Wire Routing Tool for the Mechatronics Term Project

By

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Abstract

Consumers are always seeking cost effective methods in order to make renovations to their homes. One problem that arises in such situations is that a consumer would not like to see wires hanging from the ceiling or hiding underneath carpets, thus defeating the purpose of home improvement. The home owner would be pleased to know that there is a tool available that would cause less damage to the walls in his or her home during the process of routing wire. This paper will present a new tool which will enable a home owner to route wire behind walls and out of sight. The Wire Routing tool will allow a consumer to renovate his or her home and keep cost and damage to a minimum.

Project Guidelines

The integrated term project of ME3483-Mechatronics must be selected, designed and build based on a set of guidelines presented by the professor. The following guidelines were quoted from the ME3483 course website as set forth by Professor V. Kaplia:

Project prototype must consist of the following:

a) The device will be controlled by BS2.

b) The project must incorporate and document hardware and software features to prevent damage to the BS2 IC and other components on your device. In addition, you must provide guidelines for safe operation of your device. Include a provision for instantaneous shutdown of your device in case of incorrect/unsafe operation.

c) The project must include some form of a user interface so that a human user can monitor and control your device (excluding b above).

d) The project must utilize at least one actuator (excluding b and c above).

e) The project must utilize at least one analog and one digital sensor (excluding b and c above).

f) The actuator must be controlled using sensory feedback. You can use any primitive to advance control design methodology for this purpose.

1. Introduction

The objective of this project is to design and build a wire routing tool that will allow for a home owner to reduce both cost and time involved in this process. The damage to the exterior of the dry wall would also be reduced. Instead of having to tear up the wall all the way across where the wire is desired, the home owner would be able to make two smaller holes where the wire would begin and end, and place the routing tool behind the dry wall, and thus have access to the wooden studs. The tool would be equipped with a drill in order to bore through the wooden studs. The tool itself must be able to fit entirely through a hole in order to reach the next wooden stud. The tool would be powered from outside the wall.

The unit would also have sensors on its self, both for safety and feedback to the user; a range sensor to inform the user at what point of the wall it is located, a speed sensor to inform the user of the drills status, a temperature sensor which would both act as a safety precaution and information for the user of the environment around the tool, and finally a touch sensor for the tool to know when to activate it's drill when it is up against the stud. The user would have in hand a safety cut off switch along with a display to read output data from the sensors on the tool.

The paper is written to guide the reader through the design, development and creation of the Wire routing tool. The Hardware will be discussed, which includes the mechanical and electrical design. The software used in development of the prototype will be discussed, including the theory behind the code as well as the code itself. The cost analysis for the prototype design will be outlined as well as the cost for mass production. Finally, a thorough analysis of the tool is discussed, including its advantages, disadvantages and possible future improvements.

2. Hardware

This section will discuss the Mechanical and Electronic designs that were incorporated into the prototype design for the Wire Routing Tool. This project has been broken down into two major parts. The term Mechatronics is a combination of both **Mecha**nical and Elec**tronic** concepts. Though the mechanical and electronic components are designed separately, in the end, they must be combined to form one complete concept, as can be seen in the prototype design.

Mechanical Design

2.1 Drill and Drive Motor

The mechanical design is built around the concept of a drill. The front end of the tool is the drill motor itself along with its drill bit. The drill motor for the prototype model is a Globe Motors GLOBE-MTR-01. The model number is PN#: 409A587. This motor runs at 12 VDC with an internal drive. The drive motor utilized for this model is the Lego Mindstorms Kit Motor. The motor is a DC Motor that runs on 9 VDC, with a rotational speed of 350 rpm's. Its stall current is 350 mA and stall torque is 6 N-cm.

2.2 Chassis

The actual body of the tool is a mix of different materials. The wheels and axles used are also of the Lego Mindstorm Kit, and the base structure that everything is connected to is a sheet of metal.

The tool also consists of spring loaded balancing arms. This has a dual purpose. First of all, the arms are meant to guide the tool and keep it straight. This will keep the drill bit centered and perpendicular to the wooden stud. Secondly, the arms are meant to keep the tool from tipping over due to the counter torsional force from the motor.

The actual cutting tool used is a band saw blade that has been wrapped in to a circular shape in order to cut through the supports in the wall. This improvised drill bit was used for prototyping purposes only, due to limitations on available resources for custom part fabrication. A stronger, more versatile bit will be used for production models

At this point, the prototype is only capable of cutting through Styrofoam for demonstration purposes. Future improvements will allow for a better drill bit and drill motor combination to allow for drilling through wooden studs. This will be discussed in a later section.

Electronic Design

Note: The schematics for all the components mentioned here can be found in Appendix B

2.3 <u>Microcontroller</u>

As per the requirements for the project, this section will explain in detail the electronic parts used for this prototype along with why each part was used. The requirements state that the BASIC Stamp 2 (BS2) must be utilized for this project, along with sensors and actuators which would provide information to the user as well as setup safety precautions in case of malfunction or misuse of the device.

The main driving component, or the brain, for the electrical design is the BASIC Stamp 2. This microcontroller is a 24-pin Dual inline package module. It includes its own processor, memory clock and interface in its package. Its capabilities are more than enough for the prototypes design. All sensors and actuators will be interfaced with the BS2 in order to operate the tool, as well as receive feedback to display to the user. The language used to drive the BS2 is PBASIC, Parallax's take on the BASIC language. As the name states, this language is very quick to learn and implemented to the BS2. The specifications for the BS2, as provided by Parallax, are as follows:

- Processing Speed : 20 MHz
- Program execution speed: ~ 4,000 instructions/sec
- Ram Size: 32 Bytes
- EEPROM : 2K or approximately 500 lines of code
- I/0 Pins: 16 + 2 dedicated serial
- Voltage requirements: 5 – 15 VDC
- Current draw (at 5 VDC): 3 mA Run / 50 µA Sleep

The BS2 is interfaced with a PC for programming using a USB cable and the Board of Education provided with Parallax as well. Considering the specifications of the BS2, it is more than ample for the prototype design and all the sensors and actuators that are implemented.

2.4 Range Sensor

The first sensor to be noted would be the sensors incorporated into the design. The ranger sensor used is Parallax's PING))) ™ ultrasonic sensor. This is an easy and low cost method of determining the position of the wire routing tool. This sensor can be interfaced by using just one I/O pin to the BS2. The sensor works off the concept of sonar. The distance to an object is determined by sending out an ultrasonic wave length towards the object, which in turn is bounced back to the sensor. The sensor is able to calculate how far the object is based on the travel time of the sound wave. The specifications of this sensor are as follows: The range of the sensor is 3 meters, and requires a voltage of 5V +/-10%. The supply current for this sensor is 25 mA, with a max of 30 mA. The reason this particular sensor was chosen was because it would alert the user at what point the device is located from its starting point, since during operation, the drill would not be visible.

2.5 Hall effect – Rotational Speed Sensor

The next sensor used was the Hall-effect sensor. This sensor is used to determine the rotational speed of the drill motor. Since the tool will in most cases not be visible to the user since it is behind the dry wall, feedback of the mounted drill is necessary to alert the user. The Hall-effect sensor is basically a transducer which alters its voltage based on magnetic field. The Hall Effect Sensor used for this prototype is the Anachip AH-182 Hall effect switch. This particular Hall Effect Switch was chosen on cost considerations alone. This sensor will produce a 'high' output when the sensor is inside of a magnetic field, and conversely will produce a 'low' output when the sensor is not in a magnetic field. In the case of the project, magnets will be placed on the motor's rotational part, and as the motor turns, the hall-effect sensor will produce a pulse train as its output. The frequency of the pulse train is proportional to the rotational speed if the drill bit Based on

this simple concept, the user will receive feedback on how fast the motor is spinning in terms of revolutions per minute (RPM). This same signal is also used to tell if the drill motor has stalled. The hall-effect sensor can also be integrated with the BS2 using 1 I/O pin. This sensor is incorporated into the design, as mentioned before, to alert the user the status of the drill motor.

2.6 Temperature Sensor

A Temperature sensor is also used in the prototypes design. The temperature sensor used is provided to by Parallax in their BS2 kit that was purchased for the Mechatronics course. The temperature sensor is utilized in order to alert the user of the environment around the wire routing tool. It is also incorporated as a safety precaution, where if the environment is too hot for the device to operate, or if there is a danger of a fire occurring inside the wall due to excessive temperatures, it will automatically shut down.

2.7 Touch Sensor

The final sensor designed for the tool is the touch sensor. The touch sensor is incorporated in order to allow the motor to only activate when it has pressed up against a wooden stud. This allows minimal use of the motor to reduce overall power consumption, and prevent unnecessary damage to the walls and studs.

2.8 H-bridge – Motor Control

The H-bridge utilizes 4 TIP-120 NPN type Darlington pair transistors. These transistors were chosen due to their power dissipating capability and the extremely large current gains possible from these transistors (minimum current gain of 1000, as specified on component data sheets). Upon initial prototyping, 2N2222 NPN transistors were used, due to ready availability, but these transistors proved to have inadequate heat sinking capability, and were not easily biased to operate in the saturation mode of the transistor. The freewheeling diodes used to suppress switching transient voltages of the motor are 1N914 type diodes, chosen for their fast recovery times, and availability.

2.9 Relay

A relay was incorporated into the design of the prototype. This relay was used to turn the drill motor on and off. The relay's coil was driven using a 2N2222 transistor to isolate the relay coil from the Basic Stamp, preventing any possible damage to the BS2 due to inductive kick from the coil.

2.10 Regulator

The prototype design intended to use a regulator as well. This is a component that manages values, in this case voltage. It regulates all the 5 volt circuits used in design. The component was chosen because it can supply up to 1A, and is therfore able to regulate all circuits that require a +5 volt supply. It should be kept in mind that the regulator would be fully integrated to be used with the production design, but is not incorporated in the prototype.

2.11 User Interface – Display and Emergency shutoff

Having all the sensors available for one to use to make sure everything is working properly is great, but if there is no way for the user to receive this information, it is useless. That is why a LCD-Display is integrated into the design. The LCD display is interfaced with the BS2 and can provide all the information from the sensors so the user is aware of what the tool is doing. Also on the user interface is a Run/Stop button. This button is a momentary, normally open switch. This type of switch was chosen so that the tool will only run when the button is depressed, so the user only has to let go of the button in the case os unsafe operation. This switch is also interfaced with the BS2.

3. Software

3.1 Theory

The language used to program this prototype is the PBasic language. It was developed by Parallax to be used with their Microcontrollers. Since this prototype is using the BS2 developed by Parallax, it is required that PBasic be the language used to program the BS2. A detailed explanation of the code may be obtained from Appendix A with all the comments available for all commands used for programming.

4. Example of Function

The following are some snaps shots of the actual prototype:
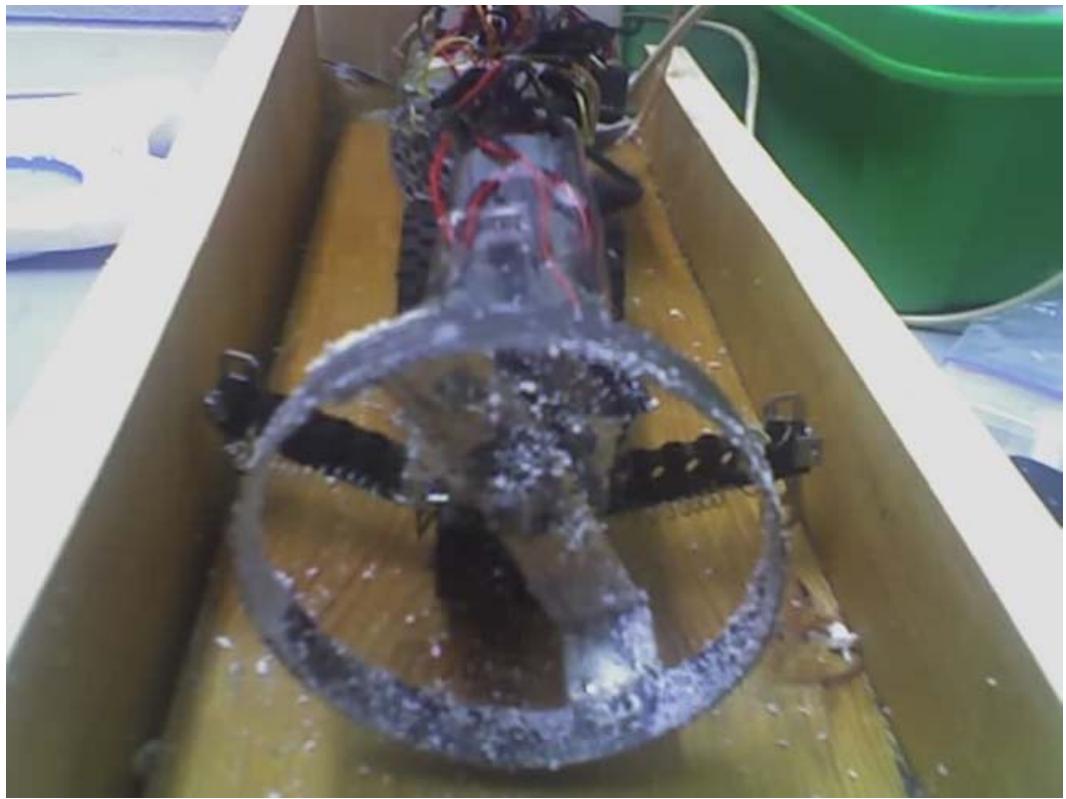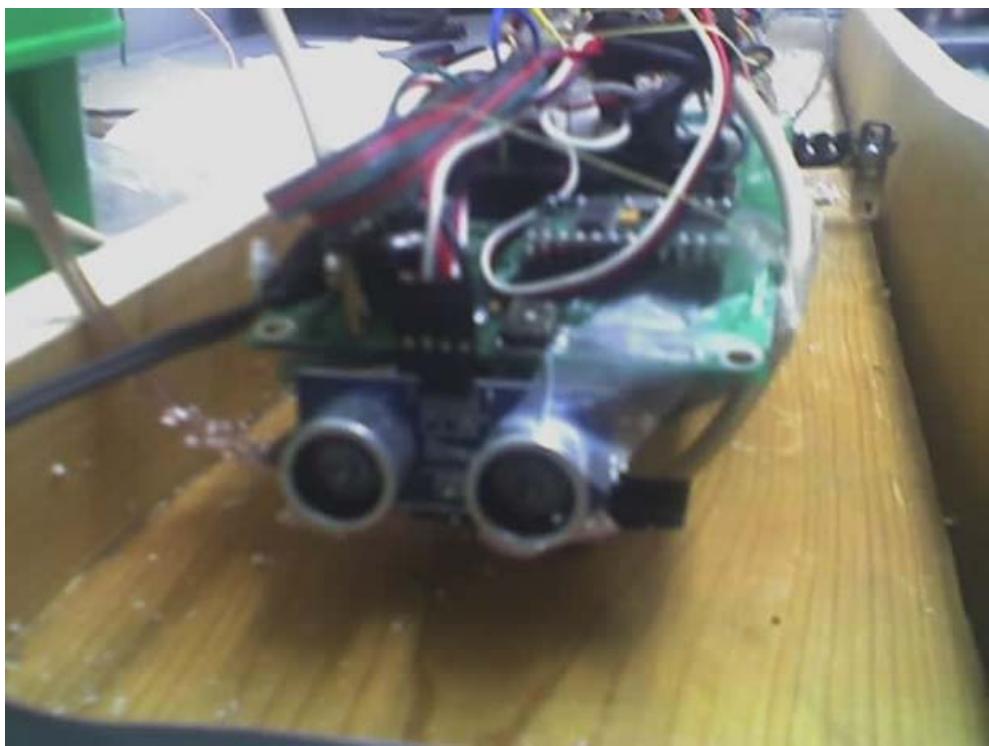
5. Cost

In this section, the cost of the prototype will be discussed. This includes all the sensors, actuators, motors and miscellaneous items.

5.1 <u>Prototype Cost</u>

The following chart shows all the parts purchased for the creation of the prototype design. These prices are the actual prices paid by the group in order to design, create and build the prototype for the Mechatronics course:

Product	Quantity	Price ($)
Drill Motor	1	25
Lego Motor	1	15
BS2 Kit	1	100
Hall-effect sensor	1	1
Thermocouple	1	Included with BS2 Kit
Ultrasonic Range Sensor	1	30
DC Motor control	1	30
LCD Display	1	30
Servo Motor	1	Included with BS2 Kit
Blade (for drill bit)	1	15
Chassis		10
Misc.		30
	Total Cost:	286

Chart 1: Pricing list for Prototype

Each part listed was discussed in the Mechanical and Electronic design of the prototype. Chassis parts include Lego pieces used for the axel and wheels as well as a sheet of metal for the base of the tool. Misc. refers to wiring, resistors, capacitors, transistors and more. Many of these parts were included with the purchase with the BS2 Kit, but in order to accommodate the electrical circuits, more were purchased in bulk from Radio Shack and www.Jameco.com

5.2 Manufacturing Cost

The following is a cost analysis done for mass production of the Wire Routing Tool. These estimates are based on the assumptions that parts would be bought in bulk, which would lower their price. Also, they would be available at wholesale pricing, thus lowering their price even further. Finally, these values are based around the fact that there would be a 100 units built.

Product	Quantity	Price ($)
Drill Motor	1	10
Lego Motor	1	5
BS2	1	40
Hall-effect sensor	1	1
Thermocouple	1	2
Ultrasonic Range Sensor	1	20
DC Motor control	1	15
LCD Display	1	20
Servo Motor	1	5
Blade (for drill bit)	1	20
Chassis		4
Misc.		10
	Total Cost:	152

Chart 2: Manufacturing Cost Mass production

6. Analysis

This section will analyze the prototype design of the Wire Routing tool. While there many advantages to the design of this prototype to assist a home owner or a contractor, it is also valid to discuss any disadvantages to the traditional method of routing wire through a finished home. Also, there is always room for improvement, and these points will also be discussed:

6.1 <u>Advantages</u>

As discussed previously, the Wire Routing tool allows for a home owner or contractor to route a wire inside a finished wall without having to tear up large portions of the whole wall. Instead, smaller access holes may be made in order to gain access to behind the dry wall of a home or office. This will reduce the cost to a homeowner, both for repairs to the walls and payment to a contractor for his or her service. Also, less repairs means less time spent repairing the abrasions to the walls. The production model was sized so it can be maneuvered into a hollow wall (framed with 2x4's) through a four inch, square access hole; a standard size for residential electrical terminal boxes.

6.2 <u>Disadvantages</u>

With its many advantages, the Wire Routing tool has its disadvantages as well. To begin, despite causing less damage to a wall, none-the-less, there is still a need to create a hole in the wall so that access may be given to the user to place the wire routing tool behind it. But still considering the advantage, the cost and time applied to this minimal damage to the wall is still much less substantial than the damage caused by the traditional method of tearing up the whole wall.

Another problem that arises with use of this tool is the debris that remains after drilling. Since the prototype uses a hole-saw type bit, a circular piece of material will be left over behind the wall. This is not a major concern since this is not visible and will be out of the way.

A consumer may require a switch or other fixture up on a wall. This tool would not be able to drill through studs at different elevations. The current prototype only

allows for wire to be routed along the floor. The final concern for the wire routing tool is the user must be aware whether or not the there is cable already there. If cable or wire already exists, the wire routing tool will continue to cut right through it.

6.3 Improvements

Since this is a prototype, there will be many changes and improvement implemented before it goes into full production for consumers. To begin, the drill motor and drill bit must be upgraded to be suitable for actual studs that exist in homes and offices. The current prototype is able to go through Styrofoam. The full consumer version must be able to drill and route wire through wood. This of course would also require an upgrade in chassis and the support for the drill motor to prevent vibrations.

Another possible improvement would be to include some sort of cable detection through sensors. This would prevent damage to already existent cable in the walls. Finally, in order to deal with the fact the current prototype doesn't allow for wire to be routed wire at different elevations, it would be ideal to perhaps attaching a drill on a telescopic arm to allow for wire to be routed at different elevations.

6.4 Considerations for Mass Production

A few considerations for mass production must be taken into consideration since they were not feasible for the prototype. Ideally, it would be cheaper and much more efficient to create a board with all the electrical components. A schematic was created using Eagle Software. This allows for creation of schematics of such boards. This software was also used to create the schematics for all the electrical components for the prototype. This software is a free-ware software that may be found at www.catsoft.de

7. Conclusion

The Wire Routing Tool is a cost efficient way for a home owner to make renovations to ones home. While the tool is still in its prototype stage and has some disadvantages in its operation, it does prove to have many advantages as well. These are the cost decrease from the traditional method of routing wire, which involve tearing up the whole wall along where the wire is to be placed. Also, the reduction of damage done to an interior wall, as was discussed in previous sections, where only two smaller holes may be created to allow access for the tool. With future improvements, such as upgrade of the drill bit and drill motor to be suitable for actual wooden studs which exist in current homes, or possible allowing the device to make holes at different elevations will allow it to be a more practical and usable tool in home construction projects. The disadvantages of the tool may be reduced as it is upgraded and tested. There are many possibilities for the future of this tool with the proper testing and availability of resources.

References

ME 3483: Mechatronics Course website:

https://my.poly.edu/webapps/portal/frameset.jsp?tab=courses&url=/bin/common/course.pl?course_id=_18912_1

ME 3483: Mechatronics Course Lectures – for an understanding of the theory involved in many of the electronics parts

Online: www.Parallax.com – for specs and information on parts used

Online: www.jameco.com – for specs and information on parts used

Online: www.wikipedia.org – for research and information

Online: www.catsoft.de – schematic drawing software

Appendix A – PBasic Code

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


' ================================================================


' -----[ I/O Definitions ]------------------------------------------
  Ping        PIN    13    'Range Sensor
  drillm      PIN    5     'drill motor
  drivem      PIN    1     'drive motor
  servo       PIN    9     'Servo
  temp        PIN    12    'temp sensor
  speedin     PIN    15    'Melexis 90217 output (LCD Display)

' -----[ Constants ]----------------------------------------------

  'range sensor
    Trigger      CON    5                  ' trigger pulse = 10 uS
    Scale        CON    $200               ' raw x 2.00 = uS

    RawToIn      CON    889                ' 1 / 73.746 (with **)
    RawToCm      CON    2257               ' 1 / 29.034 (with **)

    IsHigh       CON    1                  ' for PULSOUT
    IsLow        CON    0

  'servo
    close        CON    1000               ' used to fully close arms attached to servo
    open         CON    250                ' used to fully open arms attached to servo

  'temp sensor
    Kal          CON    15300
' -----[ Variables ]---------------------------------------------
  'lcd display
    TxPin CON 3
    Baud19200 CON 32

  'range sensor
    rawDist      VAR    Word               ' raw measurement
    cm           VAR    Word               ' Distance between Studs
    realdist     VAR    Word               ' Real distance

  'hall sensor
    rpm          VAR    Word               ' motor RPM
```

```
   pulses        VAR    Word                 ' counts pulses from hall sensor

'button
   push          VAR    IN11

'servo
   counter       VAR    Byte                 'used to open servo motor for arm movement

'temp sensor
   time          VAR    Word                 'stores time between state change
   TK            VAR    Word                 'outputs temperature in kelvin

'stud counter
   studcnt       VAR    Byte                 'counts the number of studs cleared


' -----[ Initialization ]-------------------------------------------------
 'lcd reset
   Reset:
      HIGH TxPin ' Set pin high to be a serial port
      PAUSE 100  ' Pause for Serial LCD to initialize
 'range sensor
 'hall sensor
   pulses =0
 'button
   push = 0
 'stud counter
   studcnt=0




' -----[ Program Code ]----------------------------------------------------

Main:


 'Intialize drill and drive motors
 LOW drivem
 LOW drillm

 'User Interface
 'User is asked to depress button on LCD display in order to start the tool
 'User must hold down button for duration of use
 'This is for safety, since as soon as the button is let go, the tool will cease to function
 SEROUT TxPin, Baud19200, [12]
 SEROUT TxPin, Baud19200, ["Depress button  to begin"]
```

```
GOSUB Get_Temp                           'Checks drill temperature before operation
DO WHILE push = 1 AND TK < 103

  GOSUB Get_Sonar
  HIGH drivem
  PAUSE 75
  LOW drivem
  PAUSE 50

  'controls drill
  LOW drillm
  IF cm >= 15  AND cm < 20  THEN
     HIGH drillm                  'Turns Drill motor on
     GOSUB Get_Sonar                  'Checks Distance - See Subroutine for detail
     GOSUB Get_Temp                   'Checks Temperature - See Subroutine for detail
     GOSUB Get_RPM                    'Checks Drill Speed - See Subroutine for detail

  ENDIF


  'Get through the hole
  IF cm >=21 THEN
     FOR counter = 1 TO 150          'Initially closes Arms to allow tool to pass
through hole
       PULSOUT servo, close
       PAUSE 20
     NEXT
     DO WHILE cm >= 21 AND push = 1
       GOSUB Get_Sonar              'Ensures arms stay closed during movement
through hole
       HIGH drivem
       PULSOUT servo, close
       PAUSE 20
     LOOP
     studcnt = studcnt + 1          'After stud has been cleared, studcnt is increased to
alert user of total distance traveled
     FOR counter = 1 TO 150         'Opens Arms with Servo for balancing
       PULSOUT servo, open
       PAUSE 20
     NEXT
  ENDIF
 LOOP
 GOTO Main
END
```

```
'----- Sub routines ----------------


'Ultra Sonic Range Sensor
'Checks to see distance of tool from previous stud
'From starting
Get_Sonar:
  Ping = IsLow                         ' make trigger 0-1-0
  PULSOUT Ping, Trigger                   ' activate sensor
  PULSIN  Ping, IsHigh, rawDist             ' measure echo pulse
  rawDist = rawDist */ Scale              ' convert to uS
  rawDist = rawDist / 2                  ' remove return trip
  cm = rawDist ** RawToCm                   ' Converts Raw data to centimeters
  realdist= studcnt*15 + cm              ' Real distance
    SEROUT TxPin, Baud19200, [12]          ' Resets LCD
    SEROUT TxPin, Baud19200, ["Distance = "]    ' Display Distance
    SEROUT TxPin, Baud19200, [DEC cm]
RETURN


'Temperature Sensor
'Checks temperature of motor
'If motor temperature is higher than threshold limit, device will cease to function as a
safety precaution
'This is checked before and during operation of the drill motor
Get_Temp:
    PAUSE 5
    HIGH temp                         'Sets temperature sensor pin high
    PAUSE 5
    RCTIME temp, 1, time                 'obtains temperature reading from sensor
    TK = Kal/time*10 + (Kal//time*10/time)      'Calculate Kelvin
RETURN


'Hall sensor
'Checks to see if motor is spinning
'This is checked during operation of motor
'The also ensures that drill motor runs at optimal speed
Get_RPM:
    HIGH 5
    COUNT speedin, 1000, pulses           'hall sensor
    RPM = pulses * 30                 'used 30 as a scaling constant because 2 magnets were
                             ' used to trigger hall sensot ( in attampt to balance drill Bit)
RETURN
```

# Appendix B – Schematics
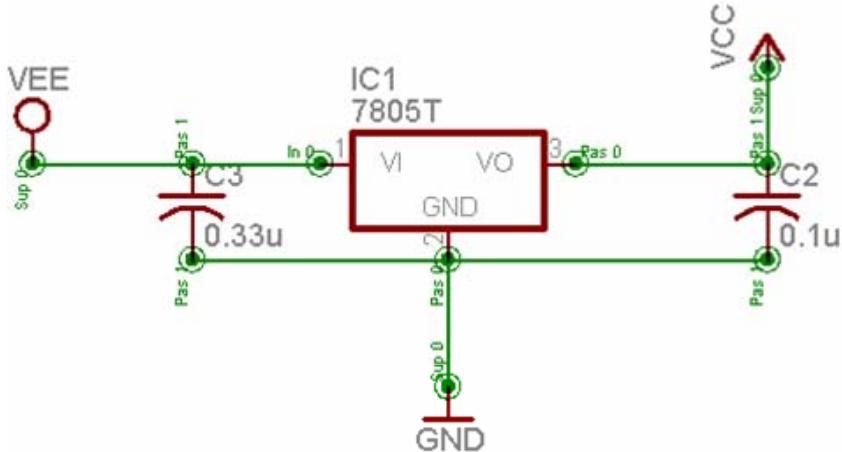
Schematic 1 – Regulator


Schematic 2 – Relay

X13-1 — 1 — Pas 0
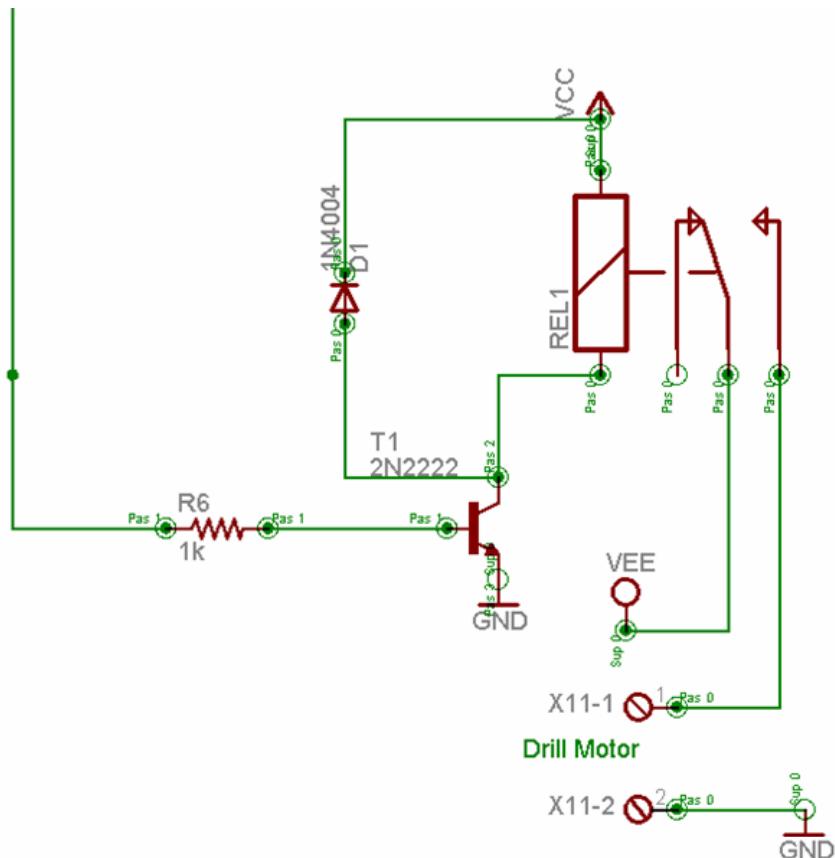
Serial LCD

Schematic 3 – LCD Display (Note: this is just the serial transmission line. Power supply for Serial LCD is (+5 volts and ground) are bussed back.

VCC

Pas 0 — 1 — X12-1

Sup 0 — Pas 0 — 2 — X12-2   Servo

Pas 0 — Sup 0 — 3 — X12-3

GND
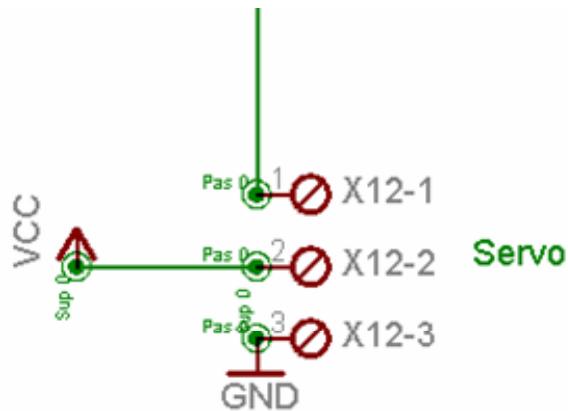
Schematic 4 – Servo motor for stabilizer arms
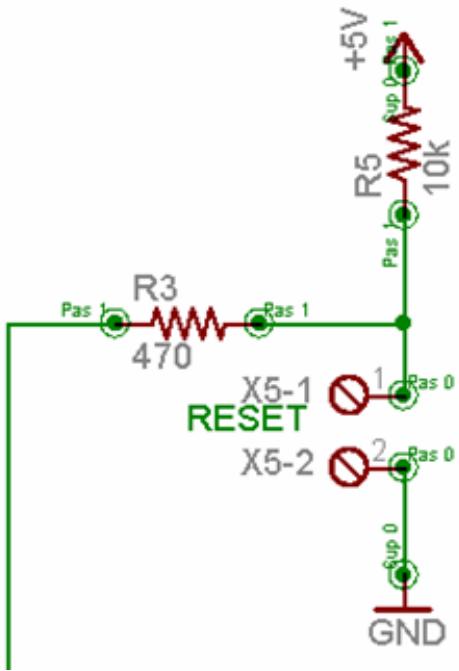
Schematic 5 – Reset function (Note: Performs same function available on Board of Education. Since the Board of education will not be used for Mass production, this was made available)
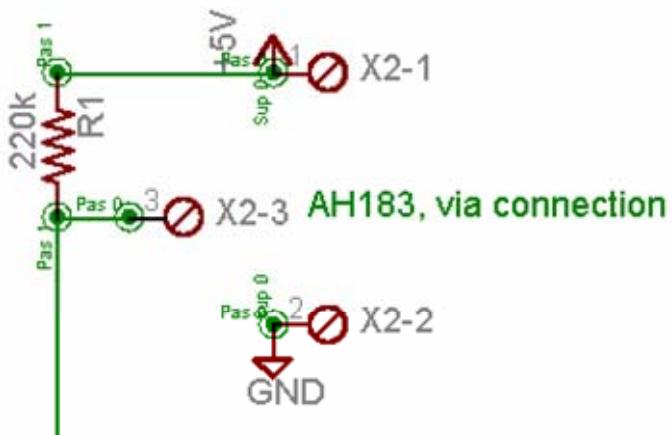

Schematic 6 – Hall Effect switch
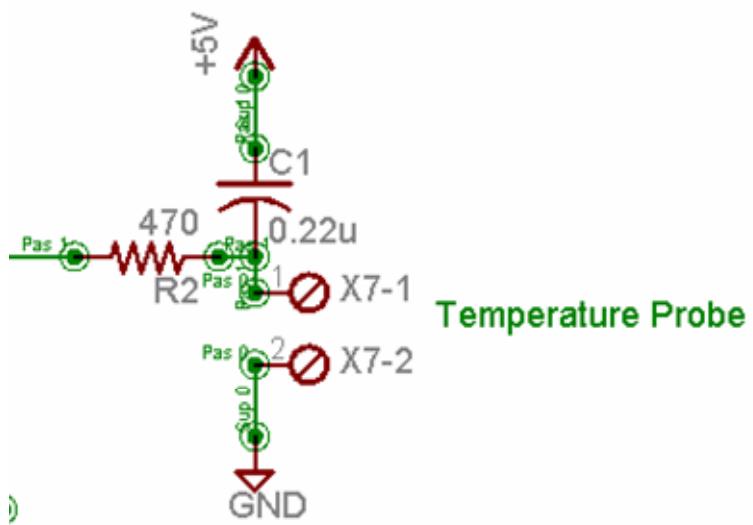
Schematic 7 –Temperature Probe
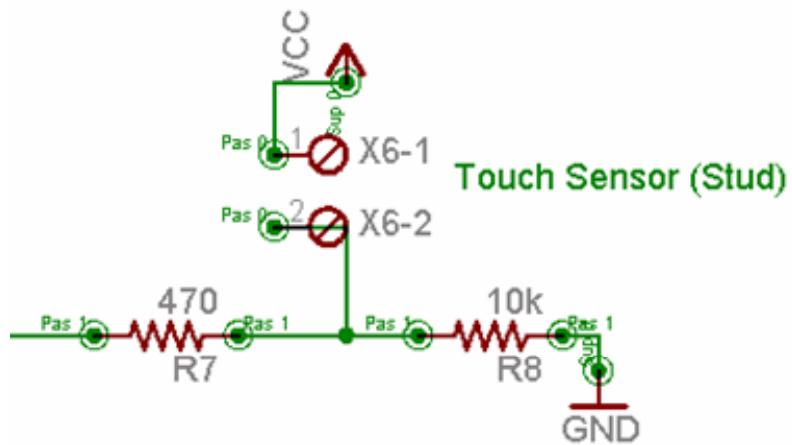
Schematic 8 – Touch Sensor for Stud detection
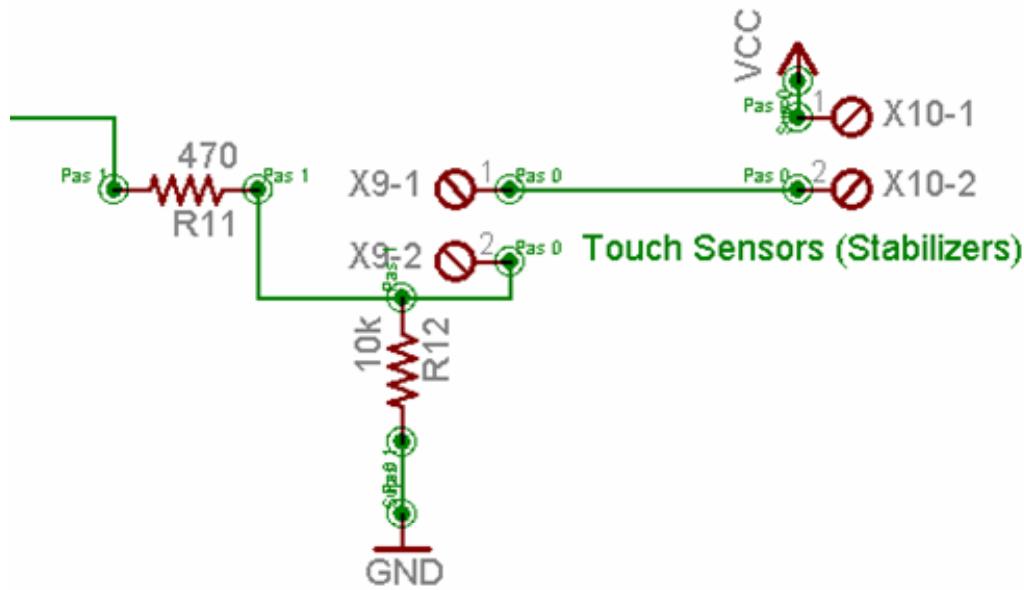
Schematic 9 – Touch Sensor for Stabilizer Arms
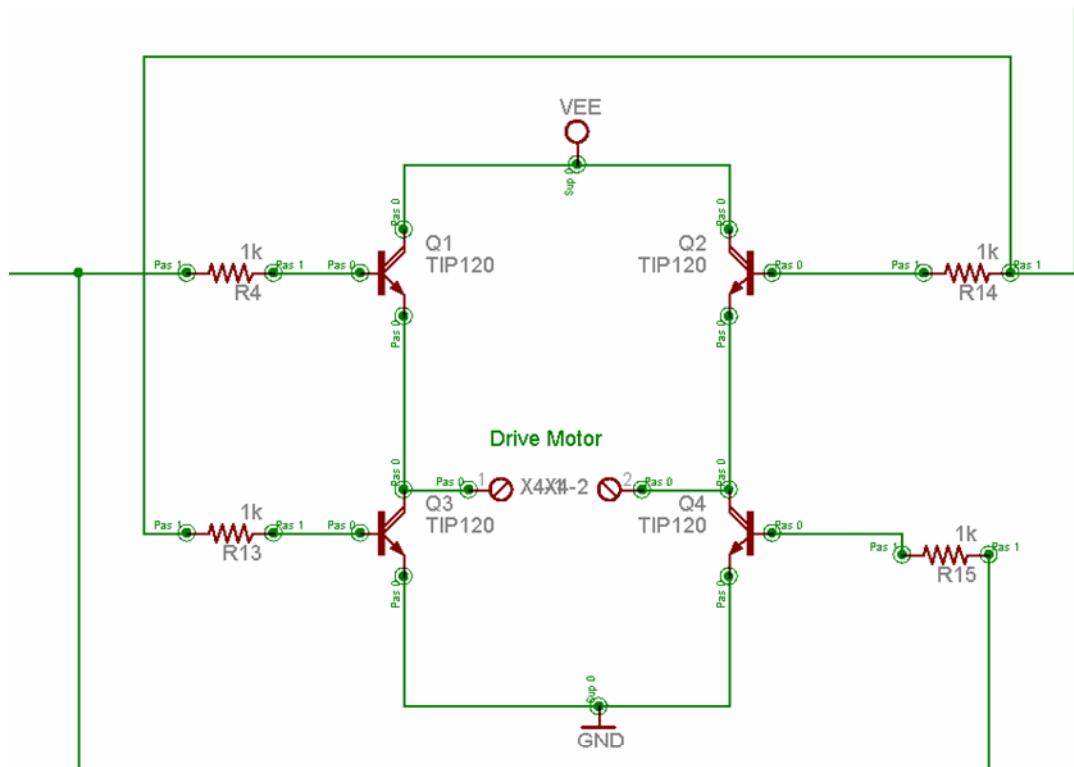
Schematic 10 – H-Bridge Design for Drive Motor (for mass production)
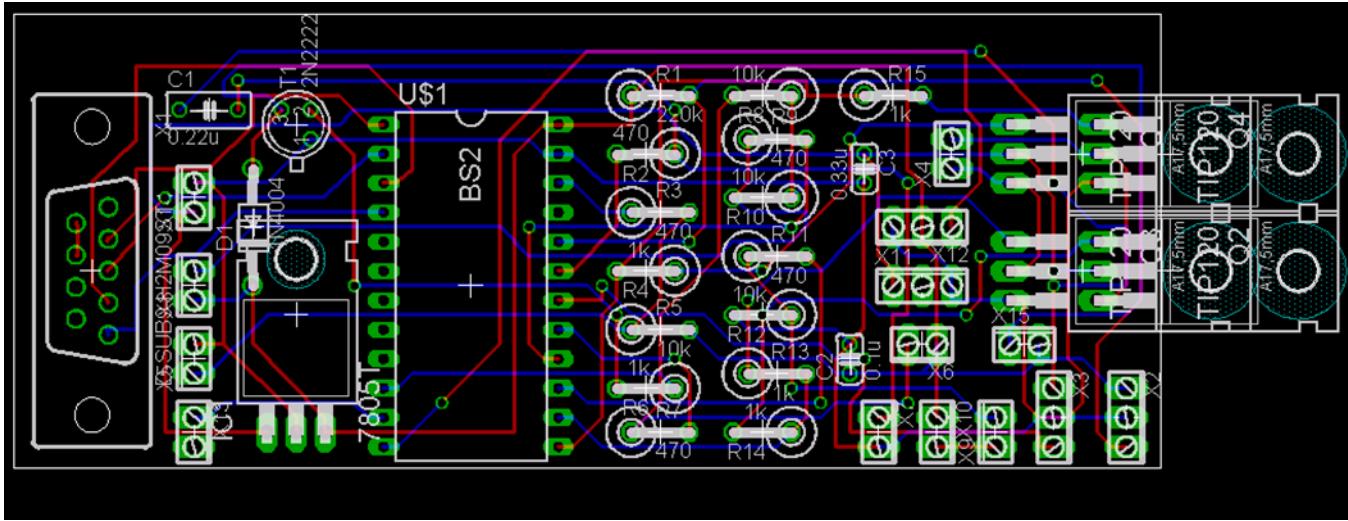
Schematic 11 – Board layout for Mass Production

Actual size of the Board is 10 cm by 4 cm