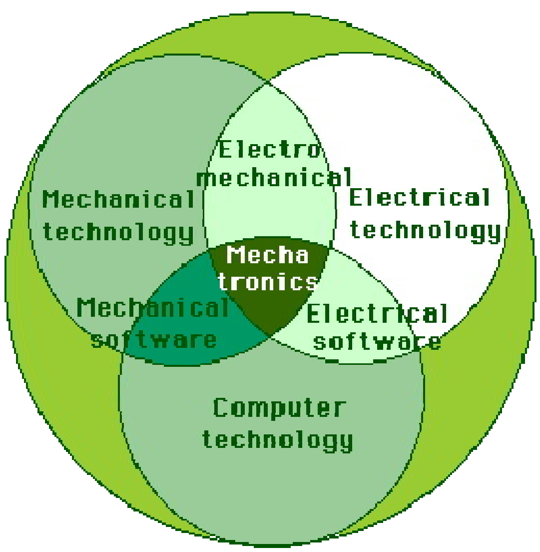
I. Abstract

The objective of the experiment is to use the principles of conservation of energy and the rules governing projectile motion in order to horizontally fire a projectile from a suspended platform into a cart of varying velocities below the platform. The velocity of the cart is altered by releasing it from an inclined plane of various angles, the angle of the incline varied from the horizontal by microprocessor control. The student is able to input the initial angle of the incline. The device then is reset and it performs the calculations automatically, launching the projectile into the cart.

This summer we had the opportunity to participate in the SMART program at Polytechnic. The focus of the program is to learn about mechatronics and bring the resources and our acquired knowledge back to the classroom. Mechatronics is the interdisciplinary fusion of Mechanics, Electronics and Information Technology. Our project on Projectile Motion demonstrates our ability to apply the mechanics of mechatronics to a physics lesson.



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II. Standard (CORE) Correlation

This project addresses the topics of projectile motion and conservation of energy which are covered in the New York State Physics CORE. This project supports the following New York State process skills:

Standard 1: Analysis, Inquiry & Design

Students use scientific inquiry and engineering design, as appropriate, to pose questions, seek answers and develop solutions.

Standard 4: The Physical Setting

Students will understand that energy exists in many forms, and when these forms change energy is conserved. In this project students will see and describe the Law of Conservation of Matter as potential energy is transferred to kinetic energy.

4.1a All energy transfers are governed by the law of conservation of energy.*

4.1b Energy may be converted among mechanical, electromagnetic, nuclear, and thermal forms.

4.1c Potential energy is the energy an object possesses by virtue of its position or condition. Types of potential energy include gravitational* and elastic*.

4.1d Kinetic energy* is the energy an object possesses by virtue of its motion.

4.1e In an ideal mechanical system, the sum of the macroscopic kinetic and potential energies (mechanical energy) is constant.*

Standard 5: Energy and matter interact through forces that result in changes in motion.

Students will be able to understand Newton's Second Law for linear motion. Students will be able to verify conservation of momentum.

5.1e An object in free fall accelerates due to the force of gravity.* Friction and other forces cause the actual motion of a falling object to deviate from its theoretical motion.
(Note: Initial velocities of objects in free fall may be in any direction.)

5.1f The path of a projectile is the result of the simultaneous effect of the horizontal and vertical components of its motion; these components act independently.

5.1g A projectile's time of flight is dependent upon the vertical component of its motion
.

5.1h The horizontal displacement of a projectile is dependent upon the horizontal component of its motion and its time of flight.

III. Introduction

Most of the operation of the device is governed by Conservation of Energy and the laws of motion. The placing the cart on the incline results in an initial potential energy

$$U = mgh$$

In which m is the mass of the cart, g is the acceleration due to gravity and h is the initial height of the center of gravity of the cart. Since the cart is on an incline

$$U = mgl \sin \theta$$

As the cart rolls down the incline the potential energy is converted to kinetic energy:

$$U = K$$

$$mgl \sin \theta = \tfrac{1}{2} mv^2$$

$$v = \sqrt{2gl\sin\theta}$$

Once the cart reaches the horizontal platform below it can be considered moving at a constant velocity since friction has been minimized. The Basic Stamp 2 (BS2) determines the speed of the cart by determining the elapsed time it takes the cart to pass through two photogate timers placed ten centimeters apart.

$$v=s/t$$

The projectile moves over a relatively small distance and at relative slow speeds, allowing the dismissal of frictional effects. Since it is launched from a horizontal platform it has no initial vertical velocity and its time of flight is based upon the height it would fall

$$t = \sqrt{\frac{2h}{g}}$$

The horizontal distance of the projectile is then easily determined:

$$s_{projectile} = v_0\sqrt{\frac{2h}{g}}$$

In order the projectile to land into the cart, the projectile and the cart must have the same horizontal distance at the end of the time it takes the ball to fall. Since the release of the projectile does align with the point that the

$$s_{projectile} = s_{cart}$$

$$v_{projectile}\,(t_{flight}) = v_{cart}\,(t_{cart})$$

Since the time for the cart equals the sum of the delay times and the time of flight, we can rewrite the equation as:

$$v_{projectile}\,(t_{flight}) = v_{cart}\,(t_{cart})$$

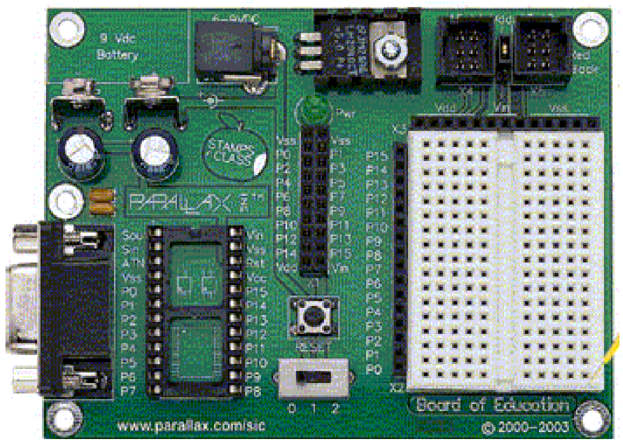
$$v_{projectile}\,(t_{flight}) = v_{cart}\,(t_{delay} + t_{flight})$$

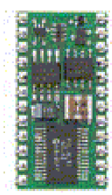
$$\frac{\left(v_{projectile}\left(t_{flight}\right)\right)}{v_{cart}} - t_{flight} = t_{delay}$$

This yields the time of delay for firing the projectile from the point in which it exits the photogate.

IV. Material List

1 Board of Education (BOE) with Basic Stamp 2 (BS2)- Parallax

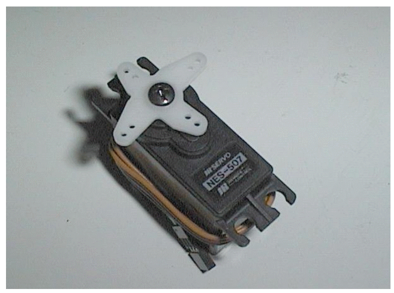




The Basic Stamp is a microcontroller which uses PBasic programming language and is able to interpret input signals, and provide output signals. You can purchase this Board of Education with the Stamp in a kit for $119.00.

1 Push Solenoid – A device which contains a coil of wire that carries current and acts like a magnet when a current passes through it. The push solenoid is used at the top of our platform to fire the ping pong ball.

1 Servomotor - A motor that controls the action of the mechanical device. In this project, a servomotor is used to control the release of the car on the ramp.

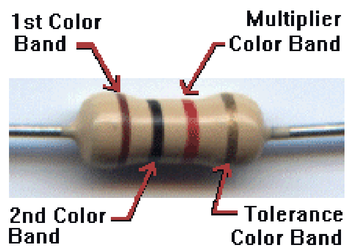


12 volts DC motor with reduction gearing – Provides the work to raise or lower the incline. The motor is geared down to increase torque and decrease angular velocity

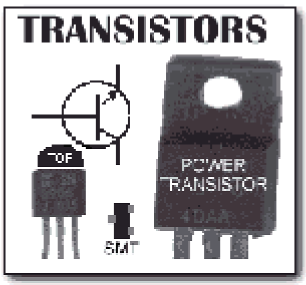
1 Rotary Potentiometer – 100k A variable resistor with an adjustable center connection. A potentiometer is used to adjust the amount of current sent to the system. In our system

the potentiometer is used to determine the angle of the incline.

4 Resistors Very small devices which are used to control current in an electric circuit by providing resistance. We used these resistors to control current through the H Bridge and the Infrared Diodes



4 Transistors A semiconductor device with three leads, a base, collector and emitter which acts as an electronic switch. If a potential is present at the base then a small current flow through the base, this in turn allows a large current to pass through the collector and emitter



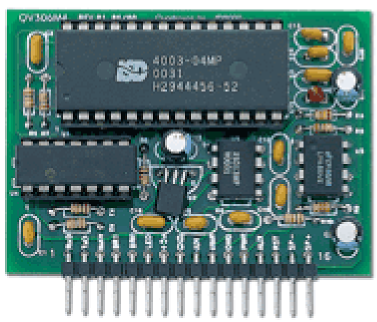
2 Infrared Emitter A semiconductor device which produces infrared light.

1 Photo Transistors A transistor which uses received light as it base rather than a small current

1 25 pin D Converter Used to provided a convenient connection between the project's circuit board and the Basic Stamp

1 DC Power Jack The jack used on the outside of the box to allow 12 volts DC to be brought to the circuit in isolation of the Basic Stamp's circuitry.

QV306m4-P: pre-programmed RS232 playback module This device allows our project to verbalize commands from the Basic Stamp



1 ADC Converter The Analog to Digital Converter converts an analog potential to a digital signal which can be interpreted by the Basic Stamp

1 Momentary Push Button (SPST) The push button provides a momentary electrical connection .

1 windows based computer with PBasic Software

PBasic software is available at:

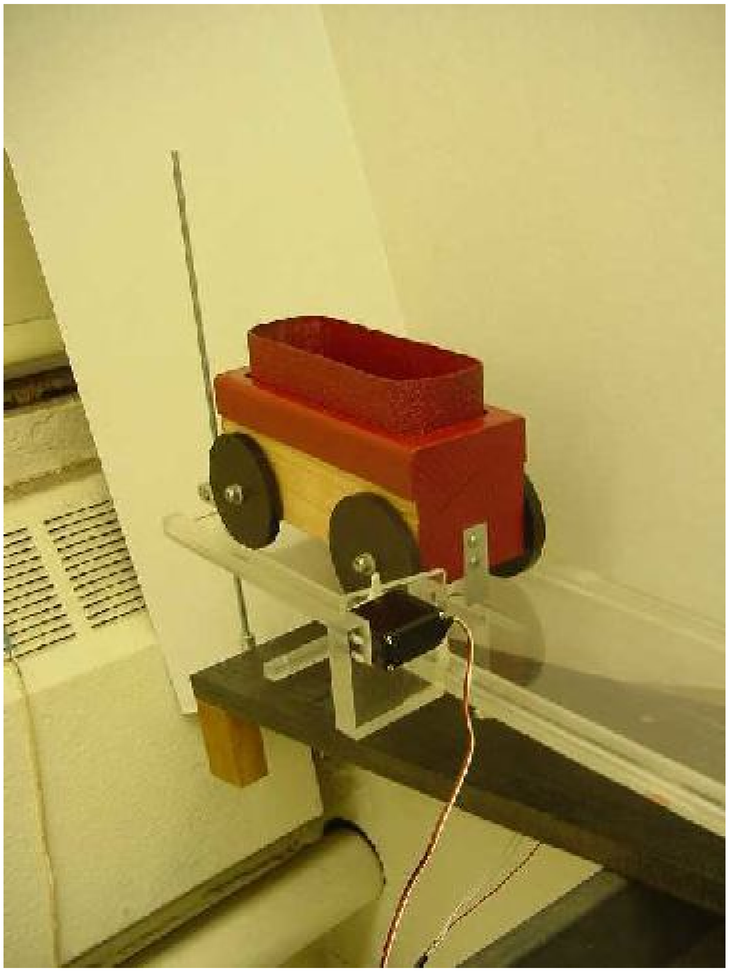
http://www.parallax.com/html_pages/downloads/software/software_basic_stamp.asp

V. Demonstration Description

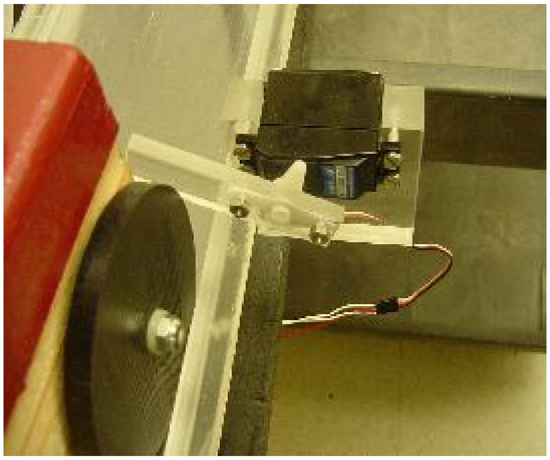
To start the demonstration, a user must press the red push button on the circuit box. Once the button is pressed, the user hears the welcoming message; "Hello." The BS2 then sends a message to the debug screen. The message requests that a user input a number for the angle that the user would like the ramp to be raised. The 12 DC motor, power of which is controlled and isolated through the H-bridge, raises the ramp to the proper angle, the angle being determined by a calibrated hinge mounted potentiometer and the 0831 AD converter. Once the ramp is raised to the correct reading, the BS2 tells sends serial instructions for the sound card to begin a countdown. At the end of the countdown the servomotor is instructed to rotate to a position 90 degrees counterclockwise, raising the gate and allowing the cart to move down the ramp. The servomotor releases the cart and the cart travels down the ramp. Once the cart reaches the base of the inclined is passes through a pair of photogate timers mounted 10 centimeters apart. Passing through the first photogate initializes a DO loop which is stopped when the cart passes through the second photogate. The time for each iteration of the DO loop is known, thereby allowing the BS2 to calculate the elapsed time, velocity of the cart, and the required pause time for the solenoid to fire. At the end of the timing loop a signal is sent through a transistor/ relay circuit allowing 12 VDC to be sent to the push solenoid, firing the ball in to the cart. The calculated speed is converted to a serial signal which is sent to the sound card, which verbalizes the average speed of the cart as it passed through the photogates

B) Demonstration Results

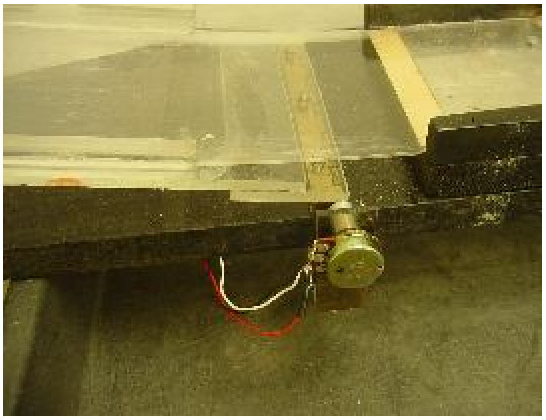
Our Results
The Projectile Demonstration works well. Here is a summary of how it works:
After the cart is placed on the ramp behind the servomotor and the ping pong ball is put at the launch platform, the users is ready to begin.



After P-Basic downloads the program, the sound card says "Hello" to greet the user.
The servomotor resets

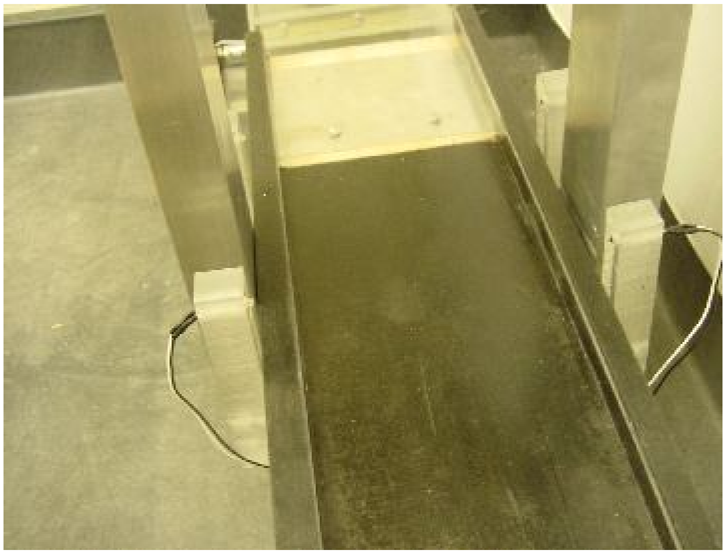


A debug window then appears and the user is asked to press the red start button on the circuit box. When the button is pressed, the user is asked to input an angle.
The potentiometer is a variable resistor which sends a potential to the ADC. The ADC converts the potential to a digital signal which allows the Basic Stamp to determine the angle of the platform based upon a calculation.



After the user inputs an angle, the Basic Stamp compares the input angle to the actual angle of the platform. The dc motor begins to raise the platform.

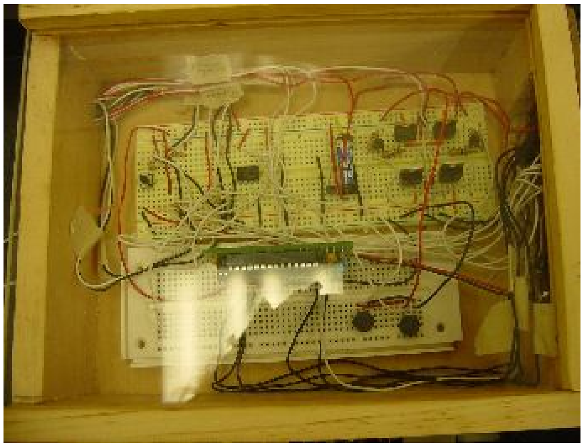
As the cart comes down it interrupts two photogates which consists of an Infrared Emitter Diode and a Phototransistor. The the cart travels along the track and interrupts the photogates, sending a signal to the Basic Stamp

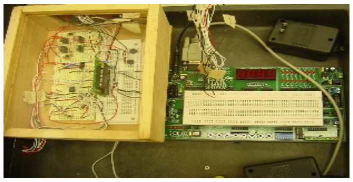


After it passes the photogates the velocity of the cart is measured. A delay time is calculated. At the proper time the push solenoid activates and launches the ping pong ball off the launch platform.

The ball lands safely into the cart.

Then the velocity of the cart is announced from the sound card.





VI. Uncertainty Analysis

Even though every effort was made to minimize error, uncertainty still exists throughout the experiment. Frictional effects and the limitations of the BS2 (in particular its inability to perform floating decimal point calculations) were alleviated by lengthening the bed of the cart, allowing for error in the firing of the ball. Angle accuracy appears to be fairly consistent as is the energy imparted to the ball by the push solenoid.

VII. Possible improvements

The constraints of this demonstration include:

a) A low powered push solenoid. If the solenoid had more power than the ball would be able to travel a longer length. It would also allow for the pulsing of the solenoid and varying the speed of the projected ball based upon the pulse.

b) The DC Motor is slow at bringing the ramp to the desired angle. A motor with a greater angular velocity would raise the ramp a reasonable rate.

c) Lower friction surfaces and wheel bearings will allow for more accurate determination of the launch time .

VII. Conclusion:

This demonstration accurately demonstrates conservation of energy and projectile motion. Within a range of angles it consistently is able to place a ball. It can be used as a motivation for students in the areas of energy and projectile motion. The student could also use the incline portion of the device to perform a calculation and determine the speed of the car based upon conservation of energy. The students can also determine the velocity of the ball using projectile motion. The addition of the sound card provides additional motivation for the students. Future improvements in the device would allow for additional permutations of the experiment, including varying the initial velocity of the projectile and allowing for student input of the ramp angle.

VIII. Suggested Activities

Projectile Motion is a difficult topic for students to understand, until you can relate it to an area of their life. They don't realize that projectile motion happens before them almost everyday. In the sports that students play: Baseball, football, shot-put and even skating, the principles of projectile motion are present. Some of these websites will assist a teacher in presenting other demonstrations of projectile motion:

Baseball Demonstration of projectile motion

http://www.exploratorium.edu/baseball/scientificslugger.html

Example relating football to Projectile Motion http://mvhs1.mbhs.edu/mvhsproj/projectile/projtea.pdf

Relating skating to projectile motion http://btc.montana.edu/olympics/physbio/biomechanics/pm-intro.html

Project made by students: http://library.thinkquest.org/10139/small/proj1.html

Use Projectile Motion to hit your neighbor

http://www.fortunecity.com/greenfield/eagles/180/projectile_motion.html

Projectile Motion Applet

http://www.phys.virginia.edu/classes/109N/more_stuff/Applets/ProjectileMotion/jarapplet.html

Simple directions to setup a demonstration on Projectile Motion

http://www.iit.edu/~smile/ph9204.html

IX. Acknowledgements

- Special Thanks to Dr. Kapila and the National Science Foundation for having this program and encouraging us all to study mechatronics.

- Also thanks to Nathan (SangHoon) Lee for his wonderful and exciting presentations every morning!

- Also thanks to Yvonne (YangFang) Li for always coming over and answering our questions, especially those about photoresistors!! We really appreciate your patience, positive attitude., long hours & assistance in the last days of this program!

- Thanks to Hong Wong, Saul Harari and Imran for their mechatronics presentations. Saul, we appreciate your help in our diagrams!

- Finally, Special thanks to Alessandro Betti for all his help in building our project in the machine shop.

X. Appendix

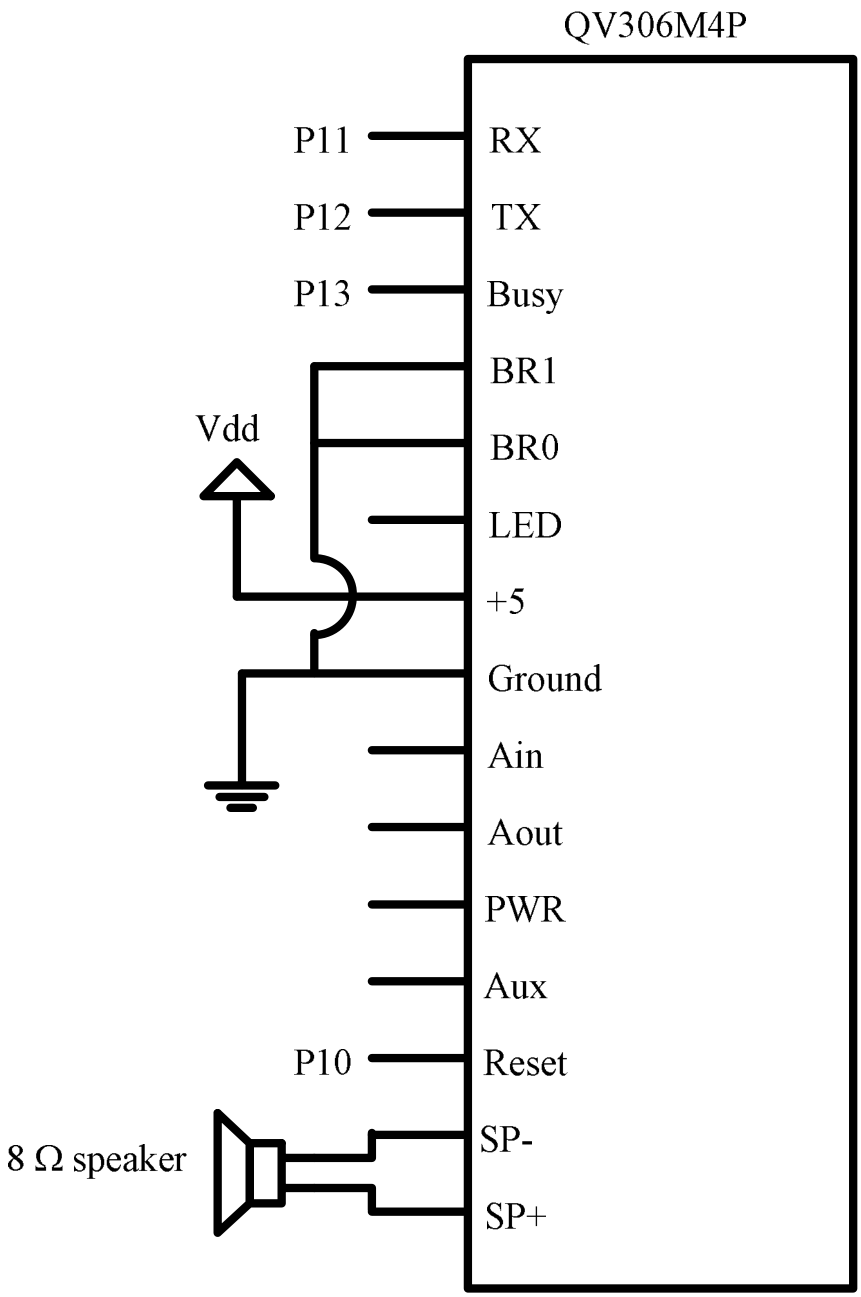
Appendix A: Pin Setup

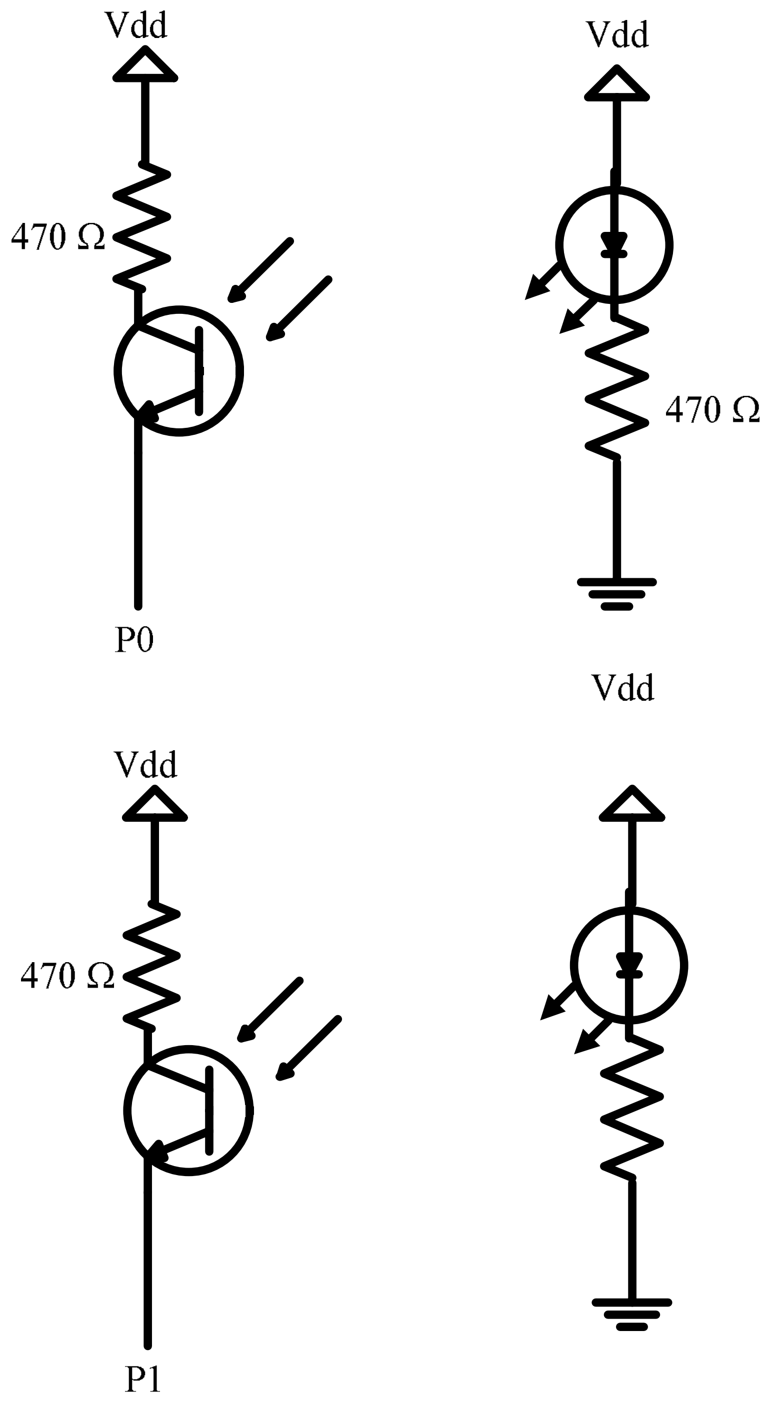
0	Photogate1
1	Photogate 2
2	Start Button
3	Release Solenoid
4	Firing Solenoid
5	/CS
6	ADC Converter 0831ADC
7	ADC Digital Output
8	Motor - Raise the Platform
9	Motor - Lower the Platform
10	Voice - Reset
11	Voice – RX (Receive)
12	Voice – TX (Talk)
13	Busy
14	

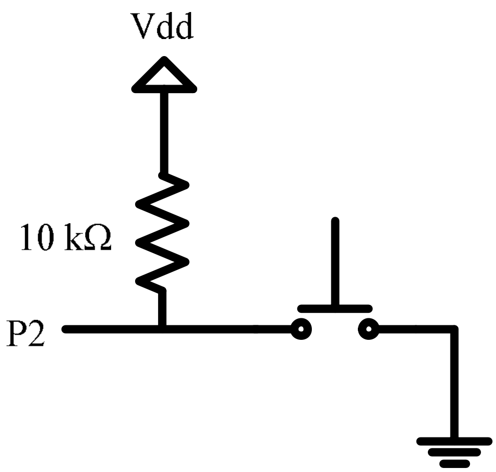
ADC Converter

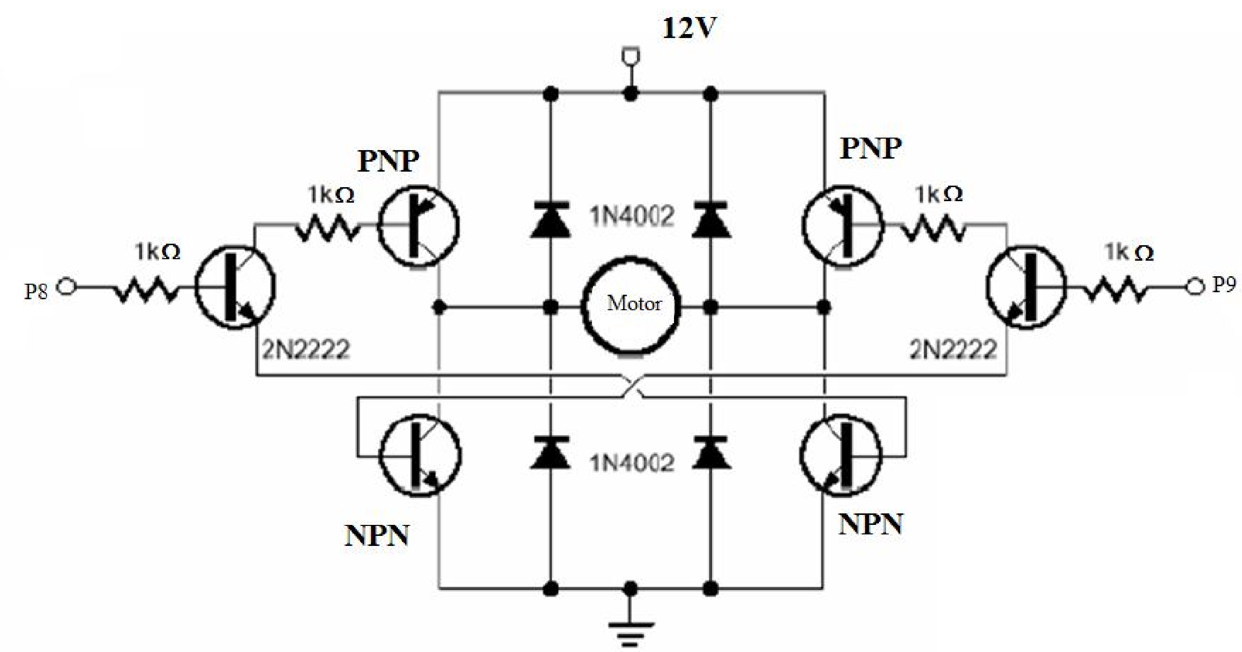
1 CS -	Attached to pin 5
6 DO – Digital Output	Attached
7 Clock - CLK	Attached to pin 6

Appendix B Circuit Schematics




Vdd
470 Ω
P0
Vdd
470 Ω
Vdd
470 Ω
P1
Vdd


Vdd
10 kΩ
P2


12V
PNP
PNP
1kΩ
1kΩ
1kΩ
1k Ω
1N4002
P8
P9
Motor
2N2222
2N2222
1N4002
NPN
NPN

Appendix C – The P-Basic Program

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

'*****************************************************************************
******************
'*                                                    *
'*                  Smart Summer Program                        *
'*                  Polytechnic University                      *
'*                     Dr. Kapilla                          *
'*                                                    *
'*                 July 14 - August 8, 2003                   *
'*                                                    *
'*                                                    *
'*             William Leacock & Marlene McGarrity                     *
'*                                                    *
'*                                                    *
'*****************************************************************************
******************


'---------------------------Declarations---------------------------------
first        VAR    Bit
second       VAR    Bit
n            VAR    Byte
counter      VAR    Word
firing       VAR    Word
delay_time   VAR    Word
angle        VAR    Byte
anglein      VAR    Byte
digital_angle VAR   Byte
```

```
adcBits      VAR    Byte
speed        VAR    Word
integer      VAR    Word
decimal1     VAR    Word
decimal2     VAR    Word
temp         VAR    Word
'temp1       VAR    Word
ans          VAR    Nib
distance     CON    1       'distance is 0.1m*10
time         CON    1078       'counter is 1078 for one second
addr         VAR    Word
phrase       VAR    Byte
sentence     DATA   _meter,_per,_second,$FF


'----------------------------Initialize-----------------------------------

INPUT 0
INPUT 1
QV_RST CON 10 ' QV306M4.14
QV_RX CON 11 ' QV306M4.1
QV_TX CON 12 ' QV306M4.2
QV_BUSY VAR IN13 ' QV306M4.3

'----------------------------Constants-------------------------------------

T2400 CON 396 ' 2400 baud, true
IsBusy CON 0
' ** QV306M4 Command Set **
QV_Direct CON $F0 ' QV modes
QV_Stop CON $F6
```

```
QV_Sleep CON $F8
QV_Volume CON $FC
QV_Reset CON $FD ' software reset
QV_Rev CON $FE ' module revision
QV_Type CON $FF ' module type

 ' ----[ Vocabulary ]-----------------------------------------------------
'
_zero CON 0 ' message # in QV306M4P
_one CON 1
_two CON 2
_three CON 3
_four CON 4
_five CON 5
_six CON 6
_seven CON 7
_eight CON 8
_nine CON 9
_ten CON 10
_eleven CON 11
_twelve CON 12
_thirteen CON 13
_fourteen CON 14
_fifteen CON 15
_sixteen CON 16
_seventeen CON 17
_eighteen CON 18
_nineteen CON 19
_twenty CON 20

_centimeter CON 118
```

```
_centimetrs CON 119
_equals CON 128
_go CON 135
_hello CON 144
_goodbye CON 139
_is CON 151
_t_speed_is CON 210
_per CON 186
_minute CON 176
_second CON 198
_point CON 191
_meter CON 166


'---------------------------Main Program-----------------------------------

startup:
initialization:
  firing=0
  FOR n=0 TO 50
  PULSOUT 3,1000
  PAUSE 10
  NEXT
  LOW QV_RST
  PAUSE 100
  HIGH QV_RST
  PAUSE 2000
Say_Phrase:
'IF (QV_Busy = IsBusy) THEN Say_Phrase ' wait until not busy
SEROUT QV_RX,T2400,[144] 'say Hello
      DEBUG "This is the Experiment of Projector Movement.",CR
```

```
   DEBUG "Please press the red button to start the experiment.",CR
clik:
   IF IN2 = 0 THEN angleinput
   GOTO clik

angleinput:

   DEBUG "Enter initial launch angle (16-19 degrees)& then press ENTER:  "
   DEBUGIN DEC anglein
   DEBUG CR

  IF anglein > 19 OR anglein < 16 THEN  error
  GOTO incline_adjust


error:
   DEBUG "Angle outside range.",CR,CR
   GOTO angleinput


incline_adjust:
  GOSUB ADC_Data
  GOSUB Display
  GOSUB Cal_Angle
   IF angle < anglein THEN Raiseinc
   IF angle > anglein THEN Lowerinc
   IF angle = anglein THEN rel_solenoid

Raiseinc:
 HIGH 8
 LOW 9
```

```
 PAUSE 5000  "pause for motor to move
 GOTO incline_adjust

Lowerinc:
 HIGH 9
 LOW 8
 PAUSE 5000  "pause for motor to move
 GOTO incline_adjust

rel_solenoid:
 LOW 8
 LOW 9

Say_Count:
IF (QV_Busy = IsBusy) THEN Say_Count ' wait until not busy
SEROUT QV_RX,T2400,[1]
PAUSE 1000
IF (QV_Busy = IsBusy) THEN Say_Count ' wait until not busy
SEROUT QV_RX,T2400,[2]
PAUSE 1000
IF (QV_Busy = IsBusy) THEN Say_Count ' wait until not busy
SEROUT QV_RX,T2400,[3]
PAUSE 1000
Say_Go:
IF (QV_Busy = IsBusy) THEN Say_Go ' wait until not busy
SEROUT QV_RX,T2400,[135]


"codes for servo motor to release the car
 FOR n=0 TO 50
 PULSOUT 3,500
```

```
 PAUSE 10
 NEXT

MAIN:
 first = IN0
 second= IN1
 counter = 0
 IF IN0=0 THEN loop1
 GOTO main     "
loop1:
  counter=counter+1
  IF IN1=0 THEN time_calc
  GOTO loop1

time_calc:
  DEBUG CLS
  DEBUG HOME
  DEBUG "The counter is :",DEC counter,CR
   "calibration need here
   'delay_time = counter * 27 - 250    'time is in milliseconds
   delay_time=counter-2
   'time=                                   '269 is based on the number of cycles of the counter FOR the car
TO
                                       '250 is the time it takes for the ball to drop in milliseconds
'Speed_Calc:
  'speed=distance/time
  'speed=17

 'DEBUG "The delay time is: ",DEC delay_time,CR
 GOTO launch
```

```
launch:
   firing = firing + 1
   IF firing = delay_time THEN firing2
  GOTO launch

firing2:
   DEBUG "Fire"  ,CR      "add the sound chip 'go' here
   HIGH 4
   PAUSE  500
   LOW 4



Say_Speed:
  IF (QV_Busy = IsBusy) THEN Say_speed ' wait for Busy to release
  SEROUT QV_RX,T2400,[210]
  PAUSE 2000

Cal_Speed:
  temp= distance*time/(counter*10)
  decimal1=distance*time/counter
  decimal2=((distance*time*10)/counter)-(decimal1*10)
  'DEBUG ? decimal2
  IF temp=0 THEN Say_decimal
  integer=temp

Say_integer:
  IF (QV_Busy = IsBusy) THEN Say_Speed ' wait until not busy
  SEROUT QV_RX,T2400,[integer]
  PAUSE 1000
Say_decimal:
  IF (QV_Busy = IsBusy) THEN Say_Speed ' wait until not busy
```

```
  SEROUT QV_RX,T2400,[191]
  PAUSE 1000
  IF (QV_Busy = IsBusy) THEN Say_Speed ' wait until not busy
  SEROUT QV_RX,T2400,[decimal1]
  PAUSE 1000
  IF (QV_Busy = IsBusy) THEN Say_Speed ' wait until not busy
  SEROUT QV_RX,T2400,[decimal2]
  PAUSE 1000

addr=sentence
Say_Sentence:
READ addr,phrase ' get a phrase from EEPROM
IF (phrase > 239) THEN ending ' $FF is EOM flag
QV306_Busy1:
IF (QV_Busy = IsBusy) THEN QV306_Busy1 ' wait for Busy to release
SEROUT QV_RX,T2400,[phrase] ' say the phrase
addr = addr + 1 ' point to next phrase
GOTO Say_Sentence ' say it

ending:
  FOR n=0 TO 50
  PULSOUT 3,1000
  PAUSE 10
  NEXT
DEBUG "Please enter 1 to repeat the experiment, 0 to end the experiment",CR
DEBUGIN DEC ans
IF ans=1 THEN  startup
IF ans=0 THEN  very_end
GOTO ending

very_end:
```

```
DEBUG "************End of Experiment****************",CR
Say_Goodbye:
  IF (QV_Busy = IsBusy) THEN Say_Goodbye ' wait until not busy
  SEROUT QV_RX,T2400,[139]
END



ADC_Data:
HIGH 5
LOW 5
LOW 6
PULSOUT 6, 210
SHIFTIN 7,6,MSBPOST,[adcBits\8]
RETURN

'Calc_Volts:
'RETURN
Display:
DEBUG CLS
DEBUG HOME
DEBUG "Decimal value: ", DEC3 adcBits ,CR,CR
RETURN

Cal_Angle:
 angle=(adcBits-7)/7
 DEBUG "angle= ",DEC angle,CR,CR
RETURN
```

XI. References

Parallax http://www.parallax.com and http://www.stampsinclass.com

Jameco http://www.jameco.com

Radio Shack http://www.radioshack.com

Mechatronics http://www.mechatronics.org/

The Physics Classroom http://www.physicsclassroom.com/Class/vectors/U3L2a.html

Multimedia Physics Classroom

http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/vectors/hlp.html

Projectile Motion Lesson http://buphy.bu.edu/ulab/intro1/projectile.pdf

Projectile Motion demonstration online

http://library.thinkquest.org/10796/ch6/ch6.htm#Sec1