CATCH ME IF YOU CAN[1]

A MECHATRONICS

DEMONSTRATION PROJECT

BY

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1. ABSTRACT

The goal of this project was to create a device that would model the physical laws in projectile motion. Using electronic and mechanical devices (mechatronics), a projectile launcher was built. This launcher will be used in a high school physics classroom to demonstrate the laws of projectile motion. When an appropriate angle (20 to 65 degrees) is entered in the software program the basic stamp raises the platform, computes the correct distance for the "catcher" and finally launches the ball towards the target. It was found that the device was consistently accurate for angles from 20 to 30 degrees. When other factors were included in the formula, the accuracy was extended from 20 to 65 degrees. It was discovered that errors in the creation of the device and the limits of the basic stamp were likely to affect the outcome of this experiment.

2. INTRODUCTION

When objects are thrown or fired from the Earth's surface their trajectory can easily be determined by using the laws of physics. These laws govern the distance that a projectile will travel across the surface of the Earth. By changing the angle at which a projectile will launch, one can determine the maximum distance that it will travel for a given velocity. One military application of this can be found in the field of artillery. When the initial velocity can be determined, it is relatively easy to determine the correct distance that a shell will travel. These calculations are typically very accurate however error does exist. One error that must be taken into account is air resistance which acts as a retarding force on the projectile. Another possible error is the Coriolis Effect that is caused due to Earth's rotation. This effect is only a serious consideration when a projectile is in the air for are extended period of time.

3. STANDARDS CORRELATION

This project meets the New York State Education Department Physics Standards in the following way;

Science Standards-Commencement Level

Key Idea 4:

4.1 Energy exists in many forms, and when these forms change energy is conserved.

- describe and explain the exchange among potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- observe and explain energy conversions in real-world situations

Key Idea 5:

5.1 Explain and predict different patterns of motion of objects (e.g., linear and uniform circular motion, velocity and acceleration, momentum and inertia).

- sketch the theoretical path of a projectile

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.

4. BACKGROUND

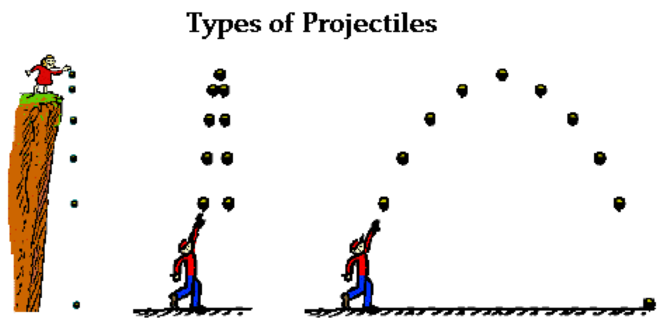
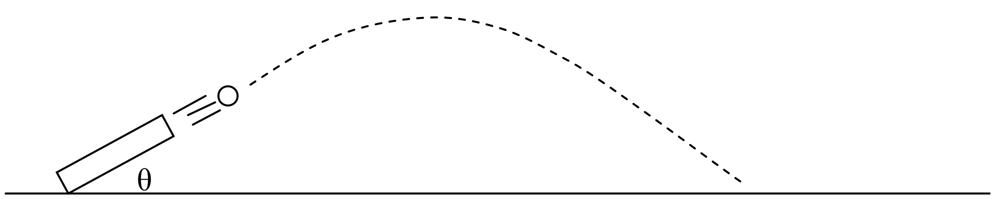


Illustration 1. Projectile Motion

Projectile Motion describes the motion of an object, in at least two dimensions, and experiences that force of gravity in the vertical direction. The motion of a projectile can be analyzed separately as two independent motions, horizontal and vertical. A projectile launched at some angle θ and initial velocity V_o will have a horizontal velocity component of $V_o\cos\theta$ and a vertical velocity component of $V_o\sin\theta$.



A projectile's horizontal velocity is constant because it experiences no net force in the horizontal direction. A projectile's vertical velocity is not constant as it experiences a net force downward, equal to the weight of the object. This net force results in an acceleration according to Newton's 2nd law and is equal to 9.8 m/s^2 downward. For the case when the launch height is equal to the landing height, the time of flight can be found by first finding the time the projectile takes to reach its maximum height. The vertical velocity of the projectile is zero at this point and this fact can be used with the equation that describes the velocity of an accelerated object to find the time.

$$V = V_{oy} + at = 0$$

and solving for t….

$$t = \frac{V_{oy}}{g}$$

The time of flight will then be two times the time found above.

$$t = \frac{2V_{oy}}{g} = \frac{2V_o \sin\theta}{g}$$

The time of flight can now be used with the equation that describes the horizontal displacement to find the range of the projectile.

$$x = V_o x t = \frac{V_o \cos\theta (2V_o \sin\theta)}{g}$$

Using the trig identity sin 2θ = 2cos θ sin θ we can rewrite the range as follows.

$$x = \frac{V_o^2 \sin 2\theta}{g}$$

This is the final formula used in the PBASIC code to launch the ball to a given range.

4. EQUIPMENT USED

This project required the use of several mechanical and electronic components.

A) Launcher

The mechanical device used to launch the golf ball is a converted Wilson Putting Pal(shown below).

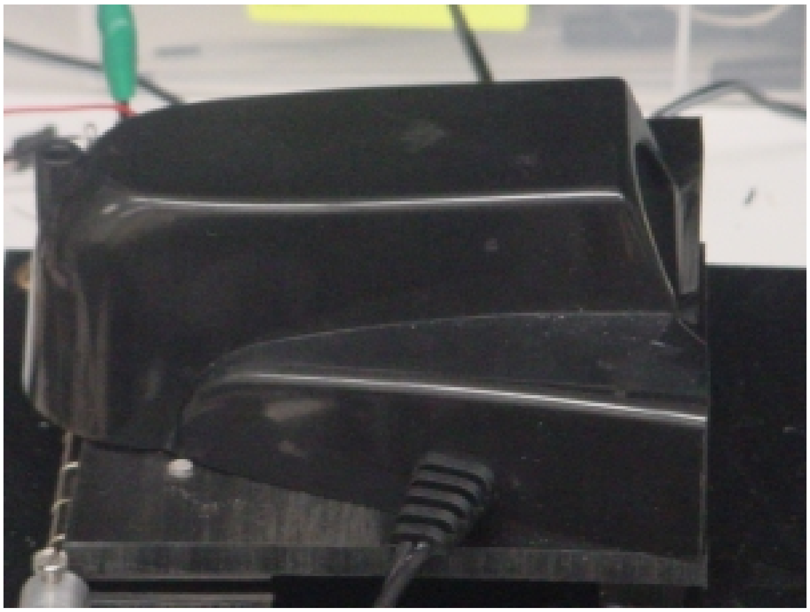


Illustration 3. The launcher

Inside the putting cup there is a solenoid which is a magnetic coil that pulls back a metallic "plunger" when current is present in the coil. When the switch is engaged the current is cut off and the plunger is propelled forward due to a spring located behind it. This force is applied to the golf ball causing it to be expelled from the front of the launcher.

In order to change the angle at which the golf ball is released, a constructed platform was connected to a DC motor and a potentiometer. The Wilson Putting Pal was then secured to the top of this platform. The potentiometer changes the voltage applied to a circuit by modifying the resistance. By attaching the potentiometer and DC motor to a hinge at the back of the platform, the varying voltage of the potentiometer could be used to determine the angle at which the DC motor had raised the platform.

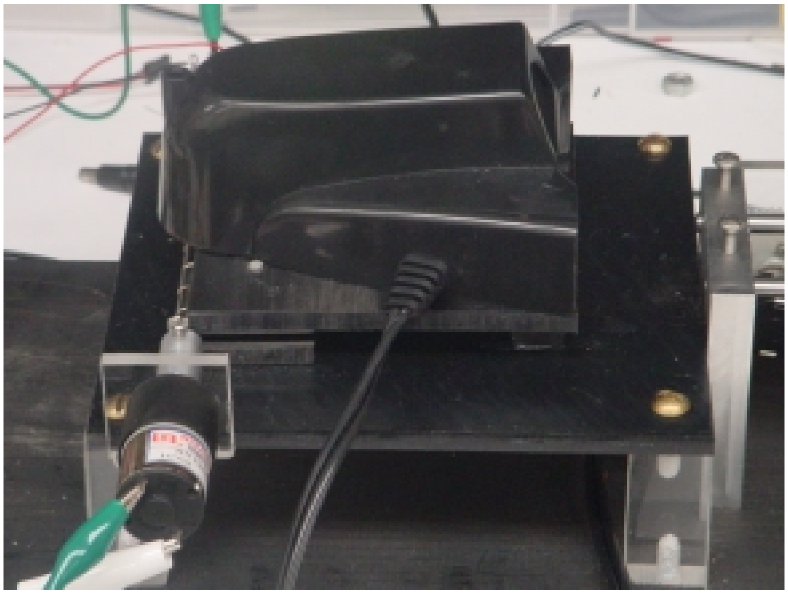


Illustration 4. The launcher and the platform.

B) Catcher

In order to "catch" the golf ball a track was built. The catcher was constructed from a piece of lucite with ball bearings drilled into it. These ball bearings allowed the catcher to move freely along two supporting metal rods. The catcher was driven by a servo motor (shown below), with a gear attached, which was used to move the catcher to a specific point along the track.

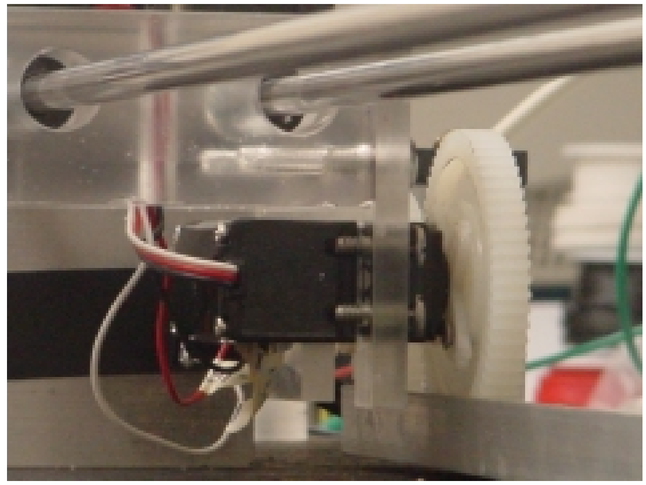
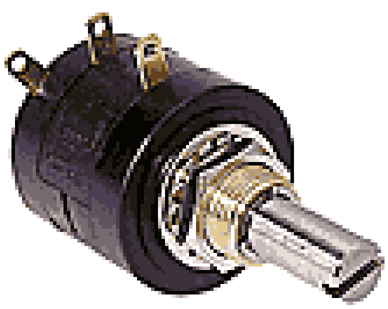


Illustration 5. Servo Motor Illustration 6. Servo Motor connected to catcher

A potentiometer (shown on next page) was used to determine the correct distance along the track to place the catcher based on human or computer input. The potentiometer changes the voltage applied to a circuit by modifying the resistance. By using another gear to connect the potentiometer to the track were able to correlate a specific voltage to the distance from the launcher.



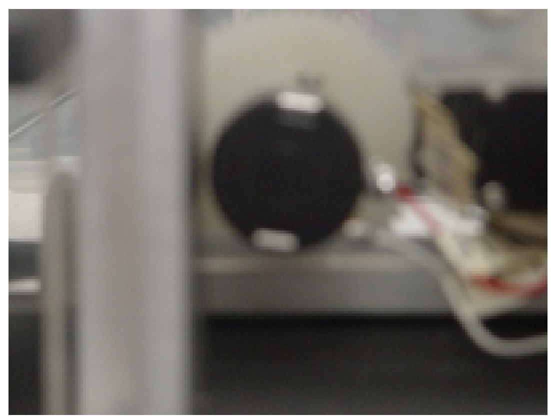


Illustration 7. Potentiometer Illustration 8. Potentiometer connected to catcher.

C) Control

As with the majority of experiments in the field of mechatronics, control is the key element in the experiment. Control systems allow us to initiate an action based on a set of defined variables. The main control system in this experiment is the Basic Stamp 2 micro-controller. This micro-controller allows for the monitoring and control as many as 16 input or output devices.

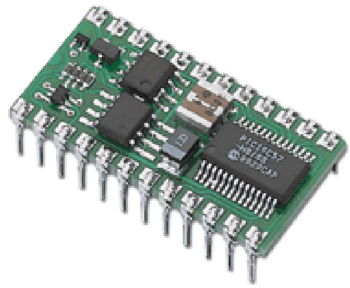


Illustration 9. The Basic Stamp.

The following table lists the pin assignments used on the Basic Stamp and the corresponding circuit element.

Basic Stamp I/O Pin	Pin Assignment
P0	Chip select for ramp position ADC
P1	Clock signal for ramp position ADC
P2	Digital output from ramp position ADC
P3	Chip select for cart position ADC
P4	Clock signal for cart position ADC
P5	Digital output from cart position ADC
P6	Servo motor control
P7	Ramp motor output A
P9	Ramp motor output B
P8	Ball launch switch

Most of the circuitry required for the experiment was built on a breadboard. An image of the breadboard is shown below.

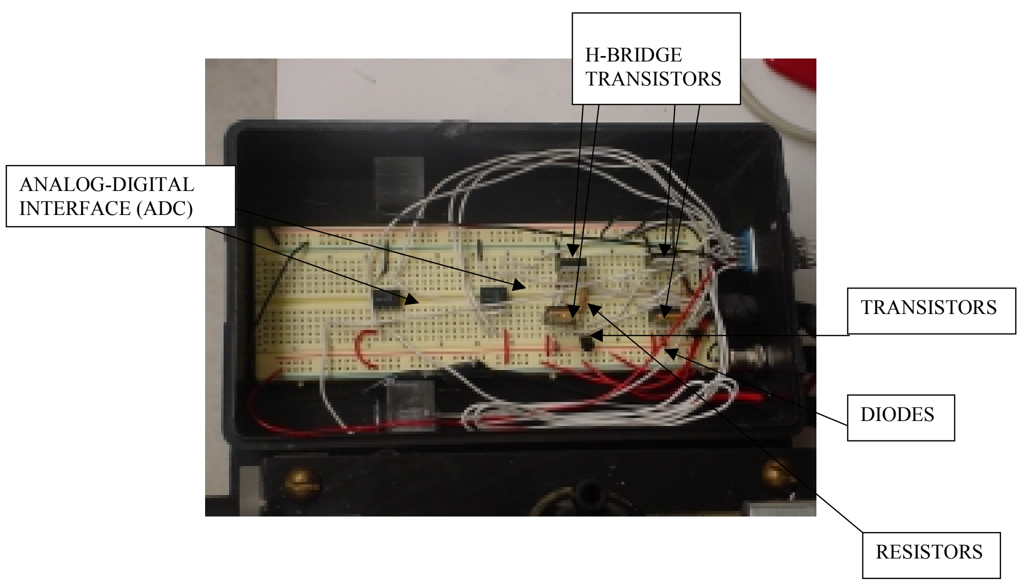


ILLUSTRATION 10. The Breadboard with components.

I) H-BRIDGE TRANSISTORS

In order to control the direction of the DC Motor, an H-Bridge had to be constructed. An H-Bridge is a series of transistors (electric switches) that allows the flow of current to pass in a particular direction. By alternating the flow of current through the H-Bridge, the direction in which the DC motor rotated could be controlled.

II) Diodes

Diodes allow current to flow in only one direction. They were used to prevent voltage spikes in the circuit.

III) ADC 0831

The ADC 0831 is an analog to digital converter. In this experiment we will need to convert to digital input and output in order to determine angle and distance. The ADC 0831 has 8 pins but can only control one 1 output or input device at a time.

IV) Resistors

Resistors are used to lower the current in the circuit in order not exceed the maximum current tolerance of the other components on the breadboard.

V) Solid State Relay

One important control device that is not on the breadboard is the solid state relay. The relay is a switch that is located inside a black box. One end of the power cord is connected to the power supply (AC wall socket) while the other end is connected to the launcher. The socket in the middle of the box is connected to the breadboard. When the ball is to be launched, the basic stamp will send an electronic signal to the relay (switch) and the ball will be launched.

Illustration 11. Solid State Relay.

5. EXPERIMENT

Procedure: Verification of Projectile Motion Formula

Goals:

1. Students will relate the angle of release to the maximum horizontal distance that the projectile travels.
2. Students will identify the angle (45^0) of maximum horizontal displacement.

Procedure:

1. Connect BS2 to the breadboard by using the DB-15 adapter and to a computer using a DB-9 serial cable.
2. Download the *CatchMeIfYouCan.bs2* file to the BS2
3. At the prompt, the student will enter the desired angle (20-65 degrees) in the window.
4. The BS2 will elevate the platform to the desired angle, student will be instructed to place golf ball in launcher.
5. The BS2 will determine the proper distance to move the "catcher" on the track. The servo motor will move "catcher" to calculated position.
6. Ball will be launched and will land on catcher.

Results:

It was determined that the projectile launcher was accurate for angles from 20 to 30 degrees. When tested at these angles the ball constantly hit the catcher. However at angles above 30 degrees, the ball was consistently short of the catcher, which was correctly placed based at the calculated distance. distance. This effect was more pronounced as the angle increased. We believed that this effect was due to the position of the golf ball in the launcher. At high angles, the motor was unable to produce the velocity (3 meters/second), required to propel the golf ball. We changed the formula so that the range of the catcher was reduced by the angle of the launcher minus twenty five. After further testing it was determined that the apparatus was now accurate between the angles of 20 and 65 degrees.

6. UNCERTAINTY ANALYSIS

A) Floating Point Calculations

One unavoidable error in this experiment is due to the limitations of the BS2. The BS2 is unable to make floating point calculations, such as including the decimal point placement in a calculated number. This means that many calculated numbers will not be rounded off correctly. It has been determined in this experiment that this could lead to an error in distance of up to three centimeters. In order to round numbers off to an acceptable level, another limitation of the BS2 comes into play. The largest variable that can be stored in the BS2 is a "word" which has a numerical range of 0-65,535. This indicates that the highest level of precision in this experiment cannot exceed the thousandth placement.

B) Initial Velocity of the Golf Ball

In this experiment the initial velocity of the golf ball is assumed to be a constant. In fact the initial velocity of the ball is highly influenced by the voltage applied to the solenoid in the launcher. Since the voltage applied to the solenoid can vary in small amounts, the initial velocity of the golf ball will have a range of values. Since the velocity of the ball is not being determined in this experiment, it cannot be used in the formula. In order to account for this range of velocities, a larger "catcher" has been used. This will allow for variations in initial velocity.

C) Mechanical Hinge

The hinge that was constructed to open the platform allows for some "play" in the angle of the platform (see image below). When the platform is raised to the desired angle, the hinge is unable to hold that angle exactly due to the mass of the platform, golf ball and launcher. This results in a small drop in the position of the platform before the golf ball is released.

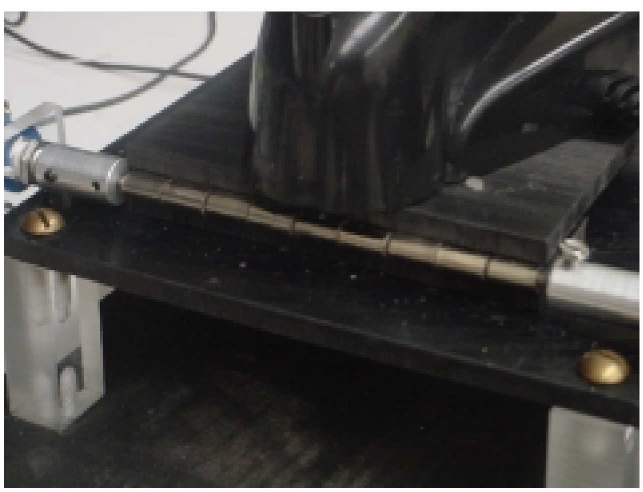


Illustration 12. The mechanical hinge.

7. PROJECT COSTS

ITEM	SUPPLIER	PART NUMBER	UNIT COST	QUANTITY	TOTAL
Ping Pong Balls	Sports Authority	N/A	1.99	1	1.99
Foam Golf Balls	Sports Authority	N/A	2.99	1	2.99
Al Angle 48"	Home Depot	N/A	3.35	1	3.35
Putting Pal	Sports Authority	N/A	12.99	1	12.99
14.5 deg Spur Gear, 32 pitch, 52 teeth	McMaster	57655K48	4.09	1	4.09
14.5 deg Spur Gear Rack, 32 pitch,	McMaster	57655K62	4.78	4	19.12
Self Aligning Ball Bearings 1/4 ID	McMaster	6489K61	14.83	2	29.66
14.5 deg Spur Gear, 32 pitch, 62 teeth	McMaster	57655K49	6.27	1	6.27
Hardened Steel Shaft 48" x 1/4"	McMaster	6061K71	22.66	2	45.32
Analog-Digital Converter (ADC0831)	Parallax	ADC0831	6	2	12
TIP 42 Transistor (PNP)	Radio Shack	276-2027	1.49	2	2.98
1K Ohm Resistors	Parallax	150-01020	0.15	4	0.6
Zener Diodes	Parallax	1N4002	0.5	4	2.00
NPN Transistor	Radio Shack	2N2222	0.69	2	1.38
NPN Transistor	Radio Shack	TIP120	1.49	2	2.98
Futaba S148 Servo Motor	Parallax	S148	12	1	12.00
DC Motor	Jameco	N/A	21.95	1	21.95
10 Turn (10K) Potentiometer	Digikey	3590	13.38	1	13.38
100 K Potentiometer	Digikey	91	9.02	1	9.02
Wood (1x10x60)	Sids Hardware	N/A	7.99	1	7.99
				Total	**212.06**

8. SUGGESTED PROJECTS

1. Determine the relationship between the angle of release and launch velocity.
2. Use sensors to verify the maximum height of the golf ball at different angles.
3. Account for discrepancy between launch height and catcher platform.

9. REFERENCES

1. The Physics Classroom and Mathsoft Engineering & Education, Inc.,The Physics Classroom, Accessed August 8, 2003, http://www.physicsclassroom.com/Default.html.

2. Hewitt, Paul, Conceptual Physics, Prentice Hall, 2001.

3. Parallax home page, Accessed August 8, 2003, http://www.parallax.com

4. Pasco Scientific resource for physics equipment, Accessed July 25, 2003, http://www.pasco.com

5. Basic Analog and Digital Student Guide, Parallax Inc., 2003

Appendix I. P-Basic Code

```
SMART Program Summer 2003
' Fu1nded by The National Science Foundation
' Polytechnic University
' Mechanical Engineering
'
' Catch Me If You Can
'
' Professor Vikram Kapila
' John Luvera      Montville Township High School  Montville, NJ
' Mike McDonnell   Midwood High School             Brooklyn, NY
'
'************************************************************************
'{$STAMP BS2}
'{$PBASIC 2.5}

'************************************************************************
****************************************
'declarartion of constants and variables used

ramp_position_cs        CON    0      'Chip select for Ramp A to D
ramp_position_clk       CON    1      'ADC Clock for ramp
ramp_position_input     CON    2      'ADC position input for ramp
cart_position_cs        CON    3      'Chip select for Cart A to D
cart_position_clk       CON    4      'ADC Clock for ramp
cart_position_input     CON    5      'ADC position input for ramp
servo_motor             CON    6      'Servo motor pin
ramp_motorA             CON    7      'Motor input A
ramp_motorB             CON    8      'Motor input B
launch                  CON    9      'Solid state relay for launcher
Vosqr                   CON    900    'Initial Velocity squared (3*3*100)
g                       CON    10     'Acceleration of gravity in m/s^2


Ready        VAR    Bit     'Var to check when ball is on launcher
Angle        VAR    Byte    'Var for Angle input from user
PotAngle     VAR    Word    'var to set pot for a given angle
PotRange     VAR    Word    'var to set pot for a calculated range
Sine2Theta   VAR    Word    'var for sin (2*Angle)
Range        VAR    Word    'var for range
datain       VAR    Byte    'var to store either angle of incline or position of cart

'************************************************************************
********************************
initial:                               'Inialization of Ramp and Ball Catcher

  LOW ramp_motorB                      'set both motor inputs to 0
  LOW ramp_motorA
```

```
                                  'Convert analog value from pot to digital
 HIGH ramp_position_cs            'Check current position of ramp and set to
 LOW ramp_position_cs             'zero degrees if not at zero
 LOW ramp_position_clk
 PULSOUT ramp_position_clk, 210
 SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]

 DEBUG "Welcome to the 'Catch Me If You Can' Projectile Motion Demo.", CR, CR

  IF datain < 31 THEN Main          'Check if at zero TEMPORARILY
COMMENTED
  IF datain > 35 THEN Zero_Ramp

Zero_Ramp:                      'Lower Motor
 LOW ramp_motorA
 HIGH ramp_motorB
 PAUSE 10

Main:

 DEBUG "Please enter the angle of launch and the computer will calculate and set the
range.", CR
 DEBUG "The angle must be >=20 and <= 65 degrees.", CR
 DEBUGIN DEC Angle

 IF Angle > 65 OR Angle < 20 THEN Main          ' Check to make sure angle is in
range

 PotAngle = (((Angle - 20) * 55) / 50 )         'Convert Angle to corresponding pot value
 'PotAngle = (Angle * 11) / 10 - 22
 GOSUB Set_Ramp_Angle                            'Set ramp angle
 GOSUB Calc_Range                              'Calculate range

 IF Angle >= 30 THEN Range = Range - (Angle - 30)   'Range adjustment for angles >
30

 'PotRange = (((Range * 165) / 105) + 36 )        'Convert Range to corresponding pot
value
 PotRange = (((Range * 85) / 125) + 156 )
 GOSUB Set_Range                              'Set cart to calcualted range
 GOSUB Launch_Ball                             'Launch Ball

 PAUSE 1000

 GOSUB Lower_Ramp                              'Lower Ramp
 GOTO Main                                'Restart


'**************************************************************************
***********************
' Subroutines
```

```
'************************************************************************
***********************
Lower_Ramp:

   LOW ramp_motorA
   HIGH ramp_motorB
   PAUSE 10

   HIGH ramp_position_cs                    'Get Current Reading on pot
   LOW ramp_position_cs
   LOW ramp_position_clk
   PULSOUT ramp_position_clk, 210
   SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]

   IF datain > 31 THEN Lower_Ramp
RETURN

'************************************************************************
***********************
Launch_Ball:
  DEBUG "Place ball on launcher and press 1 to continue.", CR
  DEBUGIN Ready
  IF Ready = 1 THEN
   HIGH launch
   PAUSE 100
   LOW launch
   DEBUG CR, "Ball is Launched.", CR
   RETURN
  ENDIF

  GOTO Launch_ball
'************************************************************************
***********************
Set_Ramp_Angle:

   LOW ramp_motorB                        'Raise Ramp
   HIGH ramp_motorA
   PAUSE 50
   LOW ramp_motorB                          'Stop Motor
   LOW ramp_motorA

   HIGH ramp_position_cs                    'Get Current Reading on pot
   LOW ramp_position_cs
   LOW ramp_position_clk
   PULSOUT ramp_position_clk, 210
   SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]

   IF datain <= PotAngle THEN Set_Ramp_Angle
   LOW ramp_motorA                            'Stop Motor
   LOW ramp_motorB
   DEBUG "Ramp is raised to given angle.", CR
```

```
   RETURN
'**************************************************************************
************************
Calc_Range:

   Sine2Theta = SIN(2 * Angle * 128 / 180) * 100 / 127
   Range = Vosqr / 100 *  Sine2Theta / g
   DEBUG "Angle= ", DEC Angle, CR
   DEBUG "Range = ", DEC Range, CR

  RETURN
'**************************************************************************
************************
Set_Range:

   HIGH cart_position_cs                    'Get Current Reading on pot
   LOW cart_position_cs
   LOW cart_position_clk
   PULSOUT cart_position_clk, 210
   SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

   IF datain < PotRange THEN               'motor needs to go forward
    DO
     PULSOUT servo_motor,937
     PAUSE 20
     HIGH cart_position_cs                   'Get Current Reading on pot
     LOW cart_position_cs
     LOW cart_position_clk
     PULSOUT cart_position_clk, 210
     SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

    LOOP UNTIL datain >= PotRange
   ELSE                              'motor nees to go backward
    DO
     PULSOUT servo_motor,637
     PAUSE 20
     HIGH cart_position_cs                   'Get Current Reading on pot
     LOW cart_position_cs
     LOW cart_position_clk
     PULSOUT cart_position_clk, 210
     SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

    LOOP UNTIL datain <= PotRange
   ENDIF

RETURN
```

Appendix II. Circuit Schematics

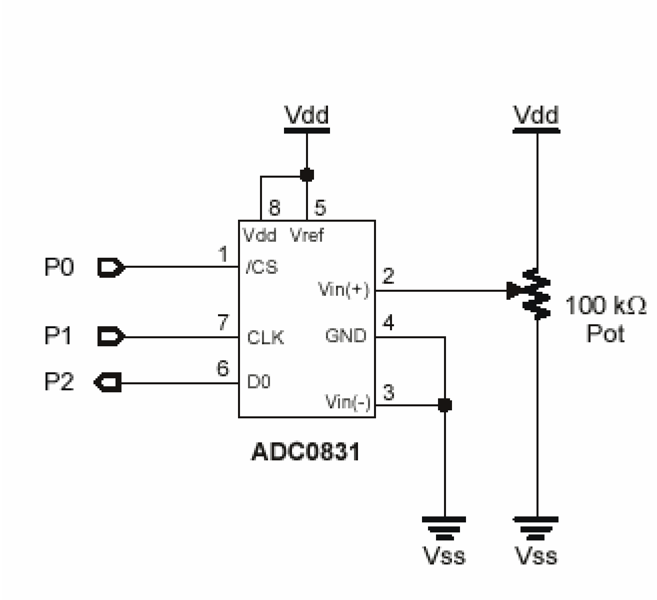


Figure A1 – General ADC Schematic

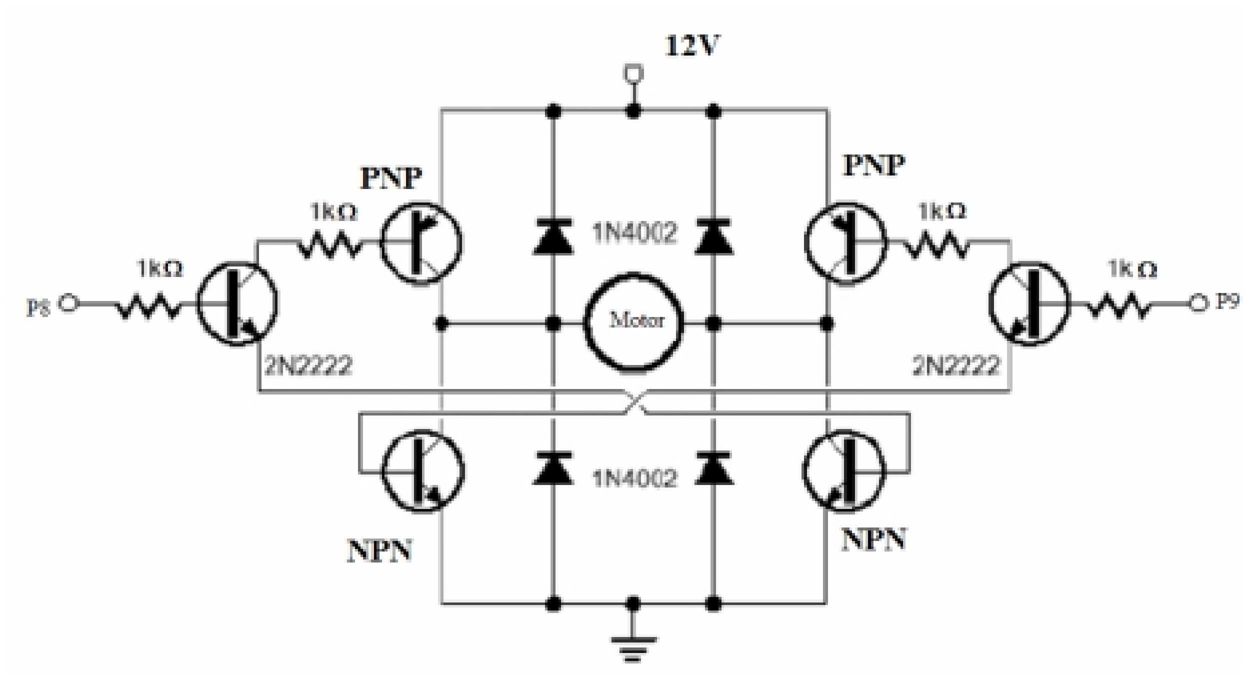


Figure A2: Schematic for H-Bridge