# I PUSH!
# YOU PUSH BACK! [1]

## A Mechatronics Demonstration Project

by

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## Abstract

Newton's Third Law of Motion is one of the harder laws to physically show in a classroom. Students can memorize the definition and say that they understand, but during class discussion, it becomes clear that this is not really the case. Students often do not understand the idea of what counts as a system and how the two objects interact. For instance, if a book is sitting on a table they often will say the action force is gravity pulling the book down while the reaction force is the table pushing back. It is obvious from this mislabeling of the action-reaction forces that the students truly do not understand the system. In order to clarify Newton's Third Law, this experiment uses mechatronics technology installed into a boxing punch mitt to produce an understandable system in which two objects act on each other and allow for the display of action reaction forces. This shows the students that the force acting on each object is indeed equal.

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## 1. Curriculum Standards Correlation

This project was designed to correlate to the topic Forces and more specifically, Newton's Third Law of Motion. This project can be used during the initial instruction of force, mass and velocity. This project addresses the following New York State Core Standards in the areas of Science and Technology:

Science Standards:
## STANDARD 1   Scientific Inquiry

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

**Key Idea:** The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

**Performance Indicators--Students:**
• learn to ask "why" questions to seek greater understanding concerning objects and events they have observed and heard about

## STANDARD 4   Physical Setting

**Students will:** understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science

**4. Key Idea:** Energy exists in many forms, and when these forms change energy is conserved.
   **Performance Indicators--Students:**
• observe a variety of forms of energy (e.g., heat, chemical, light) and the changes that occur in objects when they interact with those forms of energy

**5. Key Idea:** Energy and matter interact through forces that result in changes in motion.
   **Performance Indicators--Students:**
• investigate the use of common forces (pushes and pulls) on objects, such as those caused by gravity, magnetism, and mechanical forces

Technology Standards:
## STANDARD 1       Engineering Design

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

**Key Idea:** Engineering design is a repetitive process involving modeling and optimization, finding the best solution within given constraints, which is used to develop technological solutions to problems within given constraints.

## STANDARD 5      Computer Technology

**Students will** apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

**Key Idea:** Computers, as tools for design, modeling, information processing, communication, and system control, have greatly increased human productivity and knowledge.

## STANDARD 5      Technological Systems

**Students will** apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.

**Key Idea:** Technological systems are designed to achieve specific results and produce outputs, such as products, structures, services, energy or other systems.

## 2. Introduction

According to Newton, whenever objects A and B interact with each other, they exert forces upon each other. When you sit in your chair, your body exerts a downward force on the chair and the chair exerts an upward force on your body. There are two forces resulting from this interaction - a force on the chair and a force on your body. These two forces are called *action* and *reaction* forces. Forces always come in pairs - known as "action-reaction force pairs." In nature, single forces can not be generated.

Identifying and describing action-reaction force pairs is a simple matter of identifying the two interacting objects and making two statements describing *who is pushing on who* and in what direction. For example, consider the interaction between a baseball bat and a baseball. The baseball forces the bat to the right (an action); the bat forces the ball to the left (the reaction). Note that the nouns in the sentence describing the action force switch places when describing the reaction force. While the idea seems simple to explain, many students would not see the baseball as exerting any force on the bat. The experiment to demonstrate this interaction uses force sensors imbedded in two punch mitts. Using this apparatus, force interactions can be explored in a real experimental way and many questions can be answered such as: Why does an equal force have to exist? Can a small 5'2" girl exert an equal force against a 6'0" football player? In a collision between a car and a truck are the forces really equal?

## 3. Background

## 3.1 Theory

### 3.1A Newton's Third Law of Motion
Newton's Third Law of Motion describes the results of the interaction between two objects. Formally stated, Newton's third law is:

"For every action, there is an equal and opposite reaction."

According to Newton's Third Law, for every action force there is an equal (in size) and opposite (in direction) reaction force. All collisions are good examples of this law. For example if a truck hit a car with a 50. – Newton force then the car exerts a 50. – Newton force back on the truck.

## 3.2 Components

### 3.2. A Liquid Crystal Display (LCD)
An LCD is a unit that allows the user to display text, numerical data and custom created characters.[1] This project uses a 2 x 16 Parallel LCD with the HD44780 series driver from Hitachi. This LCD has a two-line display that can print up to sixteen characters per line. The LCD may be controlled by a 4 bit or 8 bit parallel interface. For this project, the 4 bit interface was used due to the limit of pins available. While the LCD is connected to a female 14-pin connector, for this application, it was necessary to manually wire the LCD.
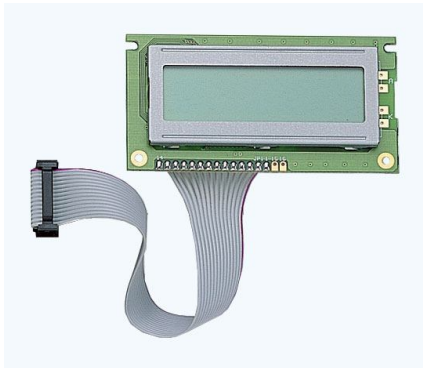


Figure 1(a): Parallel LCD [2]    (b): The LCD at Work

### 3.2.B Tekscan FlexiForce® Sensor
A force sensor measures the force between two surfaces. The *FlexiForce* single element force sensor acts as a force sensing resistor in an electrical circuit. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases.[3] The advantage to this sensor is that it is a thin-film force sensor which has a flat profile. The circuit built to use the sensor is a resistor/capacitor discharge time circuit (RC Time circuit). The circuit gives no correlation to weight in its output. The correlation needs to be found by calibrating each sensor individually. The sensors also have some element of hysteresis and drift which need to be taken into account during calibration. The sensing area on the FlexiForce sensor is .375" diameter and the force must be applied inside this area or no change in resistance will happen. For this project, a puck needed to be used to allow the push to register inside the sensing area. The puck allows the sensor to receive the applied load evenly across its contact area that is necessary to obtain good readings. In order to obtain good readings from the sensor, there must be a flat, hard surface underneath the sensing area.

Figure 2: FlexiForce Sensor[4]

**3.2.C Light Emitting Diode (LED)**

A diode is a semiconductor device that allows current to flow in only one direction. The Light Emitting Diode is a form of diode that gives off light when there is a potential difference across the diode. In this project, the LED is used to indicate when the current is flowing to the Board of Education.
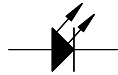
Figure 3: Schematic of LED          Figure 4: LED[5]

**3.2.D Button/Switch**

Buttons and switches are devices that can toggle the status of a circuit. Buttons and switches include two parts: how many ports it can control and how many triggers it has. A single port can toggle one device on and off while a double port can toggle two devices simultaneously. A single trigger can complete or open one circuit while a double trigger can complete one circuit or another circuit. This project uses a normally closed single pole, single trigger (SPST) button. This means that the circuit is normally complete and when the button is pressed, the circuit is broken. This button was used as an external reset button. This project also uses a SPST toggle switch. This switch is being used to control the current flow to the entire project. Both the button and the switch work only when the BOE is run from the 9V battery inside the project box.

## 4. Equipment List

## 4.1 Board Of Education (BOE) with Basic Stamp 2(BS2)

The combination of the Board of Education project board and Basic Stamp 2 module are the microcontroller used for this project. The Board of Education is a programming board that provides a regulated +5 volt source and ground as well as a direct 16-pin connection for the BS2 interface. The BOE also contains a small breadboard for circuitry and the connections to the 16 user defined digital input/output (I/O) pins found on the Basic Stamp 2. The Basic Stamp 2 also has 2 Kbytes of program space to store and run programs using the PBasic programming language. Each pin on the BS2 can source a maximum of 20mA and sink a maximum of 25mA of current. The 16 I/O pins together can source a maximum of 40mA and sink a maximum of 50mA of current.

A limitation of the PBasic programming language is the lack of support for floating decimal point numbers. The program truncates any number after the ones place, which causes mathematical errors when trying to deal with mathematical functions.
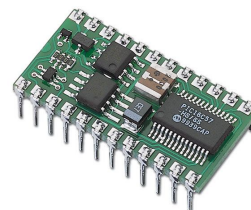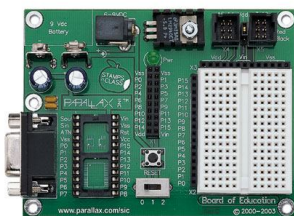
Figure 5: Board of Education[6]           Figure 6: Basic Stamp 2[7]

## 4.2 Project Design

This project is designed to demonstrate Newton's Third Law of Motion using an easily identifiable closed system. The two punch mitts makeup the system of two objects. As long as the sensors are well aligned, when the two mitts are pushed against each other by two people the LCD will display the two forces obtained. This evidence will confirm Newton's Third Law since it will work no matter what the size of each person and how hard each pushes.

The force sensors are not simple to condition and calibrate. Since the sensors act as a single contact point, the applied load must be distributed evenly across the sensing area. Calibration was repeated many times throughout the process due to trials of many surfaces surrounding the sensor looking for the best outcomes. Each sensor needs to be calibrated separately because each produces a different calibration curve. There is also the difficulty in alignment of the force sensors, so the program includes a failsafe for this problem. In this case, the users receive a sensor alignment error statement and are asked to try again.

## 4.3 Punch Mitt Design

The punch mitt used for this project is the Everlast High Performance Punch Mitt and is advantageous to use due to the zipper access to the inside of the mitt. Each punch mitt is imbedded with a FlexiForce sensor under the outer covering of the mitt. In order to do this the casing was unzipped and some of the threads at the bottom edge seam were snipped. This allowed the wires from the sensors to come out of the mitt without being in the way of use.

Since the material inside the punch mitt has flexibility, it is not the ideal base for the sensors. This can be remedied by placing a thin piece (1/8") of Plexiglas about 2.5" x 2.5" underneath the sensor. During testing, it was found that there was great difficulty aligning the two sensors for proper results. To increase the surface area that the puck would respond to another 2.5" square piece of Plexiglas was placed under the casing on top of the sensor. Spacers were used between the two plates so there was no force applied by the Plexiglas on the sensor.
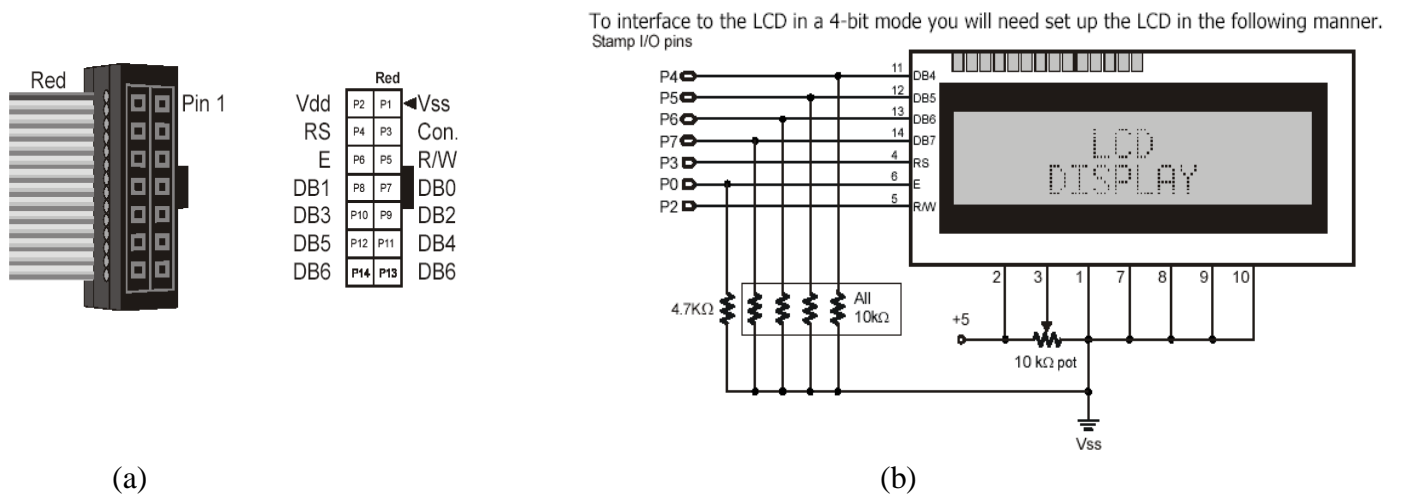


Figure 7: Everlast High Performance Punch Mitt[8]



Figure 8: Setup of mitts in project

## 4.4 Circuit Design

Each FlexiForce sensor was connected to +5-Volts through a .01-µFarad capacitor and a 220-Ohm resistor to create an RC Time circuit. The LCD was connected manually using the diagram in figure 10. The potentiometer in the circuit is used to control the contrast of the display. The LED is connect to the +5-Volt source through a 470-Ohm resistor to limit the current flowing through it and is then connected directly to ground. For this project the LED is on when there is current flowing through the Board of Education.

(a)                                                            (b)

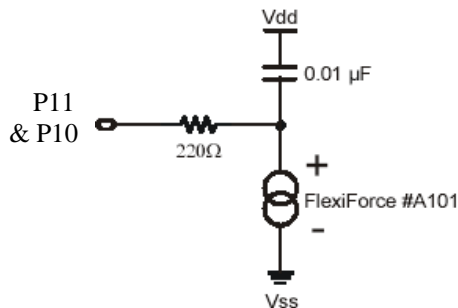Figure 9: 14-pin connector identification (a), and LCD circuit schematic (b)[9]
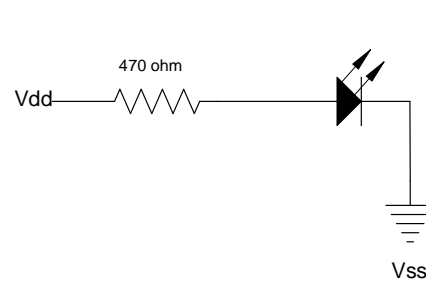
Figure 10: FlexiForce Sensor Schematic        Figure 11: Schematic of power indicating LED
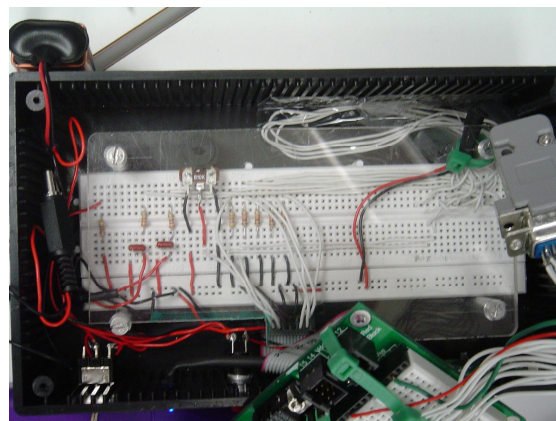
Figure 12:
The Wired Breadboard

## 4.5 Program Logic

The program starts out initializing all the variables and the LCD. A "Waiting for PUSH…" message is sent to the LCD so the users know that the device is ready for use. Once the mitts are pushed together, the program finds the minimum RCTIME value from each sensor and uses this to calculate the force in Newtons using the linear calibration curves found in testing. This data is then sent to the LCD for output and stops until the reset button is pushed. If the two forces are more than 4-Newtons apart, the program sends an error message, "ERROR!! Sensors Misaligned," since this occurs when the sensors were not aligned well during the action. If the RCTIME data is above the calibration range an error message, "ERROR!! Push Harder," shows. After either error message the program returns to the beginning and again waits for input.

## 5. Experimental Procedure
Study of Newton's Third Law of Motion

Goal:
1. Measure the force on each sensor and send output to LCD unless sensor misalignment has occurred.

Experiment Procedure:
1. Connect BS2 to a computer and download the *I Push U Push Back.bs2* file. If RCTIME output is wanted, leave the board plugged into the computer.
2. Connect BS2 to the breadboard inside the project box using the 15-pin connector.
3. Plug 9V battery power source inside the box to the BOE.
4. Flip power switch to on. You will know it is on when the blue LED lights.
5. After the LED screen shows "Waiting for PUSH…" push the mitts together.
6. Read the output from the LCD or if error repeat step 5.
7. To restart the program, push the reset button on the outside of the project box.

## 6. Results
The apparatus used punch mitts, force sensors and an LCD screen. Using this setup two people were asked to push the mitts together. After the mitts were pushed and released, the computer program then picked out the maximum force, the smallest RCTIME, applied by each mitt. The RCTIME output was then converted to a force measured in Newton's using a linear calibration curve predetermined for each sensor. If the sensors were properly aligned, the output will show each force on the LCD screen.

Out of 20 random trials performed by two people, it was noted about the force readings that the average difference between the readings was 2 N, and 3 readings showed that the sensors were misaligned. There was no significant difference as to which sensor read a higher reading.

Out of 20 random trials performed by one person applying force with both mitts, the average difference between the mitts was 1.5 N, 1 reading showed that the sensors were misaligned. It was interesting to note that larger hands had a tendency to stretch the outer cover of the mitt, leading to a low force reading and a subsequent error reading. This could be easily remedied by having students with large hands not put their hands through the wrist wraps on the punch mitts.

There were some sources of error in this project all corrected for by programming. The first type of error was because the Basic Stamp 2 can only do integer mathematics. For this reason, the program was designed to print data within a 4-Newton range allowing for this experimental error. Another error may occur if the sensors were not properly aligned. In this case, the output showed an error message on the LCD screen and asked the users to try again. Lastly, the calibrations only work within a specified range so if the RCTIME is outside the range a different error message is received and the users were asked to try again.

## 7. Conclusions

The simplicity of Newton's Third Law seems to lend itself to an elegant and seemingly simple project. The idea of showing equal forces is elegant, but the challenges are great. This project was able to overcome the many challenges using a combination of programming and the exploration of materials used around the sensors to obtain the most accurate and reproducible data. Students will be able to see the outcome from each sensor and prove to themselves that this law really is true.

## 8. Suggested Activities

1. Additional Activities with "I Push! You Push Back!"
   a. Incorporate photogates to measure the speed of pads and discuss momentum
   b. Add an accelerometer to each mitt and study Newton's Second Law of Motion.
   c. Using the DEBUG screen for output or modifying the program, the weight/mass of any object can be found by placing it on the mitt while the mitt is laying flat on a table.
   d. Using the TI-89+ or Microsoft Excel program discuss collection of calibration data and mathematics of line/curve-fitting using modern technology.

2. Real World Application
   a. Measure the force of a punch from a boxer to aid in training
   b. Embed sensors in car bumpers to get "black box" data after an accident

## 9. Project Cost Analysis

1. Construction materials:
   a. Everlast High Performance Punch Mitts (Modell's)         $ 24.99
   b. Black Project Box (Radio Shack)                          $  6.99
   c. Plexiglas                                                $ 10.00
   d. Screws, etc                                              $  5.00

2. Electrical Components
   a. Board of Education (Parallax)                            $ 65.00
   b. Basic Stamp 2 IC (Parallax)                              $ 49.00
   c. FlexiForce Sensor Demo Kit (2) (Parallax)               $ 42.00
   d. 2 x 16 Parallel LCD (Parallax)                           $ 29.00
   e. Misc: Resistors, Potentiometer, Wire, LED               $ 10.00
   TOTAL:                                                      $ 241.98

## 10. Acknowledgements

## 11.  Appendix A: PBasic Program

```
' {$STAMP BS2}
' {$PBASIC 2.5}
'*****************************************************************************
'*          I PUSH! YOU PUSH BACK!
'*  Dvora Geller, Ed Gruber, Denise McNamara
'*****************************************************************************


'Variables for LCD
E          CON      0            'Enable pin for LCD
Rs         CON      3            'LCD Register select pin, 0 = instruction, 1 = text
Char       VAR      Byte         'Character to send to LCD
Inst       VAR      char         'Induction to send to LCD. (Points to Char)
Index      VAR      Word         'Character pointer
temp       VAR      Byte
RW         CON      2

'Variables for FlexiForce Sensors
rawForce1    VAR      Word         'Gathers RCTime data
rawForce2    VAR      Word
rawforce1keep VAR     Word         'RCTime data used for conversion
rawforce2keep VAR     Word
forcemitt1   VAR      Word         'Force after conversion
forcemitt2   VAR      Word
sensor1Pin   CON      11           'I/O pin for FlexiForce sensor
sensor2Pin   CON      10


Main:                     'Main program
   GOSUB initialize
   GOSUB waiting
   GOSUB force_check
   GOSUB pick_rctime_output
   GOSUB convert_rctime_force
   GOSUB force_or_error
```

```
    GOSUB out
    IF temp > 35 THEN
        PAUSE 1000
        GOTO main
    ENDIF
    STOP


Out:                        'Prints characters to LCD screen
    READ temp, char
    IF (char = 9) THEN Next_line
    IF (char = 1) THEN RETURN
    GOSUB Sendtext
    temp = temp + 1
    GOTO Out



Initialize:
'Setup Flexiforce
    rawforce1keep = 65535
    rawforce2keep = 65535

'LCD Setup stamp pins & data
    LOW rw
    OUTS = %0000000000000000
    DIRS = %0000000011111111
    DATA @00, "ForceM1 = "
    DATA @15, "N", 9, "ForceM2 = "
    DATA @32, "N", 1
    DATA @34,"ERROR!! Sensors", 9, "Misaligned",1
    DATA @100, "Waiting for",9, "PUSH...",1
    DATA @150, "ERROR!!",9, "Push Harder",1
    GOSUB Initlcd

    DEBUG CLS               'Clears screen on computer
RETURN

Initlcd:                    'Initialize the LCD
    PAUSE 200
    OUTS = %00110000            'Wakeup for the LCD
    PULSOUT E,1                'Send command three times with required delays
    PAUSE 10
    PULSOUT E,1
    PAUSE 1
    PULSOUT E,1
    PAUSE 1
    OUTS = %00100000           'Set to 4-bit operation
```

```
  PULSOUT E,1
  Inst = %00101000            'Setup the LCD for two line display
GOSUB Sendinst
  Inst = %00001110            'Turns on cursor
GOSUB Sendinst
  Inst = %00000110            'Set to auto-increment cursor and on display shift
GOSUB Sendinst
  Inst = %00000001            'Clears LCD
GOSUB Sendinst
  Inst = 14                   'Turns cursor to underline
GOSUB Sendinst
RETURN

Sendinst:                     'Send an instruction to LCD

  LOW Rs                      'Sets instruction mode
  OUTB = Inst.HIGHNIB         'Send high nibble
  PULSOUT E,1
  OUTB = Inst.LOWNIB          'Send low nibble
  PULSOUT E,1
  HIGH Rs                     'Sets LCD back to text mode
RETURN

Sendtext:                     'Send text to LCD
  OUTB = Char.HIGHNIB         'Send high nibble
  PULSOUT E,1
  OUTB = char.LOWNIB          'Send low nibble
  PULSOUT E,1
  PAUSE 100
RETURN

Next_line:                    'Send cursor to line 2
  Inst = %11000000
  GOSUB Sendinst
  temp = temp + 1
GOTO out

waiting:                      'Prints waiting msg on LCD
  temp = 100
  GOSUB out
RETURN

force_check:                  'Checks to see if the mitts are being used
  HIGH sensor1pin
  HIGH sensor2pin
  PAUSE 10
```

```
        RCTIME sensor1pin,1,rawforce1
        RCTIME sensor2pin,1,rawforce2
        DEBUG HOME, "RawForce1 = ", DEC5 rawforce1, CR  'Prints RCTIME to DEBUG
        DEBUG "RawForce2 = ", DEC5 rawforce2, CR        'screen if hooked to computer
        IF rawforce1 = 0 THEN force_check
RETURN


pick_rctime_output:                'Picks max RCTIME value for each mitt

    DO WHILE (rawforce1 <> 0 AND rawforce2 <> 0)
        IF rawforce1 < rawforce1keep AND rawforce1 <> 0 THEN rawforce1keep = rawforce1
        IF rawforce2 < rawforce2keep AND rawforce2 <> 0 THEN rawforce2keep = rawforce2
        HIGH sensor1pin
        HIGH sensor2pin
        PAUSE 10
        RCTIME sensor1pin,1,rawforce1
        RCTIME sensor2pin,1,rawforce2
        DEBUG HOME, "RawForce1 = ", DEC5 rawforce1, CR  'Prints RCTIME to DEBUG
        DEBUG "RawForce2 = ", DEC5 rawforce2, CR        'Screen if hooked to computer
    LOOP

RETURN


convert_rctime_force:              'Converts RCTIME to FORCE and clears LCD

    IF rawforce1keep < 3682 THEN
        forcemitt1=(3682 - rawforce1keep)/29
    ELSE
        temp = 150
    ENDIF

    IF rawforce2keep < 4870 THEN
        forcemitt2=(4870 - rawforce2keep)/43 + 10
    ELSE
        temp = 150
    ENDIF

    DEBUG "actual force1 = ", DEC5 forcemitt1 , "  N", CR
    DEBUG "actual force2 = ", DEC5 forcemitt2 , "  N", CR

    Inst = %00000001
    GOSUB Sendinst

RETURN


force_or_error:                    'Prints error msg or force
```

```
    IF temp = 150 THEN RETURN
    IF ABS(forcemitt1 - forcemitt2 > 4) THEN  temp = 34 ELSE GOSUB force_write

RETURN

Force_write:                    'Sends the Force data to the EEPROM

    temp = 0

    WRITE 10, forcemitt1/10000+48
    WRITE 11,(forcemitt1/1000)//10+48
    WRITE 12,(forcemitt1/100)//10+48
    WRITE 13,(forcemitt1/10)//10+48
    WRITE 14, forcemitt1//10+48

    WRITE 27, forcemitt2/10000+48
    WRITE 28,(forcemitt2/1000)//10+48
    WRITE 29,(forcemitt2/100)//10+48
    WRITE 30,(forcemitt2/10)//10+48
    WRITE 31, forcemitt2//10+48

RETURN
```

## 12.  References

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2. http://www.parallax.com/images/prod_jpg/603-00006.jpg
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4. http://www.parallax.com/detail.asp?product_id=30056
5. http://www.radioshack.com/product.asp?catalog%5Fname=CTLG&product%5Fid=276-311
6. http://www.parallax.com/detail.asp?product_id=28150
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