Mechatronics Term Project

P5643 Projectile Launcher

Group 3

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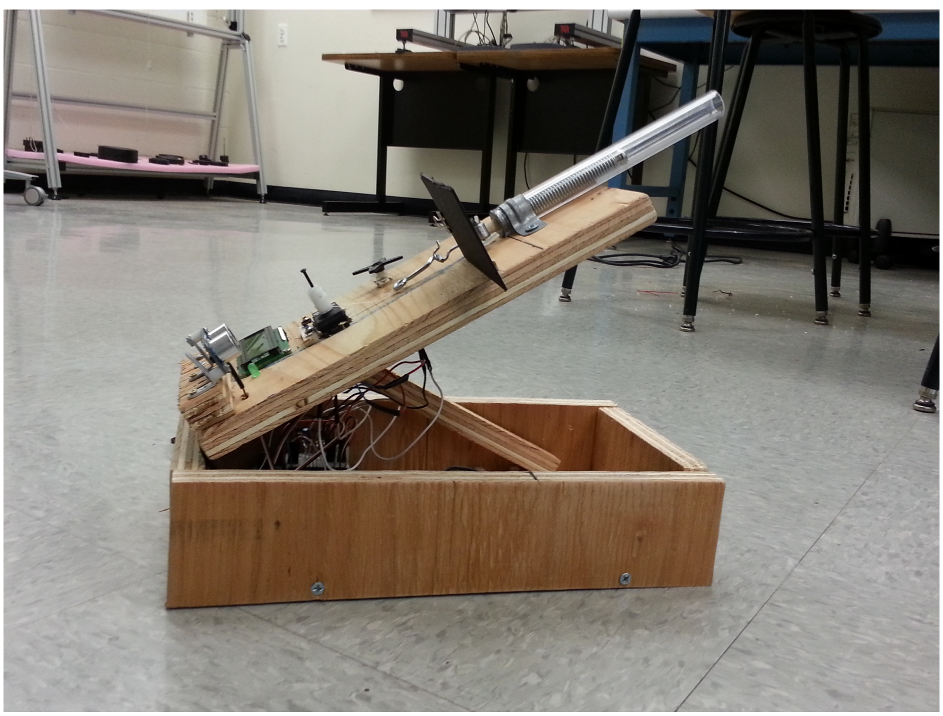

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Abstract

The purpose of this project was to develop, and build a projectile launcher that can be used in a K-12 learning environment. The projectile Launcher can be used to help teach and/or enforce basic Newtonian physics. The physics that can be taught are the relationship between velocity and distance traveled and how various angles change the distance. Also how potential energy can be transferred to kinetic energy through a spring. Finally, the idea of frictional losses through mechanical interfaces can be reinforced by examining measured and theoretical results. The results show a close match between the theoretical and measured distance values, with percent differences ranging from 4.55% to 16.36%.

Motivation and Introduction

Science, technology, engineering, mathematics and physics are typically difficult subjects to illustrate and integrate into the K-12 classrooms. Studies have shown that most students are visual and tactile learners, however it appears that the best instruments and demonstrations to exhibit these difficult subjects are the most costly. With budget cuts and our current economical times, our educational systems can not handle the financial strains, and unfortunately both students and educators are left to suffer the consequences of an under-educated system due to a lack of resources.

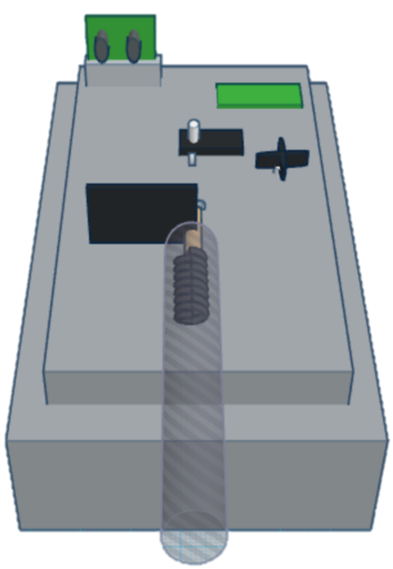

Figure 1: P5643 CAD Design

The motivation of this project is provide GK-12 physics educational systems with a new economical approach to demonstrating projectile motion in the classrooms. P5643 is a smart and integrated projectile launcher, which utilizes the intelligence of micro-controlled actuators and sensors to characterize and execute projectile motion according to preset values administered by the user.

What's unique about P5643 is not only it is a "smart" projectile device; additionally it integrates three of the most commonly taught Physics experiments into one device. These experiments include 2-dimensional projectile motion, Hooke's Law and conservation of energy. Educators and students will be given the opportunity to experiment with common projectile settings characterized by varying initial conditions such as initial launch angle, initial launch velocity and initial height to help solidify their understanding of Newtonian Physics.

Mathematical Background

The mathematical background of the trajectory of the projectile can be calculated using a few simple equations. For this exercise only the horizontal component distance of the projectile will be calculated and used. Calculating the force exerted by the spring on the projectile is seen in the equation below, which is derived from Hooke's Law.

$$F = -kx$$

Where F is the force, k is the spring constant, and x is the displacement of the spring. From the above equation the velocity of the projectile is calculated. From the conservation of energy, the potential energy and the kinetic energy must equal zero. Thus the potential energy that is stored up when the spring is pulled back must equal the kinetic energy that is released. The equation below demonstrates this idea.

$$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$$

Where m is the mass of the projectile, and v is the velocity of the projectile and with solving the above equation yields the following solution for the velocity.

$$v = \sqrt{\frac{kx^2}{m}}$$

Since the projectile launcher will be used to shoot projectiles at different angles the components of the of the velocity vector must be derived to calculate the distance the projectile flies. Since the experiment is only concerned with the horizontal component that is the only component that will be derived. The following equation is thus used to find the horizontal distance.

$$d = \frac{v\cos\theta}{g}\left(v\sin\theta + \sqrt{(v\sin\theta)^2 + 2gy_o}\right)$$

Where θ is the angle between the horizontal and the barrel of the projectile launcher, g is the gravitational constant, and y_o is the initial height of the projectile from the horizontal.

Materials and Methodology

P5643 is constructed from the following materials.

User Interface

To provide ease of usage, the P5643 is equipped with the following user-friendly components.

LCD: The Parallax 2x16 Serial Liquid Crystal Display (LCD) provides a low-cost monitoring display to allow users the ability to visualize user specified input of spring compression distance, as well as step-by-step instructions to properly operate the P5643. The Parallax 2x16 Serial LCD is interfaced using a 3-pin connection to BS2.

LED: Green Light Emitting Diode (LED) indicator alerts user when the P5643 launching mechanism is in position and ready to launch the projectile into space. Users will additionally be notified via the LCD panel of the "Ready To Launch" alert.

Adjustable Knob Control: Adjustable knob control allows user to specify spring compression distance in order to configure the preferred stored potential energy within the spring utilized in the projection. The adjustable knob control is implemented using a 10K potentiometer with a 3-pin connection to the BS2. Compression Spring Distance Range includes: 0 mm to 29 mm

Pushbuttons: The blue and red pushbuttons on the wooden lid of the P5643 are used to proceed through launching instructions displayed on the LCD panel, as well as a kill/reset button to dismantle the entire P5643 system respectively.

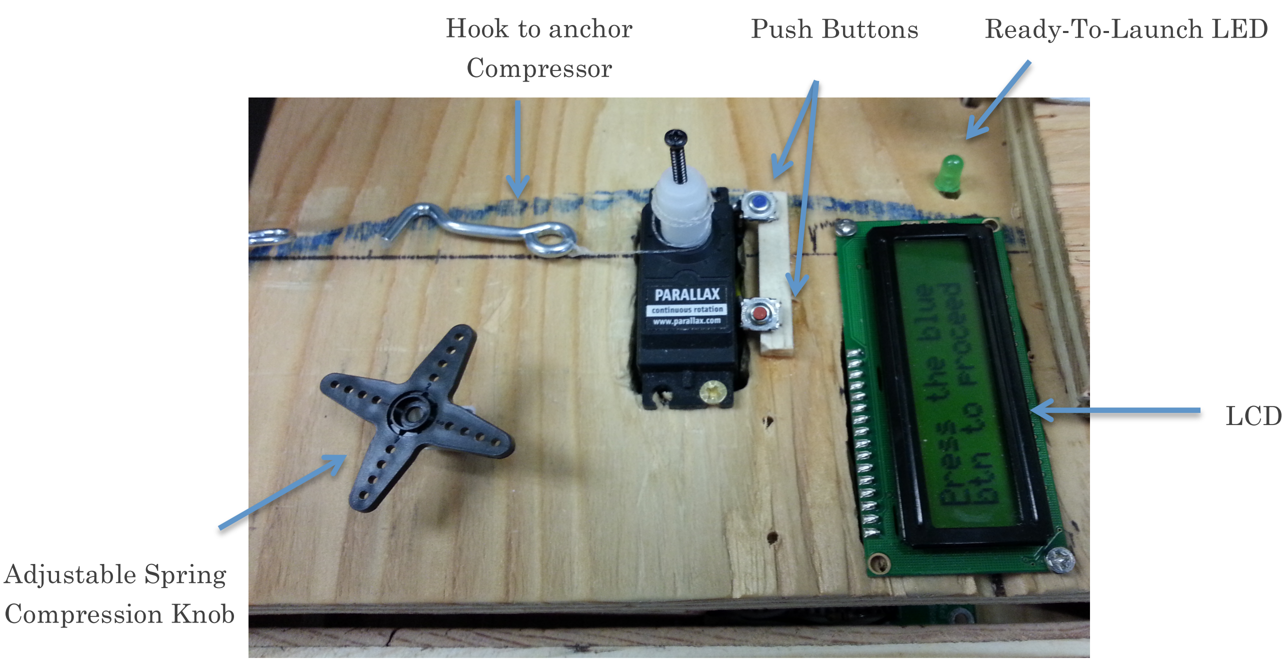

Figure 2: P5643 User Interface

Actuator and Sensors

Actuator: The Parallax Continuous Servo is the actuator of choice used to pull the Compressor to a specified user-input distance. Power requirements include 6VDC power supply with pulse-width-modulation for communication. The actuator has a max torque pulling force of 13 lbs with a shaft radius of 3/16", which is sufficient for the 3.7 pound force needed to compressed the spring to its max. The servo motor is interface with the BS2 using a 3-wire ribbon connection (Vdd, Vss and Input), as well as it receives feedback input signaling provided by the ultrasonic sensor detection in order to position the P5643 launching mechanism to a user specified setting.

Sensor: The Parallax PING))) Ultrasonic Distance Sensor provides a very low-cost mechanism to provide accurate feedback distance measurements in compressing the spring to a user-specified amount. This functionality allows P5643 the unique capability to integrate three key kinematic experiments into one: Hooke's spring law and 2D projectile trajectory motion and conservation of energy.

The PING))) Ultrasonic sensor measures distance using sonar technology to transmitted ultrasonic pulses to a targeted object at a distance. The distance is measured by the time required for the ultrasonic sensor to detect the echo ultrasonic pulse in return. Specifically within the P5643 setup, the ultrasonic sensor detects for the movement of a black panel indicator that is attached to the Compressor that compresses the spring to a user-specified distance. This distance is inputted using the adjustable knob control located on the user panel o the P5643. The ultrasonic sensor is interfaced with the BS2 using a 3-wire ribbon connection (Vdd, Vss and Output) and fed a feedback control to the continuous servo, which is actuating the pulling force of the compressor. **Note:** The ultrasonic sensor is position at an elevated height on a wooden plank to avoid echo reflection dissipated from the wooden lid and not the black panel.

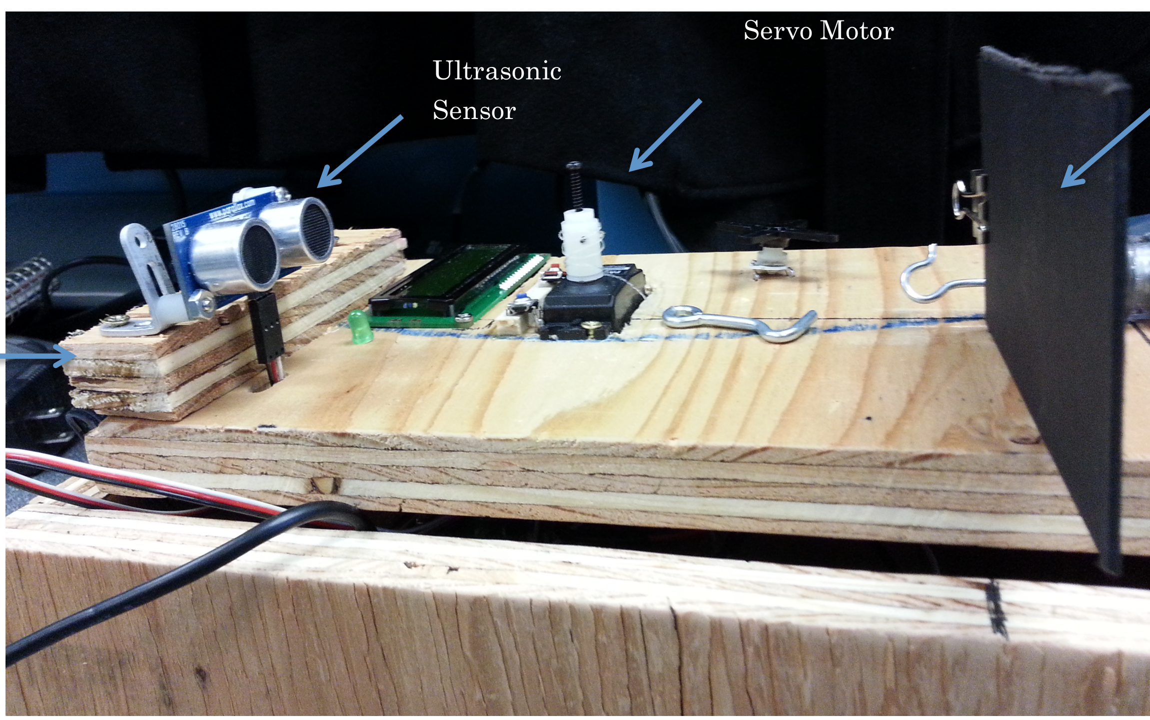

Figure 3: P5643 Actuators and Sensors

Other Electrical Components

Electrical Components

- Resistors
- 1O µF Capacitor
- 6V Battery Power Supply
- Electrical Leads
- Parallax BS2 Board of Education Board

Launching Apparatus and Building Material

The P5643 launching apparatus is located on top of the P5643 mainframe wooden lid. It is used to launch an alloy steel metric ball bearing into space. It can be adjusted to a 0°, 30°, 45° or 60° launch angle configuration when adjusted. The launching apparatus consists of a 7” cylindrical launching barrel composed of clear plastic cellulose with an outer diameter of ¾” and inner diameter of ½ ”. The launching barrel is single-open ended tube capped with a ¾” outer diameter and 5/16 “ inner diameter steel washer used as the stopping mechanism to compress the spring. The launching barrel is anchored to the mainframe wooden lid using one U-clamp and two steel wood nails. Encased within the launching barrel is the 3.5” in length steel compression spring with an outer diameter of 0.438” and K value of 3.25 lbs/inch. The apparatus known as the Compressors is what’s used to compress the spring to a user-specified compressed distance. This is distance is inputted using the adjustable knob located on the lid of the P5643. The Compressors is composed of a 5/16” diameter wooden dowel rod that is capped with a ¼ “ Steel mirror mount nut at one end, and a mild steel hook and pipe clamp at the other end. The Compressor is completely fed through the launching barrel and spring, respectively, to be then connected to the servo motor that will generate the pulling force to compress the spring. Attached to the servo motor is a 3 ½” 8 lbs double twined monofilament fishing line attached to a mild steel hook. This steel hook attachment is the connector piece between the servo motor and the Compressor’s steel hook.

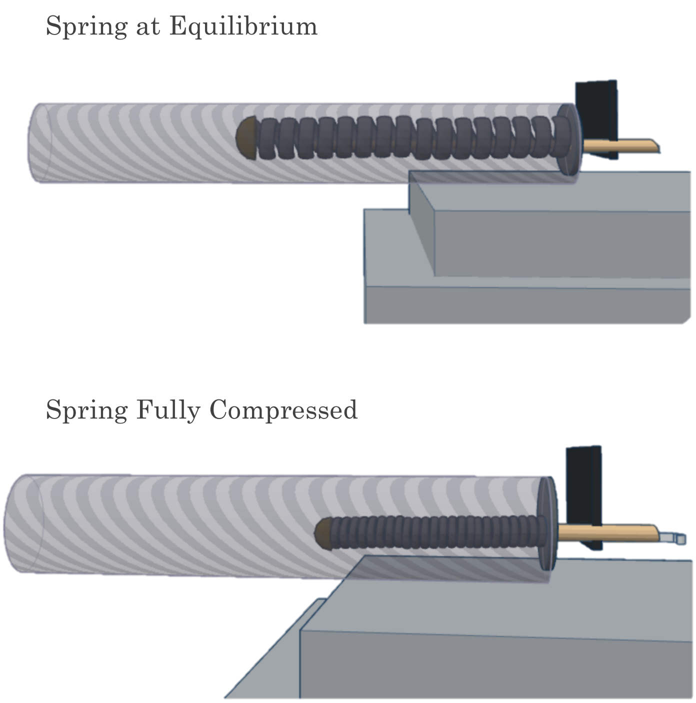

Figure 4: Launching Apparatus

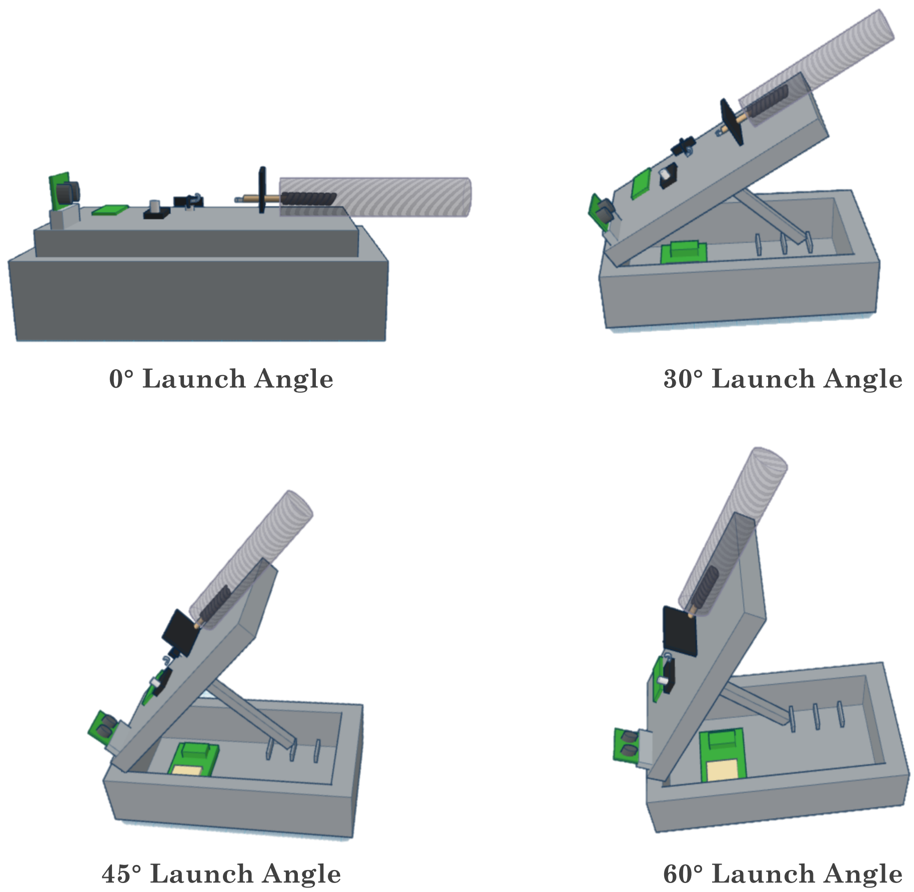

Figure 5: Customizable Launch Angles

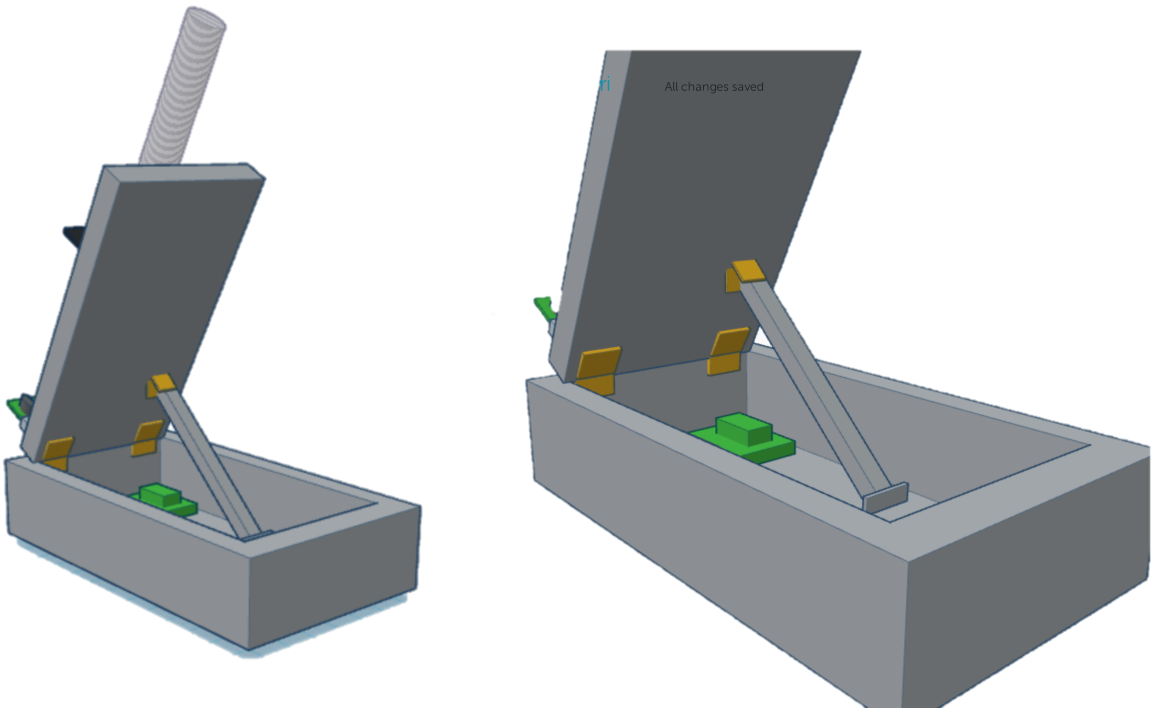

Figure 6: Hinges and Angle Lever

Final Product

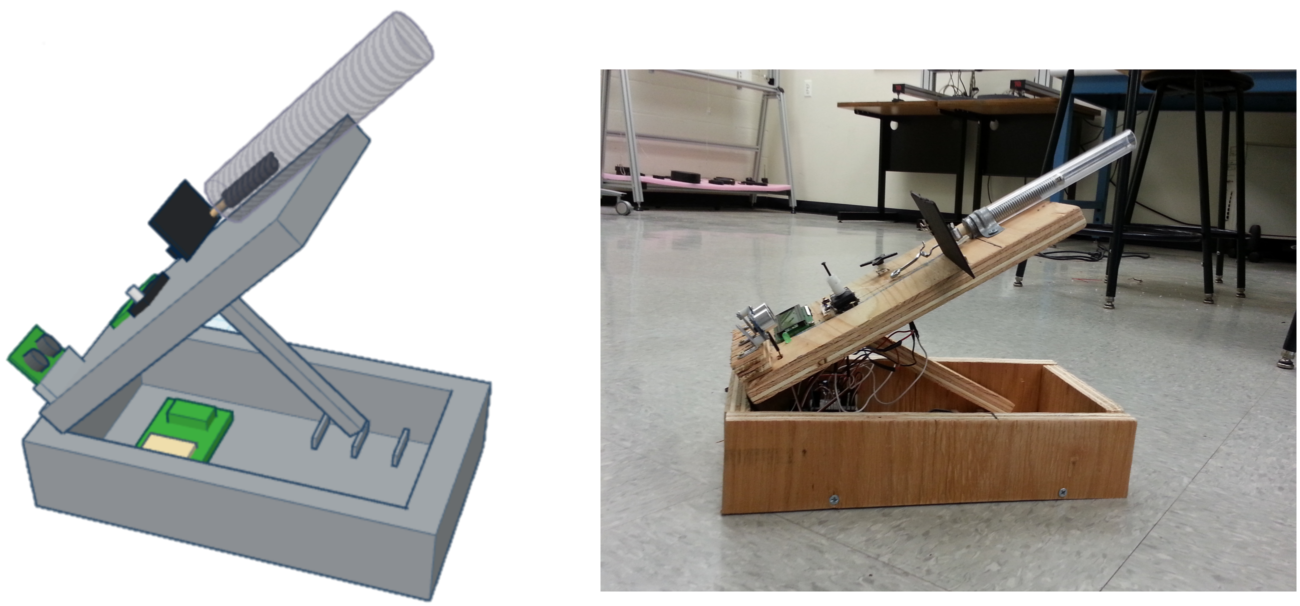

Figure 7: CAD and Final Product

Bill Of Material and Cost

The below table represents all material and the total unit cost for the construction of the P6543. The total construction cost for the came to an estimate total of $220.30. The greater part of the total cost was primarily composed of electronic components including the Parallax Board of Education Development Board and Parallax 2x16 Serial LCD. In preparation for mass production, the total cost for each unit of P5462 can be estimated at a total price of $150. This estimated cost is based upon the expected decrease in manufacturing cost (approximately 25% decrease) in printing electrical circuitry such as Parallax Development Board, ultrasonic sensor and LCD, as well as the cheaper cost in bulk purchasing of hardware material such as steel wood screws, compression springs, plywood, battery power supplies, as well as electrical components

Materials	P5463 Qty Usage	Unit of Measure	Unit Cost	P5462 Usage Cost
Parallax Board of Education Development Board (Full Kit)	1	Each	$99.99	$99.99
Parallax (Futaba) Continuous Rotation Servo	1	Each	$12.99	$12.99
Servo Rotary Driver	1	Each	$5.95	$5.95
Parallax 2x16 Serial LCD (Non-Backlit)	1	Each	$27.99	$27.99
PING))) Ultrasonic Distance Sensor	1	Each	$29.99	$29.99
10K Potentiometer, Trim	1	Each	$1.50	$1.50
LEDs (Red and Green)	2	Each	$0.50	$1.00
Tact Switch (Pushbuttons)	2	Each	$0.50	$1.00
14" 3-wire F/F Extension Cable	2	Each	$2.50	$5.00
7" Clear Plexiglass Pipe	1/10	6'	$8.42	$0.84
Zinc-Plated Steel Compression Spring	1	6 Pack	$9.77	$1.63
12 mm Diameter Alloy Steel Metrical Ball	1	10 Pack	$4.16	$0.42
Monofilament 8lb Fishing Line	8"	One Roll	$4.99	$0.55
U-Clamp	1	Each	$0.49	$0.49
Hose-Clamp	1	Each	$0.99	$0.99
1-1/2" Butt Hinges	3	2-pack	$3.99	$5.99
¼" Steel Washer	1	Each	$0.11	$0.11
4'x 2' Pine Project Panel Plywood	1/3	1 Panel	$19.99	$6.63
40" Wooden Rod	1/4	1-40"	$1.29	$0.32
8-1/2" Wood Screws	12	25 Ct	$3.99	$2.00
Screw Hook	2	Each	$1.49	$2.98
¼" Steel/Zinc Plated Mirror Mount Nut	1	Each	2.96	$2.96
1.5 V AA Batteries	4	4-pack	$7.99	$7.99
Gorilla Glue Adhesive	0.05 oz	0.22 oz	$4.37	$0.99
	Prototype Total Cost:			$220.30

Electrical Design

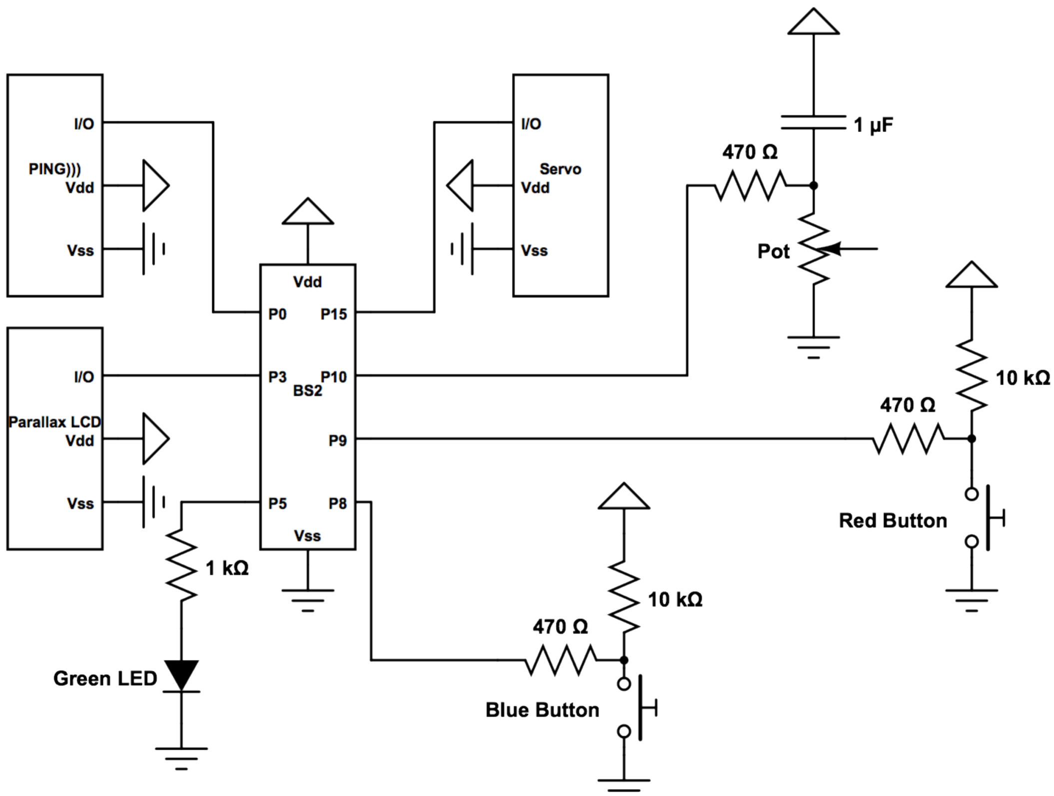

Figure 8: P5643 Electrical Circuit

Detailed Analysis/Conclusion

The results were calculated from both the theoretical mathematical model and the measured values from the experiment. The theoretical values were calculated using the mathematical model, which was discussed earlier.

Angle (Theta)	Theoretical Dist. (Inches)	Measured Dist. (Inches)	Percent Difference
30	33	31.5	4.55
45	33.8	31	8.28
60	27.5	23	16.36

The chart above shows the theoretical horizontal distance that the projectile will travel, in inches. As seen above the actual distance that the projectile traveled was less than the theoretical. The most obvious reasons being the friction between the various mechanical interfaces of the projectile launcher. The interface between the barrel and the spring rode and the interface between the motion sensor plate and the top of the board, contribute to the majority of the frictional losses. Also there will be losses with the projectile as it travels through the air, due to drag. The increase in angle decreases the efficiency of the energy transfer in the spring to the projectile, as seen in the table above. This is due to the increase in vertical component of gravity increases as the angle increases, thus meaning the spring has to fight gravity at a greater rate.

Advantages and Disadvantages

Key advantages to P5643 include its ability to provide a low cost alternative for GK-12 Physics educating systems. When manufactured in bulk, P5643 will have the lowest price entry of approximately $150, compared the comparative products in the market. These products include:

- U10360 Projectile Launcher priced at $408.00
- Vernier Projectile Launcher priced at $289
- PH0340 Projectile Launcher priced at $199.95

Additionally at a plus to its low cost, P5643 utilizes the intelligence of micro-controlled actuators and sensors to characterize and execute projectile motion according to preset values administered by the user. Educators and students will be given the opportunity to experiment with common projectile settings characterized by varying initial conditions such as initial launch angle, initial launch velocity and initial height to help solidify their understanding of Newtonian Physics.

Finally, P5643 not only provides a low cost alternative to teaching projectile motion in the classroom, it also provides a unique approach in in cooperating three key physics experiments into one device. Educators and students will be given the opportunity to experiment with 2-dimensional projectile motion, Hooke's spring law and the conservation of energy all in one experimental settings. Otherwise, these experiments will typically be done separately and requires the purchasing of additional instruments and equipment – an additional financial strain to educating systems.

Unfortunately, P5643 has its lost advantages. Because it is spring loaded and high tension develops between the spring and the string that it is attached, P5643 elevates some safety concerns of its use. P5643 is built with a dismantle kill switch for additional safety. Additional safety precautions should be considered. An automatic release would be preferred to release the spring to prevent any bodily injury. Also, P5643 does not provide users with flexibility to test additional launching angles other than what's fixated and built in to P5643 at 0°, 30°, 45° or 60°.

Conclusion

The final prototype of the projectile launcher produced accurate results with a low percent difference between the theoretical and measured values. The prototype design was cheap to manufacture and simple to operate, with little user training required. There are various design improvements that could be implemented to further enhance the projectile launcher experience, such as fully automating the release and pull back mechanism. The prototype projectile launch will help teach and enforce basic Newtonian physics in the K-12 classroom.

PBASIC CODE

```
' {$STAMP BS2}
' {$PBASIC 2.5}

part VAR Bit
pressb VAR Bit
pressr VAR Bit
mmDist VAR Word         'actual distance in mm
rawtime VAR Word        'raw time of PING sensor
stopdis VAR Word        'distance between starting and ending displacement
startpos VAR Word       'starting displacement
maxpos VAR Word         'maximum allowable displacement
counter VAR Word
rctimer VAR Word
i1 VAR Word
i2 VAR Word
i3 VAR Word

'initialize
DIRS = %0000000000000000
SEROUT 3, 84, [22, 12]              'Initialize LCD
PAUSE 5


main:
  GOSUB start
  GOSUB motor
  GOSUB ready
GOTO main

start:
  SEROUT 3, 84, [128, "Welcome         ", 148, "                "]
  PAUSE 2000
  SEROUT 3, 84, [128, "Press the blue  ", 148, "btn to proceed  "]
  part = 0
  GOSUB bluebutton
  SEROUT 3, 84, [128, "Input spring    ", 148, "comp length     "]
  part = 1
  GOSUB bluebutton
  part = 2
  SEROUT 3, 84, [128, "Start motor?    ", 148, "                "]
  GOSUB bluebutton
RETURN


bluebutton:                     'Subroutine for checking blue button press
pressb = 0                      'Press blue button to proceed to next step
pressr = 0
DO
  IF IN8 = 0 THEN
    pressb = 1
  ELSEIF (IN8 = 1) AND (pressb = 1) THEN
    RETURN
  ELSEIF part = 1 THEN
```

```
      GOSUB enterinput
   ENDIF
   GOSUB redbutton
LOOP


redbutton:                       'Reset button to restart the experiment procedures
IF IN9 = 0 THEN
  pressr = 1
ELSEIF (IN9 = 1) AND (pressr = 1) THEN
  GOTO kill
ENDIF
RETURN


enterinput:                      'Potentiometer knob used to take user input
HIGH 10
PAUSE 20
RCTIME 10,1,rctimer              'RC time with 1 uF capacitor and 470 Ohm resistor
stopdis = rctimer/68             'Displacement knob for 0-85 raw time units
mmDist = stopdis*7/20            '7/20 is the conversion factor to get mm from rawtime
IF mmDist > 9 THEN
  SEROUT 3, 84, [159, "=", DEC mmDist, 162, "mm"]
ELSEIF mmDist < 10 THEN
  SEROUT 3, 84, [159, "= ", DEC mmDist, 162, "mm"]
ENDIF
RETURN


motor:                           'Subroutine for motor functions
startpos = 0
FOR counter = 1 TO 10            'For loop to obtain the initial displacement
  PULSOUT 0, 5                   'by averaging ten values
  PULSIN 0, 1, rawtime
  IF (rawtime < 480) AND (rawtime > 420) THEN
     startpos = startpos + rawtime   'positions use raw time values during calculations
  ELSE                               'convert to distance later when displaying
    startpos = startpos + 450
  ENDIF
  PAUSE 20
NEXT
startpos = startpos/10

maxpos = startpos - 85          'maximum spring displacement
IF stopdis > maxpos THEN
  stopdis = maxpos              'If user inputs higher than max, it is changed to max
ENDIF

i2=startpos
i1=startpos
SEROUT 3, 84, [128, "Comp Length     "]

pressr = 0
```

```
DO WHILE (counter < 1000)
  PULSOUT 0, 5
  PULSIN 0, 1, rawtime
  i3 = i2
  i2 = i1
  i1 = rawtime                  'smoothes out reading from PING sensor
  rawtime = (i3+i2+i1)/3        'by using a moving average of last 3 values
  IF rawtime > (startpos - stopdis) THEN
    PULSOUT 15, 775             'motor will turn
    counter = 0
  ELSE
    PULSOUT 15, 750             'motor will stop and hold position
    counter = counter + 25      'counter to determine duration of motor on
  ENDIF
  mmDist = (startpos - rawtime)*7/20
  IF mmDist > 99 THEN           'Display results
     SEROUT 3, 84, [148, "=", DEC mmDist, 152, " mm",155,"         "]
  ELSEIF (mmDist < 100) AND (mmDist > 9) THEN
     SEROUT 3, 84, [148, "= ", DEC mmDist, 152, " mm",155,"         "]
   ELSEIF mmDist < 10 THEN
     SEROUT 3, 84, [148, "=  ", DEC mmDist, 152, " mm",155,"         "]
   ENDIF
  GOSUB redbutton
  PAUSE 20
LOOP
RETURN


ready:
HIGH 5                          'Green LED on to show launch ready
SEROUT 3, 84, [128, "Ready for launch", 148, "                "]
pressr = 0
rawtime = maxpos
DO WHILE (rawtime < (startpos - (stopdis/2)))
  PULSOUT 15, 750               'Holds motor position until user releases ball
  PULSOUT 0, 5
  PULSIN 0, 1, rawtime
  i3 = i2
  i2 = i1
  i1 = rawtime
  rawtime = (i3+i2+i1)/3
  GOSUB redbutton
  PAUSE 20
LOOP
LOW 5                           'Green LED off after release
SEROUT 3, 84, [128, "                ", 148, "                "]
PAUSE 2000
RETURN

kill:
LOW 5
GOTO main
```

Work Cited/References

[1] *Parallax*. Parallax Incorporated, 15 2012. Web. 17 Dec 2012. <www.parallax.com>.

[2] . "ABRA Electronics Inc.." *ABRA Electronics Inc. Purchasing*. ABRA Electronics Inc., 15 2012. Web. 17 Dec 2012. <www.abra-electronics.com>.