rotation

This test passed by showing the motor control working as expected, which meets our Requirements (Functional requirement 1, 2 and Non-functional requirement 3)

2.2 Motor Speed Control Test

2.2.1 Purpose

We perform this test to verify if the speed of the motors can be controlled. This needs to be done for smooth movement of the projector (Constraint 4). The motors will have to start at a low speed, gradually accelerate, and decelerate before stopping. Since the projectors are made to be stationary, we had to chose a low acceleration so as to not damage the lens and bulbs. We estimated that the acceleration would have to be less than $0.5°/second^2$. Along with the acceleration a maximum and a minimum speed of movement will be selected. To determine if the rate of acceleration is satisfactory we will compare the time taken for movement of the projector with our calculated values based on the selected speed and acceleration. While testing we must ensure that we start at lower speeds that what we calculate. For our tests to pass we expect that if the time taken to move the projector mount should be less than the time we calculated for this acceleration.

2.2.2 Test Set-up

Test 1: Speed control with Constant speed

The setup for this test is the same as the previous test as seen in figure 2.1. Since the motor would step on every rising edge of an input signal we can control its speed of the motor by changing the its frequency. We were able to adjust this frequency with a signal generator as well as with the microcontroller. When we tested our signals

$$Rotations\ per\ minute(RPM) = \frac{Frequency}{3200} * 60$$

When we apply various frequencies we can observe the following results. The change in frequency can be verified on the oscilloscope as seen in figure 2.3.

Figure 2.3 - Variable frequency output from microcontroller

To compare our results with measured values we can use a counter of pulses. Since our last test resulted in 100% accuracy we can use the number of pulses outputted to calculate the RPM. We run the motors for a minute and measure the RPM as:-

$$RPM = \frac{Number\ of\ pulses\ in\ a\ minute}{3200}$$

We can tabulate the results and calculate the error as seen below

Test frequency	Expected RPM	Pulses Counted	Measured RPM	Error
100	1.875	6000	1.875	0
500	9.375	30000	9.375	0
1500	28.125	90000	28.125	0
9000	168.75	540000	168.75	0
25000	468.75	1500000	468.75	0

Test 2: Test with acceleration

This test is done on the complete system. Using a pre determined rate of acceleration we can create a acceleration control algorithm in our software which will regularly change the frequency of movement. The frequency had to be calculated for the desired speed.

$$Frequency = \frac{Angular\ velocity}{360} * 3200$$

For example- By estimating the the maximum speed as 35°/second and the minimum speed at 2°/second. This gives us pulse frequencies of 311Hz and 17.8Hz respectively. We can calculate the time taken for movement from one position to another using the relation of acceleration, time and initial speed.

$$\theta/2 = \omega_{initial}t + \frac{1}{2}\alpha t^2$$

This operation has to be repeated twice for acceleration and deceleration.

Before this we must calculate the time that it takes for reaching maximum speed. This will be used if the acceleration time is long.

$$t = \frac{\omega_{final} - \omega_{initial}}{\alpha} = 13.2\ seconds$$

Since the first half of the movement will be acceleration the time taken for deceleration will be calculated as

$$\theta/2 = (\omega_{initial} + \alpha t)t + \frac{1}{2}\alpha t^2$$

As an example, using the initial speed $\omega_{initial}$ of 0.1°/second,we perform a test for θ as 180° and α as 2.5°/second^2 . This gives us a time value of approximately 13.3 seconds Now we can measure the speed of the moving system using a stopwatch to compare our result. We were able to measure that the time taken for 180° movement was 14.5 seconds.

We perform a few more tests with different values of θ to verify the acceleration as shown below.

Angle of Rotation	Calculated Time	Measured time	Error
45	4.6	5.2	0.6
90	6.7	7.2	0.5
180	9.4	12.5	3.1
360	15.7	19.4	3.7

2.2.3 Results and Conclusion

From the above tests we were able to observe that the speed can controlled by changing the frequency given to the motor driver. For a fixed frequency, the speed of rotation is very accurate. When we test the system with acceleration currently the speeds we measure for our movements are slower than the results we expect. One of the main reasons for this is that the rate of change of speed/acceleration is done by a digital system which will not be as smooth as an analog system. The rate of change of acceleration is not 0 and is determined by the clock speed and the number of instructions executed before changing speed. We can conclude that the mount moves slower than the expected rate of acceleration. We know we can tune the projector to go at a faster rate for the future design. Considering this it is considered safe to use the projector mount without damaging the projector satisfying our constraints (Constraint 4).

2.3 Bluetooth Range and Signal Strength Test

Figure 7 -Test Environment Figure 8 -Test Circuit

2.3.1 Purpose

To have wireless connectivity of sufficient range(Non functional requirement 9) the range of the Bluetooth 4.0 Low Energy module must be tested. We will test this by measuring signal strength and connectivity.

2.3.2 Test Set-up

The experimental setup was to use a simple program on the Arduino board to turn a pin on when it was connected to a bluetooth device. We connected an LED to this pin and used a simple smartphone app to communicate with it in an open environment. When the bluetooth module established a connection to the smartphone, the LED would turn on. Conversely, when the bluetooth is disconnected, when it moves out of range, the LED would turn off. We tested this by connecting the smartphone to the bluetooth module and moving away. To test the signal strength of the bluetooth module we used a third party app that would show the signal strength of nearby devices.

2.3.3 Results and Conclusion

We were able to measure the following results:-

Status	Distance	Signal Strength
Connected	0m	-45dBm
Connected	30m	-80dBm

Table 2- Test Result

When signal strength is lower -90 dBm, the iPad was disconnected from the Arduino connectivity. As per Non-functional requirement 9, the required connectivity range is 10 meters. The result shows that 30m connection exceeds 10m. The test passed.

2.4 Rotary Encoder Test

2.4.1 Purpose

As we have mentioned in our design document, it is important to have feedback control for our system, for this reason we use Rotary Encoders for detecting change in angle. For this test we will measure the accuracy of measurements

2.4.2 Test Set-up

The first test for the Encoder, the E6B2-CWZ3E, was to check outputs based on its data sheet. We did this by probing each of the encoder outputs with an oscilloscope. For this we powered the encoder with 5V and then connected pin A to yellow, pin B to blue and pin Z to pink. We rotated the shaft of the Encoder at a non constant speed and observed its outputs on the Oscilloscope. We were able to verify that the outputs on pin A were always preceding pin B when rotating clockwise. We also observed that the pin Z would be pulled low when the shaft would pass a fixed 0 position.

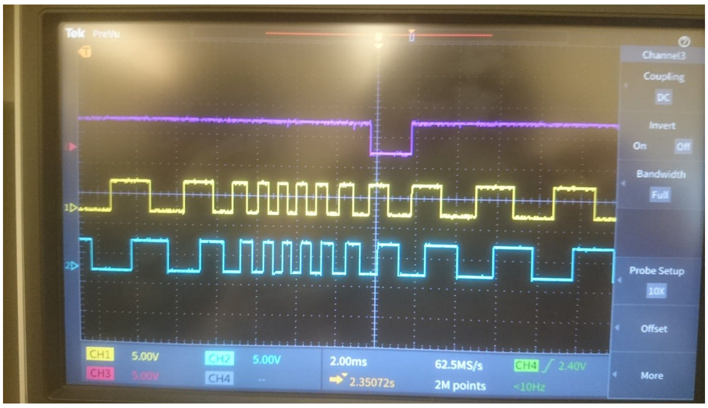

Figure 9 - Outputs from rotary encoder

To read these signals from the Arduino, we used hardware interrupts to count the pulses,through the digital IO pins. From the datasheet the resolution is 1024 pulses per revolution. Every angle is calculated as pulses times 360/1024. We printed out the values the Arduino received. We were able to get the following results:

Actual Angle change of Motor	Pulses counted by the Arduino	Calculated Angle	Percentage Difference
0	0	0	0
30	85	29.88	0.4%
60	170	59.7	0.5%
90	256	90	0
135	384	135	0
180	512	180	0
270	800	280	3.7%
360	1024	360	0

Table 3 - Encoder Values Test Result

2.4.3 Results and Conclusion

We know there will be a discrepancy in the measured values of position between the motor and the encoder, this is because of the difference in precision of movement. (it can be seen that there is no error for positions with common factors). With this precision for reading the motor, we will have a tolerance of approximately 0.01 when connected to the system through the gear ratio. The test passed, and the rotary encoder satisfies our requirements (Non-functional requirement 3).

2.5 System Current and Power Test

2.5.1 Purpose

The test of the electronics section should be of the whole electronic system, to see if maximum consumption of current and power exceeds the source limit.

2.5.2 Test Set-up

We connected a 10A Amp meter between 19V DC input and the AC-DC rectifier and power the system on to read the actual current values in standby and motor working condition .

2.5.3 Results and Conclusion

The result is shown by following:

Condition	Voltage	Maximum Current	Current Limit	Maximum Power	Power limit	Pass/Fail
Standby	19 V	0.9 A	3.42 A	17.1 W	65 W	Pass
Both motors working with projector Panasonic PT-DZ6700 projector	19 V	1.5 A	3.42 A	28.5 w	65 W	Pass

The result shows maximum current and power are always less than source limit, which not only meets requirements (Non-functional requirement 6) but also operates within safe limits. This test passed.

3. Software

3.1 Writing Data to Arduino from iPad Test

3.1.1 Purpose

To test if the data being sent from the iPad is being read accurately by the Arduino. This is important to see if we will be able to send information about positions to the arduino.

3.1.2 Test setup

Firstly, we tested the wireless connectivity of the bluetooth modules. This was similar to the Bluetooth range test as mentioned above. We did this test by trying to turn an LED on and off. After writing simple test code on the Arduino emulator to receive data from the iOS app on the iPad, to turn on an LED. As shown in the figure below, the LED turned ON and OFF when the button on the iOS app was pressed and released.

Figure 3.1 - Bluetooth Connection LED is shown High

After establishing wireless connection with the Arduino, we moved on to sending and receiving more complex values. According to our design we would send 8-bit integers through the bluetooth module. Needing to send values such as 360.0 and -360.0. After running our numbers through the necessary methods inside the iOS app, we sent over 3 different values that describe one angle that's chosen by the user. As shown in the figure 3.2 below, the user selects the value of 110 degrees. The Serial port of the Arduino shows the values received by the bluetooth module that is to be reconstructed using the appropriate method to translate the 3 numbers back to the 110 degrees that was originally sent by the user.

Figure 3.2 - Terminal outputs from microcontroller

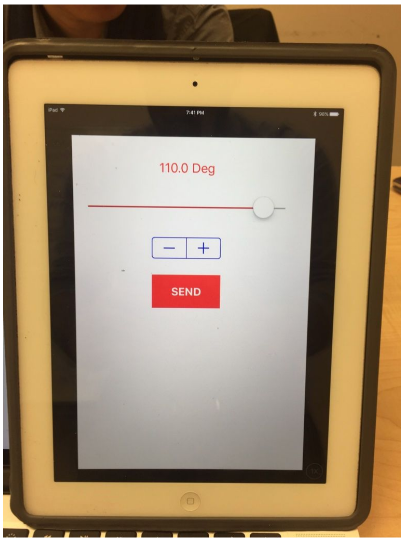

Figure 3.3 - iOS App Interface

3.1.2 Conclusion

Communication tests for the iPad were proven to be successful. We were able to read all data sent accurately.

3.2 Preset Value and Name Storage test

3.2.1 Purpose

In order to test the preset storage capability of the iOS application, we will store different pan and tilt values inside different segmented control elements and view their results to verify that they are operating as expected by changing the Pan and Tilt Values correctly. We will also test the capability of changing the names of the presets. This will be done by changing the views from Settings to Projector 1 Figure 3.4 below shows the Settings View in which the different names were entered. As shown, for preset 1, the text London was entered, for preset 2 New York was entered, and for preset 3 Vancouver was entered into the textField.

3.1.2 Test setup

In order to test the preset title change capability of the application, we will use the XCode Simulator

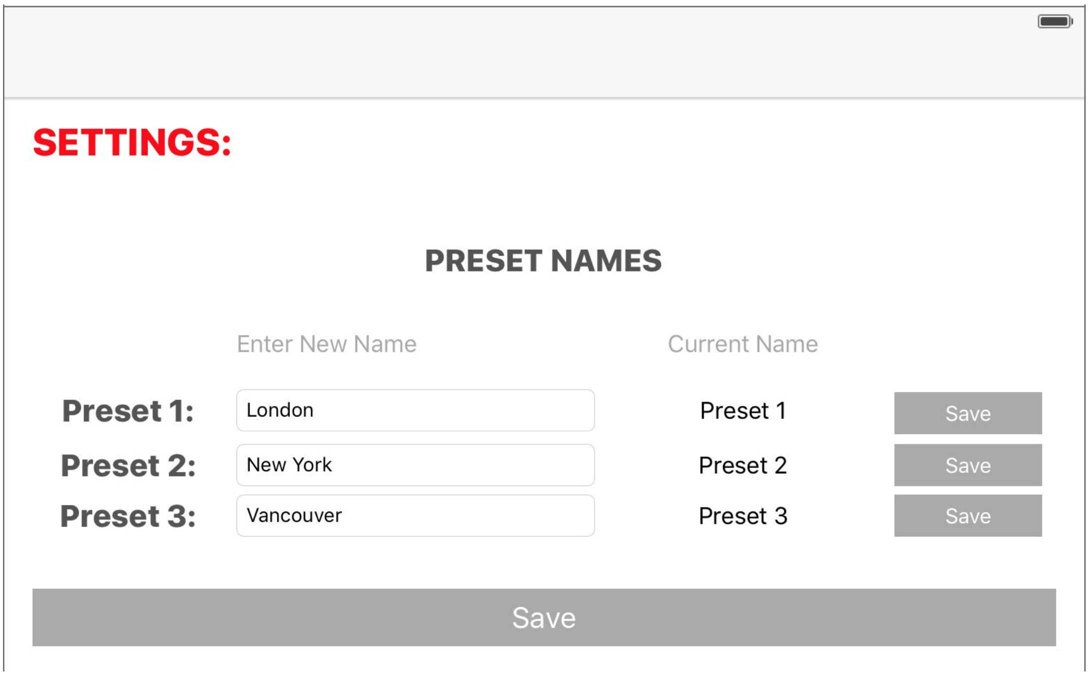

Figure 3.4 - The Texts Entered into Preset Name Settings View

Figure 3.5 illustrates the Projector 1 View in which the results of the entered texts into the preset settings view is validated and the requirement (Constraint 9) passed.

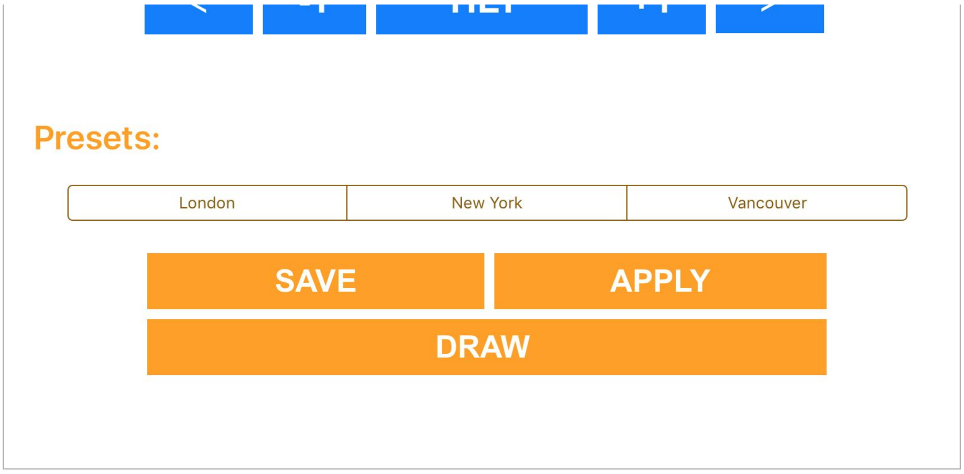

Figure 3.5 - Results from Text Entered Into Preset Settings

The table 3.1 shows the values of the pan and tilt that were attempted to be stored in the presets, and the values the preset gave back after a time of 3:00 minutes of change the pan and tilt values multiple times.

Iteration	Pan Value Stored (º)	Tilt Value Stored(º)	Pan Value Retrieved (º)	Tilt Value Retrieved (º)	Pass/Fail
1	110.0	-90.0	110.0	-90.0	PASS
2	-20.2	37.2	-20.2	37.2	PASS
3	-180.0	22.0	-180.0	22.0	PASS
4	-179.5	-12.0	-179.5	-12.0	PASS

Table 3.1 - Preset Value Test Table

According to the test that was done on the XCode Simulator, it is shown that the preset capability of the application passed the requirement (Constraint 9).