Automated, Motorized, Chromatic String-Tuning Device

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Abstract

The goal of this project was to design and build a compact and inexpensive device which could automatically analyze the pitch of an instrument's string and adjust the string's tension to achieve a desired frequency of vibration. Many musicians find the process of tuning their instruments difficult and time-consuming—the combination of auditory and physical elements is hard to master for both beginners and advanced players. While existing models of electronic tuners simply display whether a string is sharp or flat compared to a reference frequency, our model also automatically adjusts the mechanical tuners on an instrument using a high-torque motor. Thus, a user does not have to manually tune his or her instrument; rather, our device handles both the aural and mechanical aspects of tuning.

The final prototype of our design consists of a Korg CA-40 chromatic tuner which analyzes the frequency of a vibrating string and sends an output signal of either sharp or flat to a L293D four-channel h-bridge which determines the polarity of power routed to a gearhead motor. This high torque, low rpm motor (7500 g.cm torque, 24 rpm) can be coupled with attachments that mate with various types of instrument tuning heads, including guitar, cello, violin, harp and mandolin. A hand-held unit housing both the gearhead motor and the activation button connects to the main chassis via a CAT-5 cable. The green or "correct" output from the chromatic tuner, which is enabled when the desired frequency of the string is reached, is fed into an Arduino UNO microcontroller. Upon the depression of a user-controlled button, the Arduino begins monitoring the status of the green LED and activates a buzzer when the string reaches a desired frequency. Lastly, a printed circuit board was designed to unify all of the device's processes, including activation of the tuner, operation of the motor, input from the end user, and output in the form of LED's and a buzzer.

We envision that our device could revolutionize the way that people tune their instruments and bring a new level of precise intonation to the music of beginners and professionals alike.

1 Purpose

To design and construct a device which can automatically analyze the pitch of an instrument's string and adjust the string's tension to meet a desired frequency.

2 Introduction

Tuning string instruments, especially those of the orchestral variety, is a difficult and time-consuming task that can be daunting to both beginners and advanced players. Manual tuning involves listening to a target note and adjusting one's own string in the appropriate manner (either by increasing or decreasing tension). Our automated string-tuning device would not only eliminate the listening and analyzing elements of the tuning process (as such a device already exists), it would also automatically adjust the string tension based on examination of the string's harmonic frequency.

3 Engineering Goals

- Compact and handheld
- Inexpensive
- Can analyze string frequency to the nearest Hz and precisely adjust motor
- Detachable motor head for use with multiple types of instruments
- Output various color LED's based on string frequency
- Output signal when string is desired tension

4 Materials and Resources

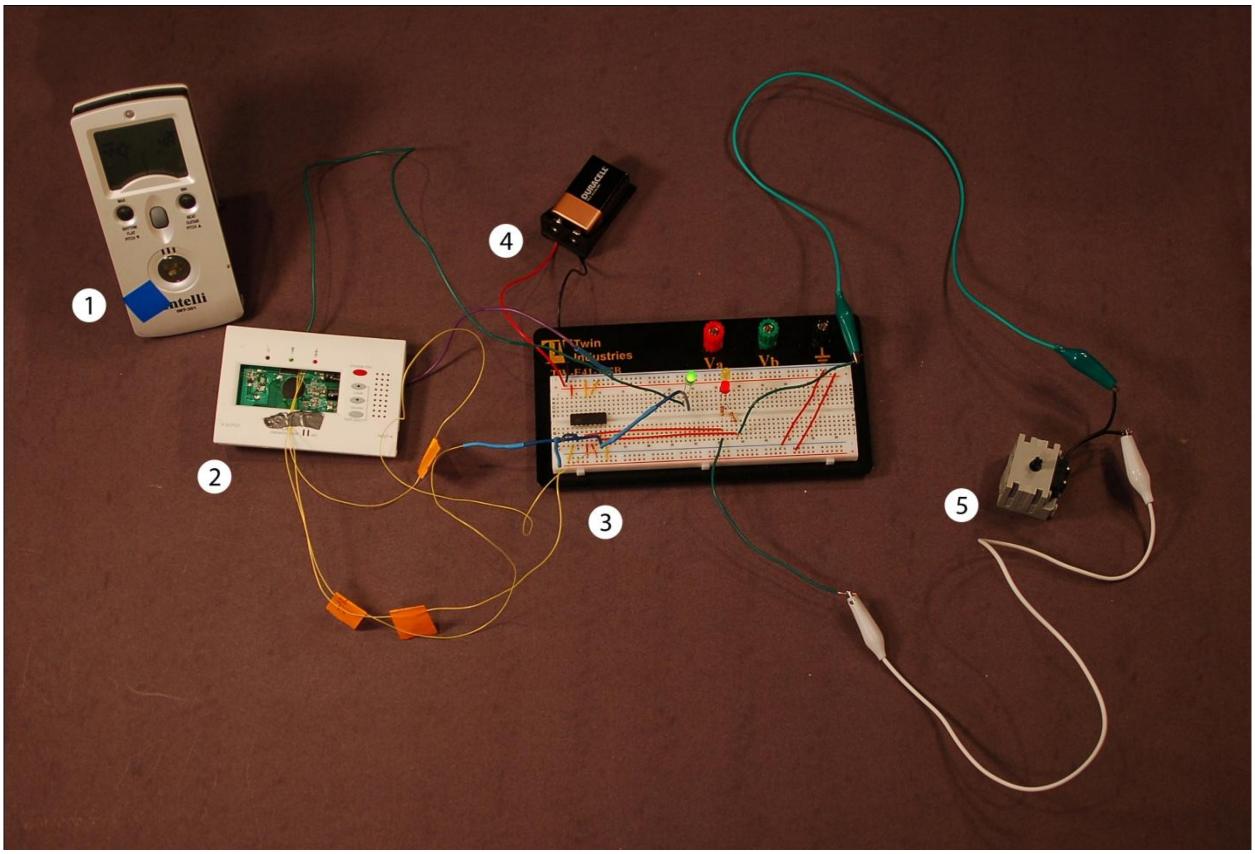
- Solderless breadboard
- Korg CA-40 chromatic tuner
- Planet Waves CT-01 chromatic tuner
- Matrix SR-1050 chromatic tuner
- Intelli IMT-301 tuner/metronome

- Arduino UNO microcontroller
- Arduino software
- 220Ω resistors
- 17KΩ resistors
- 10 uF capacitors
- Digital multimeter
- 9v battery holder
- 6v battery holder
- 3v battery holder
- LEGO Mindstorms 71427 9v motor (250 rpm, 230g.cm)
- 12v, 24rpm, 7500g.cm Jameco Reliapro motor
- 12v, 30rpm, 6400g.cm Jameco Reliapro motor
- L293D half-bridge
- Push-button switch
- Variable-voltage power supply
- Custom-designed printed circuit board
- ON-OFF-ON toggle switch
- Rocker switch
- Soldering iron
- Solder
- Solder-sucker
- Wire strippers
- Stranded and solid core wire of various gauges
- 5v coil voltage relay
- Surface mount toggle switch
- Illuminated surface mount rocker switch
- 3v surface mount LED's with leads
- 5v surface mount LED
- 3v voltage regulator
- ABS plastic enclosure
- 5v buzzer
- ¼" surface mount 3-contact jack
- Ethernet male/female jack
- PVC pipe and caps
- Hot glue gun and hot glue
- Guitar tuner-head
- Machine screws/bolts
- Helping hands
- Alligator clips
- AA batteries
- 9v batteries
- Jeweler's screwdrivers
- Drill press
- Band saw
- Vice
- Pliers
- Eagle PCB
- Viewplot
- Autodesk 3ds Max
- Services of Advanced Circuits for PCB fabrication

5 Prototypes

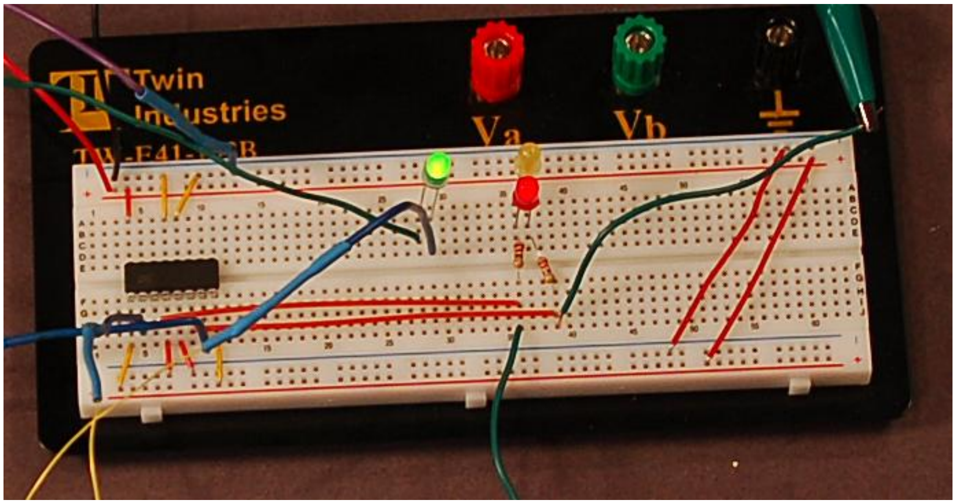
We began by constructing a test rig to simulate the properties of a cello so that we could test our prototypes without the risk of damaging a real instrument. Pictures to come…

First Prototype



1. Intelli IMT-301 tuner/metronome used to generate a specific pitch for testing purposes.
2. Korg CA-40 chromatic tuner with wires soldered to LED leads and positive/negative terminals of the battery. There are 2 AAA batteries inside of the tuner providing power.

3. Breadboard closeup:



L293D chip on solderless breadboard. Sharp and flat outputs are wired into pin 2 and pin 7 respectively on the chip. The motor (5) is connected to pins 3 and 6. Pin 4, 5, 12 and 13 ground the chip to the 9v battery (4) which is connected to both power rails. Pin 9 provides voltage to power the logic of the chip while pin 8 provides voltage to power the motor. Thus, while the LED inputs are only ~3.3v, the motor is powered by a 9v battery. In addition to driving the motor, pins 3 and 6 also output to LED's through 220Ω resistors. Finally, the green LED's high side is connected to the positive end of the battery while its low side is connected to the green output of the Korg CA-40. (This is due to the circuitry of the tuner. In the tuner, one side of the LED is constantly connected to 3v while the microcontroller determines whether the opposite side is 3v or 0v. Therefore, the LED is "on" when the microcontroller sends 0v while "off" when it sends 3v)

4. 9v battery
5. LEGO Mindstorms 71427 9v motor (250 rpm, 230g.cm)

Pros:

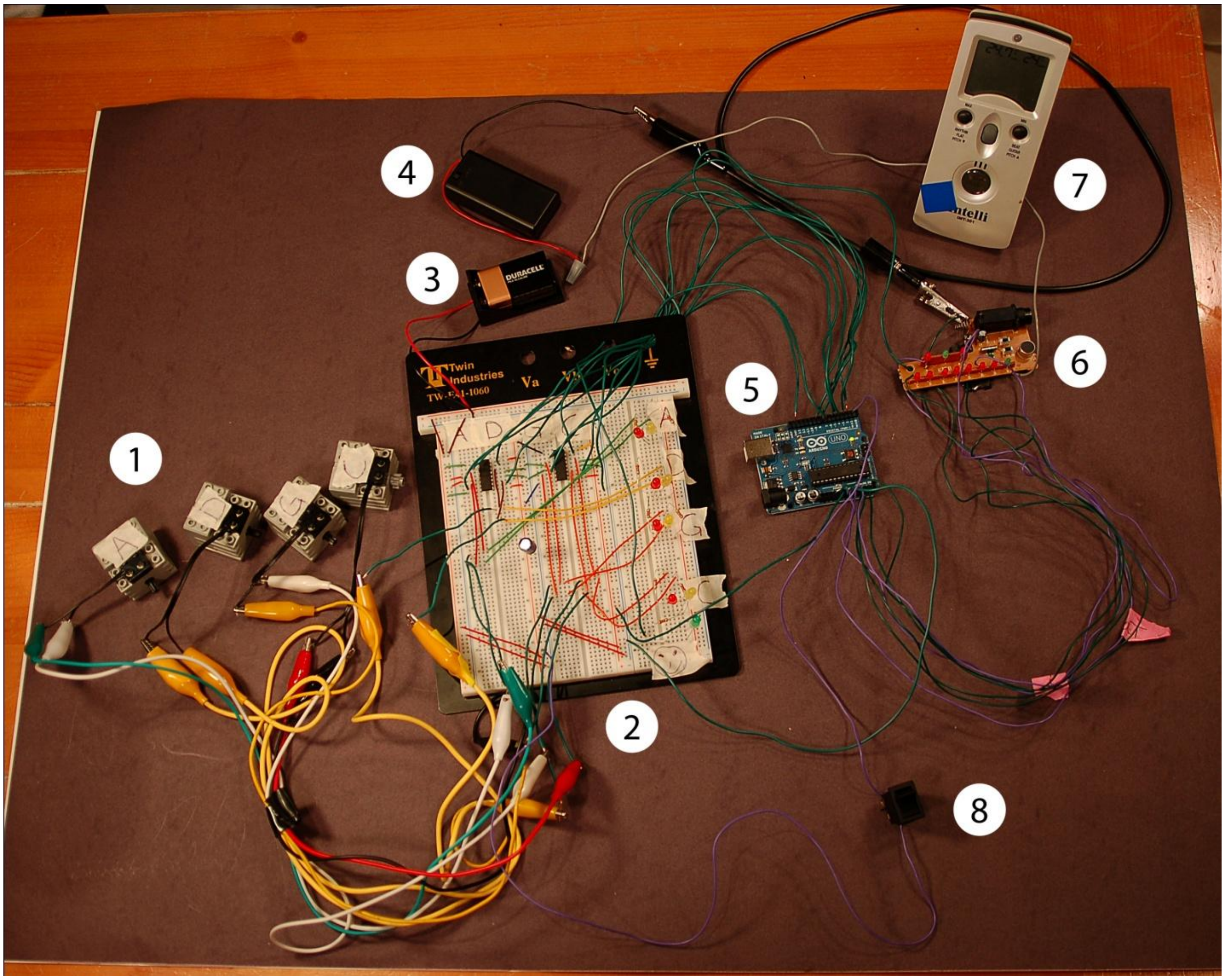
- Simple operation
- Accurate
- Simple circuitry

Cons:

- Low torque motor
- No on/off switches

– No confirmation of tuning completion
– Two different voltage requirements (3v for chromatic tuner, 9v for motor)
– Can only tune one string at a time
– If string is more than one half-step off correct pitch, device will tune to wrong note

Second Prototype



1. 4x LEGO Mindstorms 71427 9v motors (250 rpm, 230g.cm) Each motor responds to a different note. (In the picture, the system is configured for a cello with A, D, G, and C motors respectively)
2. Solderless breadboard with twin L293D four-channel h-bridges. Takes output from Arduino to drive specific motor as determined by Arduino. Also takes Arduino to activate various LED’s on right side of breadboard.
3. 9v battery which powers motors and Arduino

4. 3v battery (2xAA) which powers Matrix SR-1050 chromatic tuner (6).
5. Arduino which takes outputs from Matrix SR-1050 chromatic tuner to first determine which motor to turn and then create a high/low signal to power the motor based on desired frequency. (see program `Multiple_Tuner_v3` for full code)
6. Matrix SR-1050 chromatic tuner with wire leads.
7. Intelli IMT-301 tuner/metronome used to generate a specific pitch for testing purposes.
8. Rocker switch used to control power to entire system.

Pros:

- Able to control multiple strings
- Provides potential for a device that could tune instrument without any human control
- Sharp/flat indicators for each string
- On/off switch

Cons:

- Low torque motor
- No confirmation of tuning completion
- Two different voltage requirements (3v for chromatic tuner, 9v for motor)
- Extremely bulky
- Would be difficult to implement in an inexpensive and compact manner
- If string is more than one half-step off correct pitch, device will tune to wrong note

```
/*

Program Multiple_Tuner_v3

Program reads input from LED's connected
to analog A0 - A6 and produces a motor signal to
four different motors. Output is in the form of alternate
high/low signals to be analyzed by h-bridge

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  December 15, 2010

*/

//digital output pins; two wires are used for each motor
//so that high-low signal can turn motor one way while
//low-high signal turns motor opposite way
const int buttonPin = 1;
```
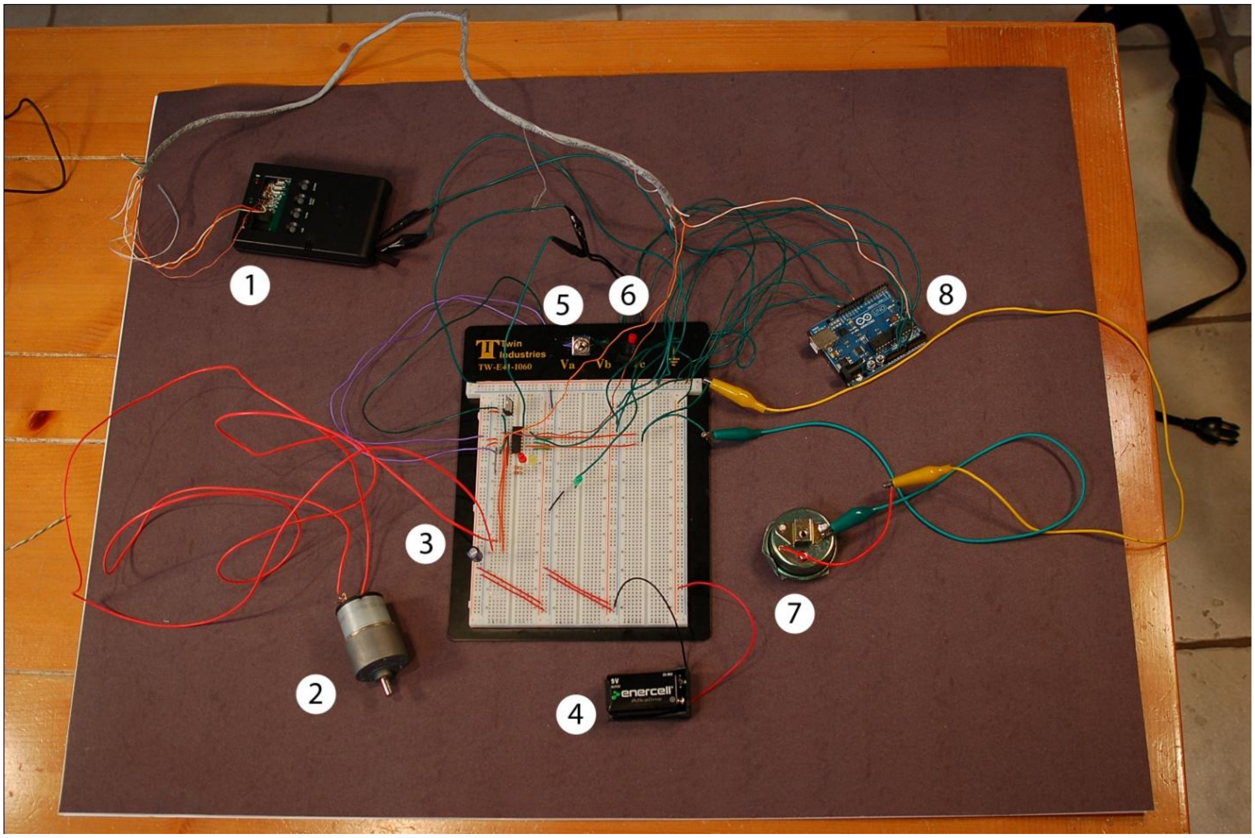

```
const int THRESHOLD = 300;

const int motor_A1 = 2;
const int motor_A2 = 3;

const int motor_D1 = 4;
const int motor_D2 = 5;

const int motor_G1 = 6;
const int motor_G2 = 7;

const int motor_C1 = 8;
const int motor_C2 = 9;

//initialize variable (calculated based on analog inputs)
int sharp = 0;
int flat = 0;
int string_A = 0;
int string_D = 0;
int string_G = 0;
int string_C = 0;
int buttonState = 0;

//function designed to output information to
//serial for debugging purposes
void printInfo(){
  Serial.print("Sharp: ");
  Serial.print(sharp);
  Serial.print("    Flat: ");
  Serial.println(flat, DEC);
  Serial.print("A: ");
  Serial.print(string_A);
  Serial.print("  D: ");
  Serial.print(string_D);
  Serial.print("  G: ");
  Serial.print(string_G);
  Serial.print("  C: ");
  Serial.println(string_C, DEC);

  return; //return to main loop
}

//reset all motors to default low state
void resetMotors(){
  digitalWrite(motor_A1, LOW);
  digitalWrite(motor_A2, LOW);
  digitalWrite(motor_D1, LOW);
  digitalWrite(motor_D2, LOW);
  digitalWrite(motor_G1, LOW);
  digitalWrite(motor_G2, LOW);
  digitalWrite(motor_C1, LOW);
  digitalWrite(motor_C2, LOW);
```

```
 return; //return to main loop
}

void setup() {
  Serial.begin(9600); //begin interface with serial
  pinMode(buttonPin, INPUT); //initialize inputs and outputs
  pinMode(motor_A1, OUTPUT);
  pinMode(motor_D1, OUTPUT);
  pinMode(motor_G1, OUTPUT);
  pinMode(motor_C1, OUTPUT);
  pinMode(motor_A2, OUTPUT);
  pinMode(motor_D2, OUTPUT);
  pinMode(motor_G2, OUTPUT);
  pinMode(motor_C2, OUTPUT);
}

void loop() {
  //get analog inputs
  sharp = analogRead(A0);
  flat = analogRead(A1);
  string_A = analogRead(A2);
  string_D = analogRead(A3);
  string_G = analogRead(A4);
  string_C = analogRead(A5);

  buttonState = 0; //reset buttonState (if button was enabled on
previous loop, this rechecks whether button is activated)
  buttonState = digitalRead(buttonPin);

  printInfo();

  if(buttonState == 0)
  {
    if(string_A > THRESHOLD) //if the A LED is ON
     {
       if(flat > 0) //if the string is flat
        {
          digitalWrite(motor_A1, HIGH);
          digitalWrite(motor_A2, LOW);
          goto newLoop;

        }
        if(sharp > 0) //if the string is sharp
        {
          digitalWrite(motor_A1, LOW);
          digitalWrite(motor_A2, HIGH);
          goto newLoop;
        }
     }

     if(string_D > THRESHOLD) //if the D LED is ON
```

```
    {
      if(flat > sharp) //if the string is flat
       {
         digitalWrite(motor_D1, HIGH);
         digitalWrite(motor_D2, LOW);
         goto newLoop;
       }
       else //if the string is sharp
       {
         digitalWrite(motor_D1, LOW);
         digitalWrite(motor_D2, HIGH);
         goto newLoop;
       }
    }

    if(string_G > THRESHOLD) //if the G LED is ON
    {
      if(flat > sharp) //if the string is flat
       {
         digitalWrite(motor_G1, HIGH);
         digitalWrite(motor_G2, LOW);
         goto newLoop;
       }
       else //if the string is sharp
       {
         digitalWrite(motor_G1, LOW);
         digitalWrite(motor_G2, HIGH);
         goto newLoop;
       }
    }

    if(string_C > THRESHOLD) //if the C LED is ON
    {
      if(flat > sharp) //if the string is flat
       {
         digitalWrite(motor_C1, HIGH);
         digitalWrite(motor_C2, LOW);
         goto newLoop;
       }
       else //if the string is sharp
       {
         digitalWrite(motor_C1, LOW);
         digitalWrite(motor_C2, HIGH);
         goto newLoop;
       }
    }
 }
  newLoop:
    delay(100); //let motor operate for 100 ms
    resetMotors(); //reset all motors back to default states
}
```

Third Prototype



1. Planet Waves CT-01 chromatic tuner with soldered leads
2. 12v, 24rpm, 7500g.cm Jameco Reliapro motor
3. Solderless breadboard with L293D four-channel h-bridge. Takes output from Planet Waves chromatic tuner to operate motor. Also has circuitry which can adjust voltage based on toggle switch (5).
4. 9v battery which powers motors and Arduino.
5. Two-sided, three state, ON-OFF-ON toggle switch which controls both master power and voltage fed to motor (9v in one position, 6v in other).
6. Pushbutton spanning pin 9 (logic supply) of L293D and 9v battery. When depressed, motor is able to turn.
7. Buzzer which is activated when green light has been on for set amount of time.
8. Arduino UNO microcontroller which controls buzzer based off of green output from Planet Waves chromatic tuner. We used program `Green_Test_v1` to understand the type of

output the tuner was sending and implemented `Buzzer_Operator_v2` which constantly monitors the green LED until it has counted a certain number of instances of the LED in an activated state.

Pros:

- High torque motor able to turn all string instrument tuners
- Confirmation of tuning completion
- Relatively simple circuitry
- LED lights to indicate sharp/flat/correct
- Requires only one power source (9v battery)
- Pushbutton to activate motor
- Variable speed
- Master power switch

Cons:

- Breadboard is not ideal for final implementation
- Can only tune one string at a time
- If string is more than one half-step off correct pitch, device will tune to wrong note

```
/*
Program Green_Test_v1

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December 17, 2010

Program displays green light input value to serial
*/

void setup() {
  Serial.begin(9600);
}

void loop() {
  int greenVal = analogRead(A0);

  Serial.print("Green: ");
  Serial.println(greenVal);
}
```
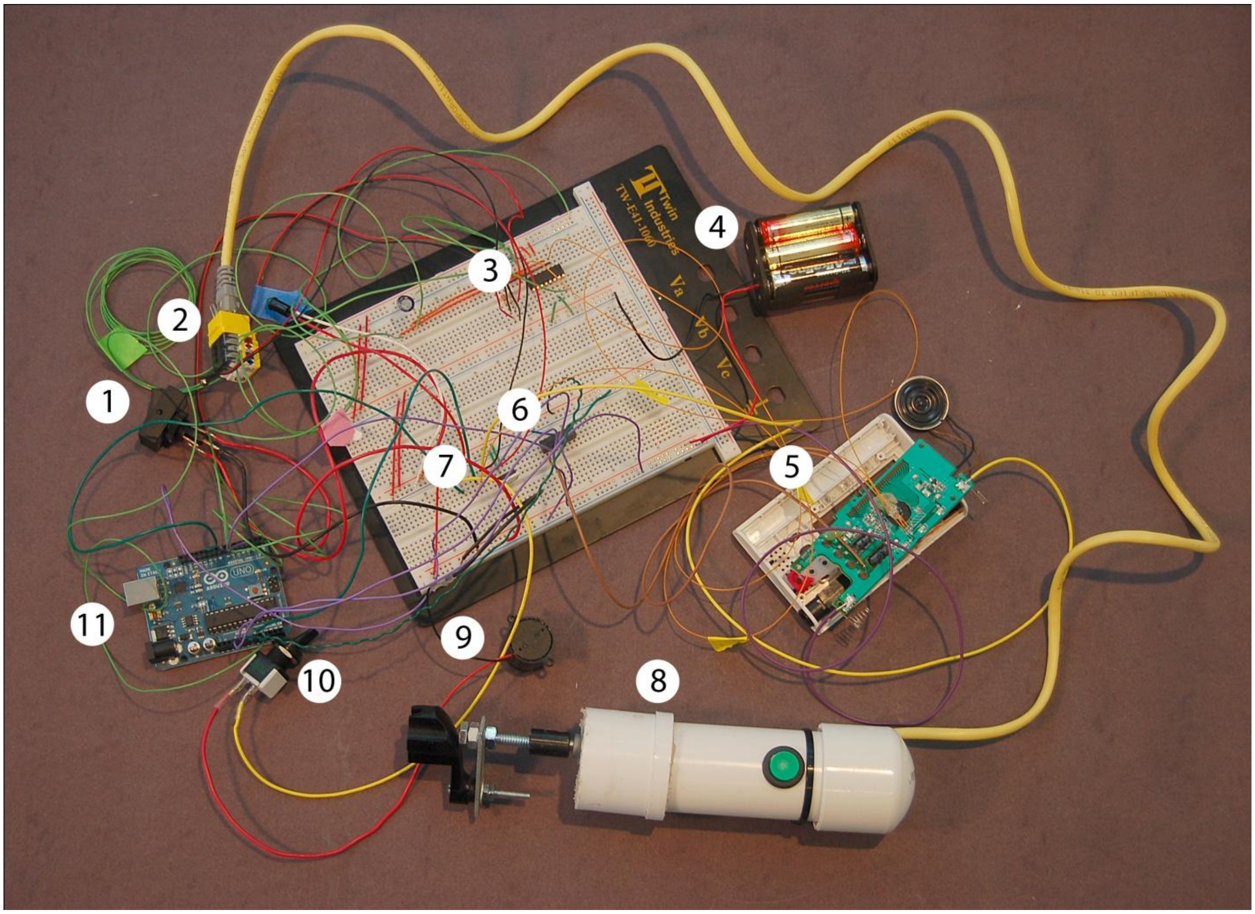

```
/*
Program Buzzer_Operator_v2

Creators:
Matthew Arbesfeld
Benjamin Edelstein

December 17, 2010

Program increases counter if green is enabled and waits for counter to
reach threshold before producing buzzer signal
*/

const int BUZZER = 10;
const int BUZZER_TIME = 1000;
const int THREHOLD = 100;

int counter = 0;
void setup() {
  Serial.begin(9600);
  pinMode(BUZZER, OUTPUT);
}

void loop() {
  int greenVal = analogRead(A0);

   Serial.print("CURRENTLY GREEN... V: ");
   Serial.print(greenVal);
   Serial.print("  counter: ");
   Serial.println(counter);

  if(greenVal < 250)// < 250 is the value at which green LED is ON
  {
    counter++;
  }

  if(counter > THRESHOLD)
  {
    digitalWrite(BUZZER, HIGH);
    delay(BUZZER_TIME);
    digitalWrite(BUZZER, LOW);
    delay(3000);
    counter = 0;
  }
}
```

Fourth Prototype



1. Illuminated rocker switch for master power
2. Ethernet jack to connect with hand-held device (8).
3. L293D controls polarity of motor current.
4. 9v (6x AA) battery holder
5. Korg CA-40 chromatic tuner
6. Relay which is controlled by Arduino to activate Korg tuner.
7. 3v voltage regulator to power Korg tuner.
8. Hand-held motor unit with activation button.
9. 5v buzzer which emits audible beep when tuning is complete
10. Toggle switch which controls buzzer ON/OFF status
11. Arduino UNO

Pros:

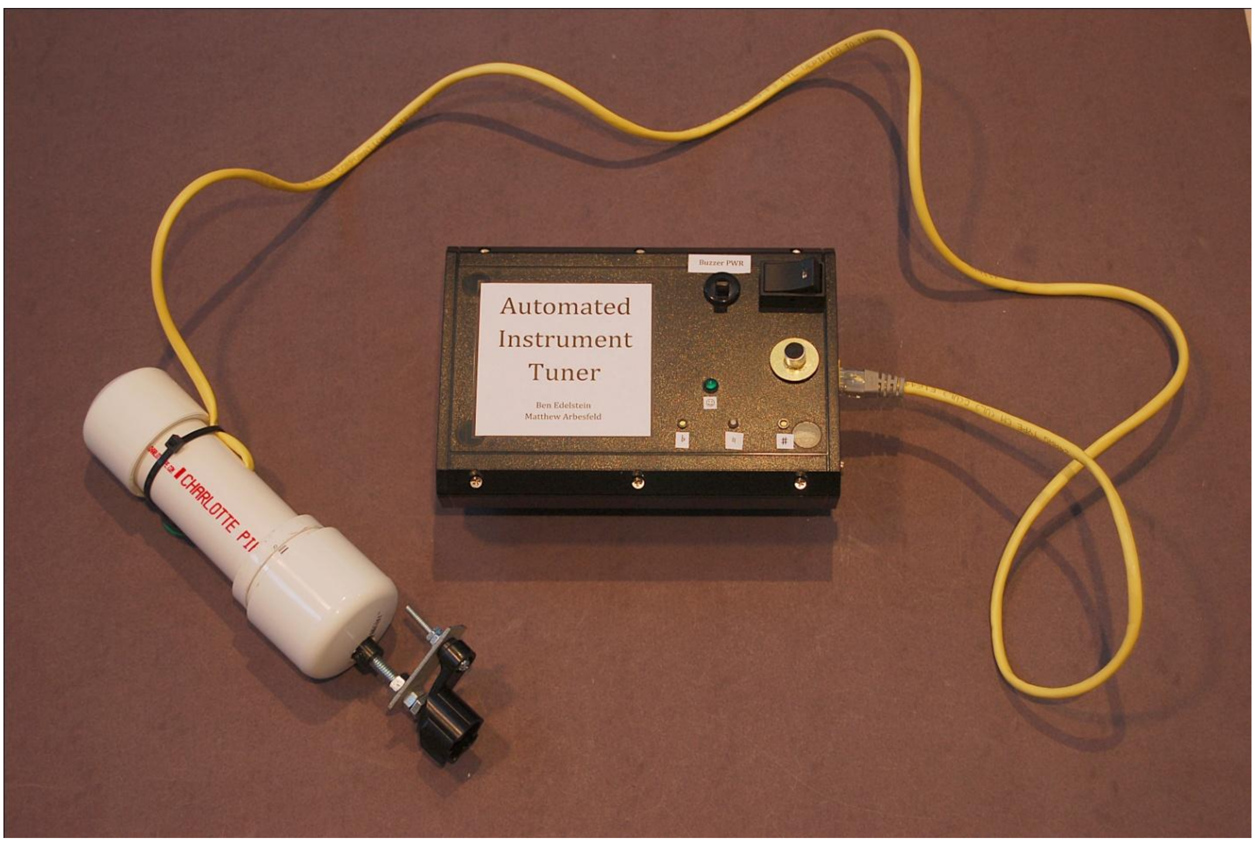
- High torque motor able to turn all string instrument tuners
- Confirmation of tuning completion

- LED lights to indicate sharp/flat/correct
- Requires only one power source (9v battery)
- Pushbutton to activate motor
- Master power switch
- Hand-held control unit with modular connection
- Buzzer ON/OFF switch
- Relay to activate Korg tuner

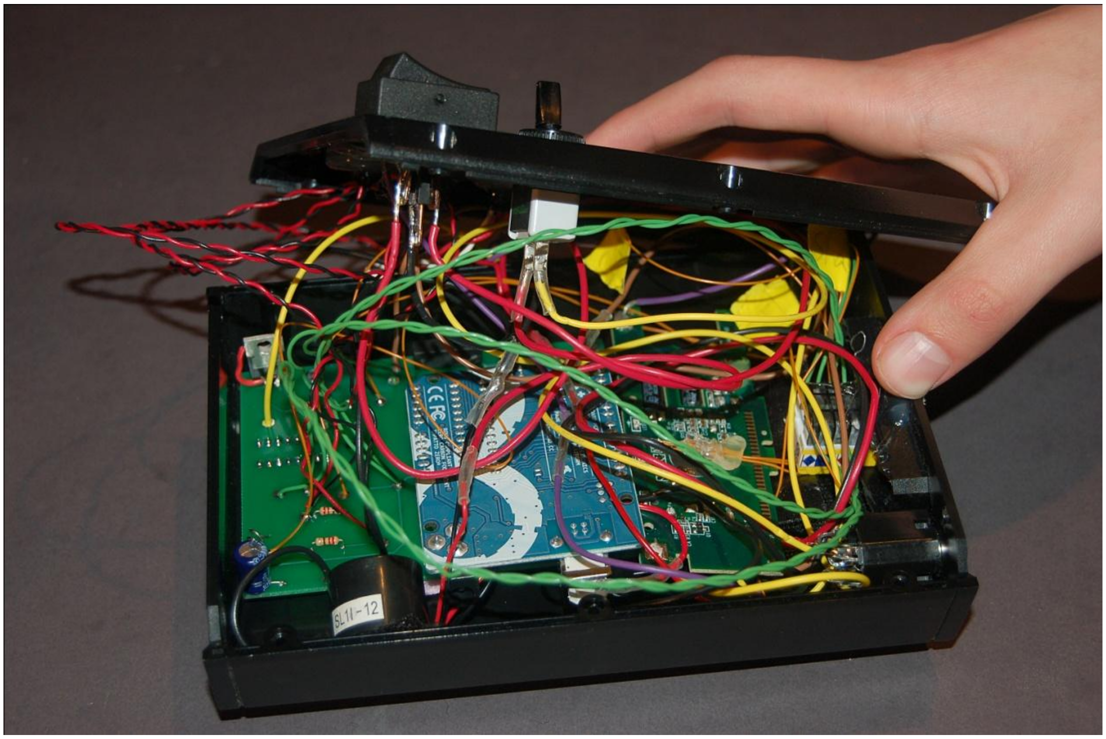
Cons:

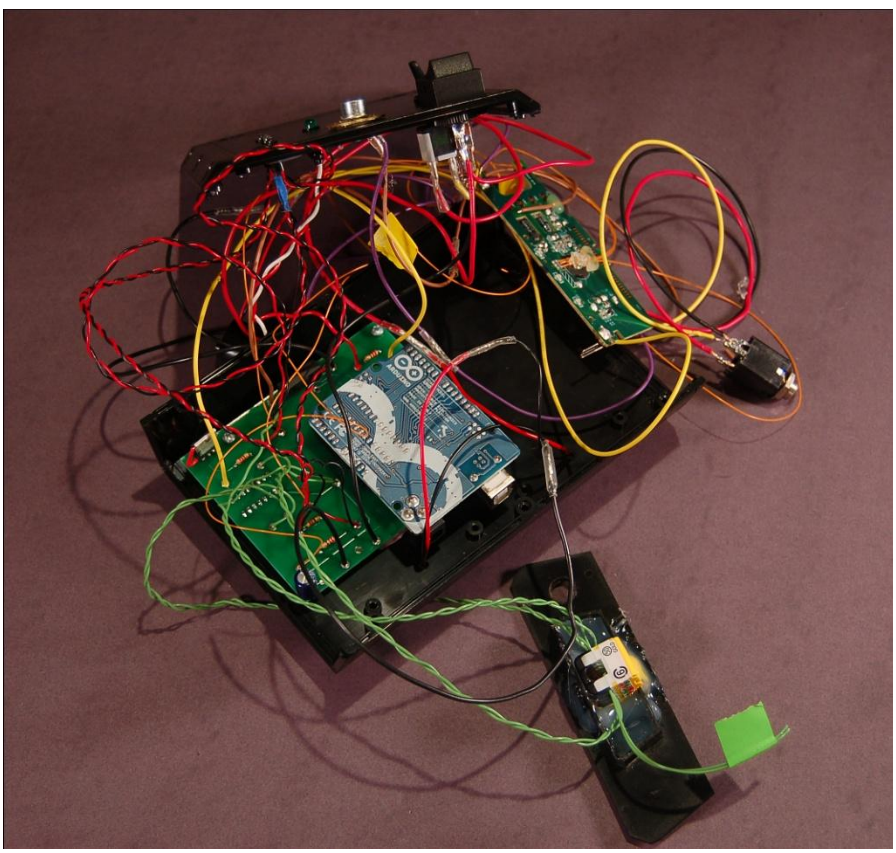
- Breadboard is not ideal for final implementation
- Can only tune one string at a time
- If string is more than one half-step off correct pitch, device will tune to wrong note

Final Prototype

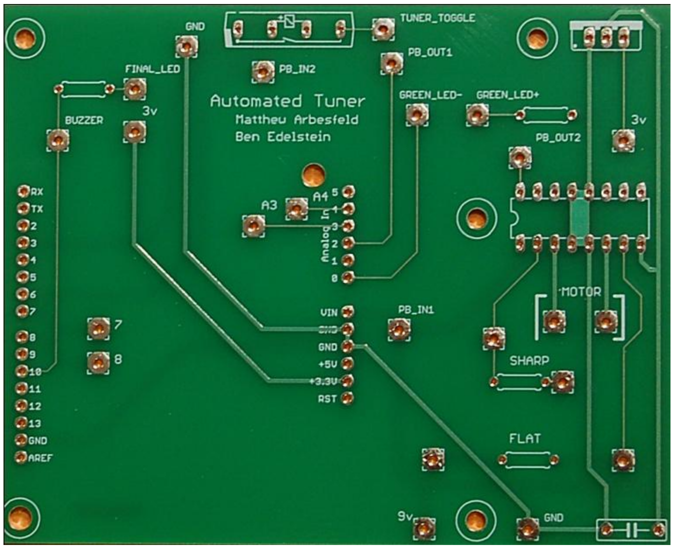


Finished box with hand-held extension

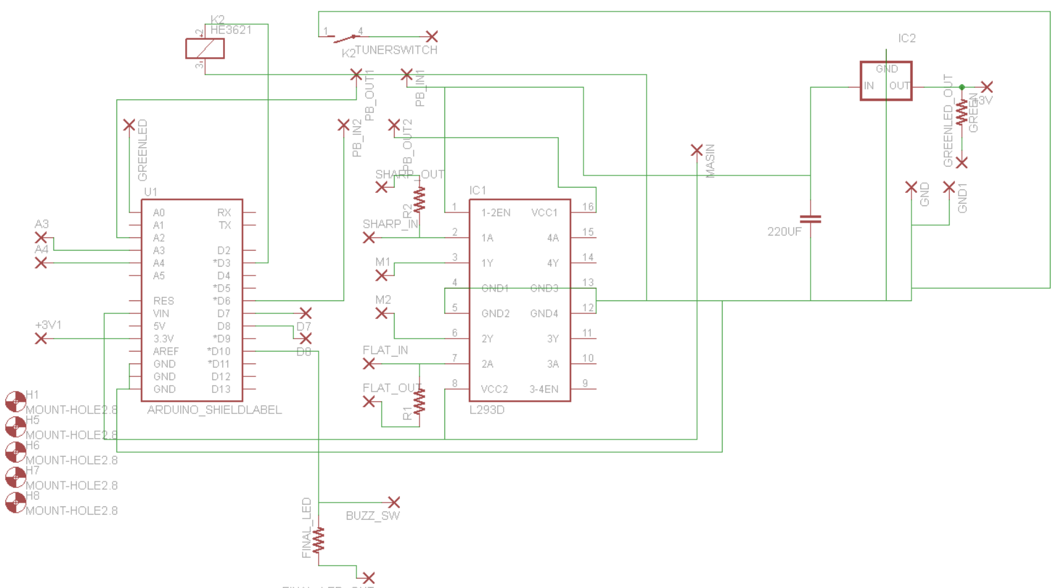




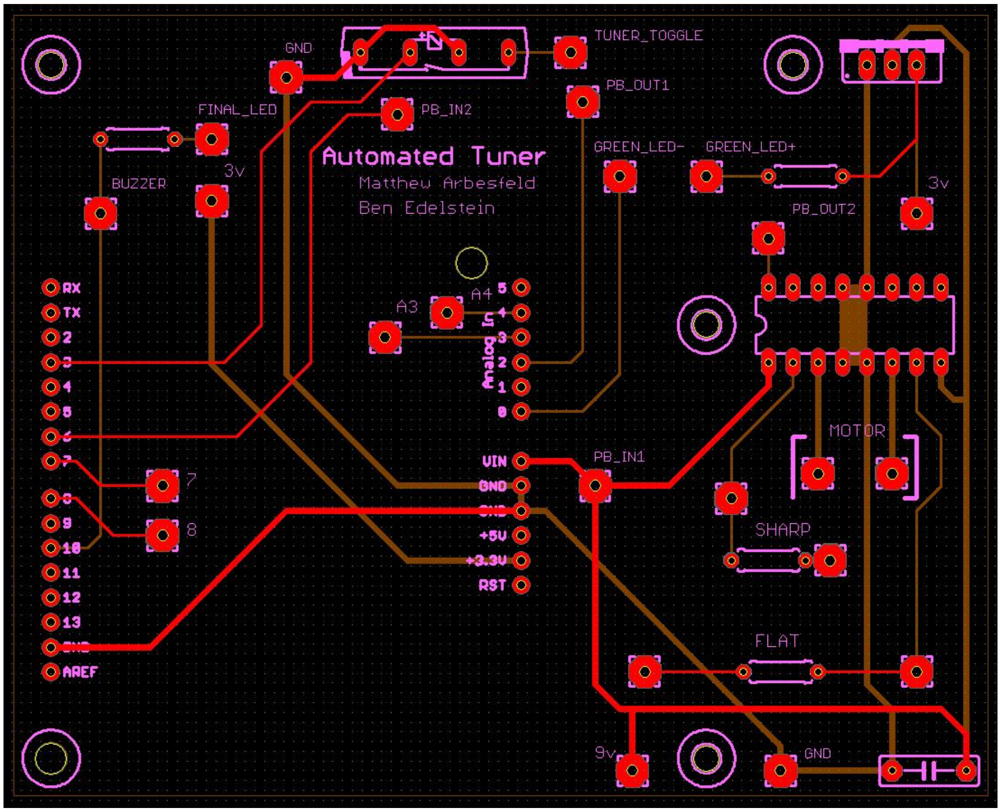
Immediately prior to sealing of the box



The PCB was designed in accordance with the fourth prototype using Eagle PCB software and Viewplot was used to produce the images. The design was sent to Advanced Circuits for fabrication.

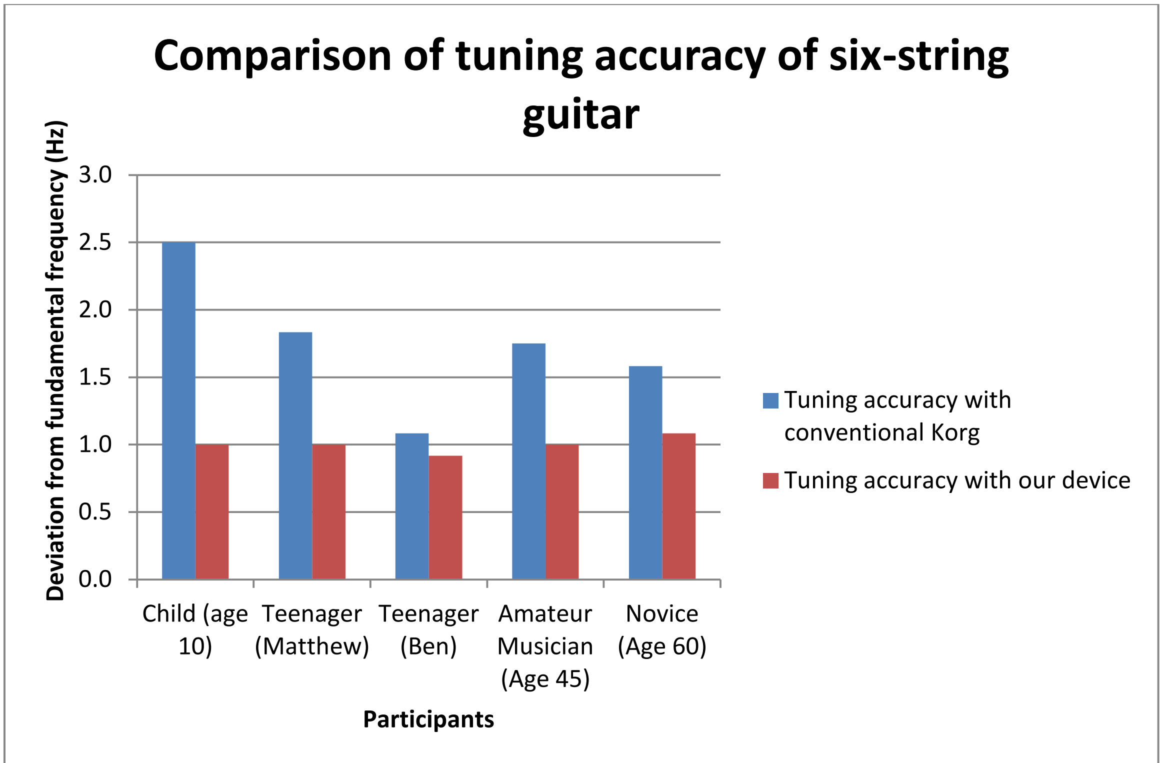


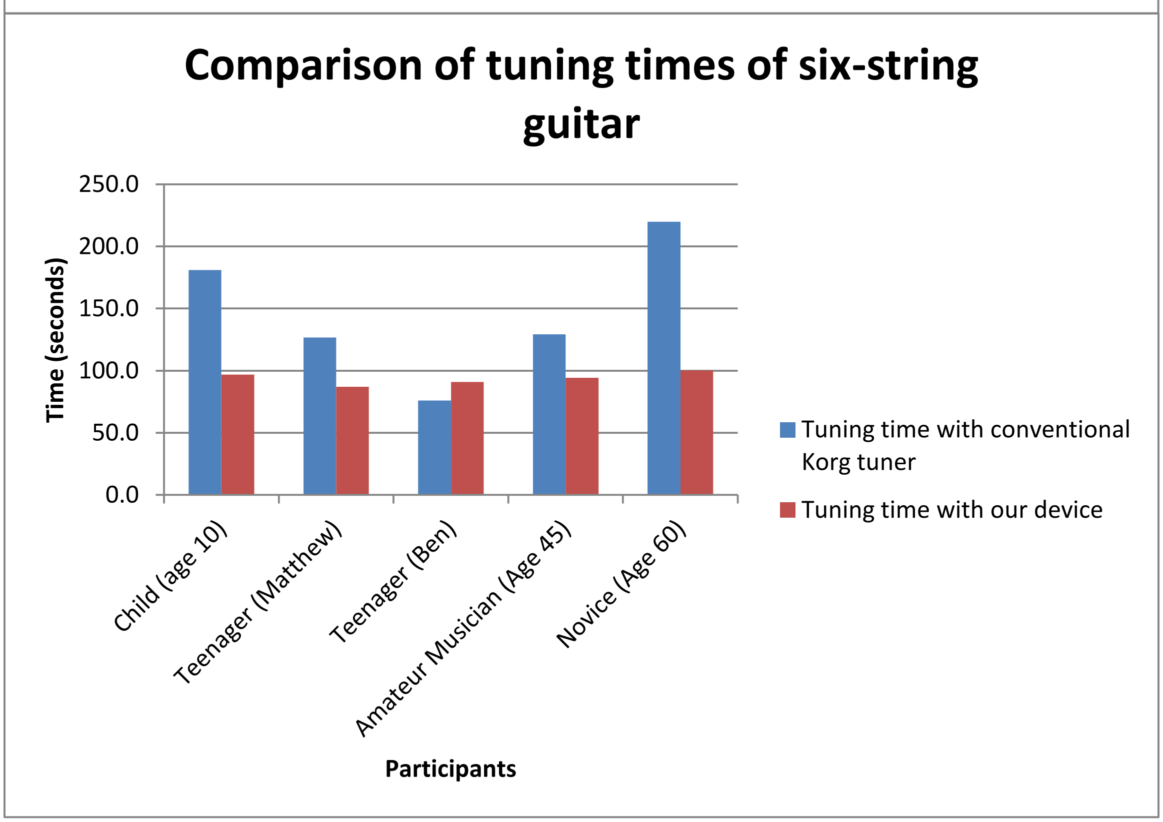
Schematic view of PCB



Board view of PCB. Pink text is top silkscreen.

6 Data





See data table for values from all 6 trials.

7 Data Analysis

- For time trial, data was collected by measuring total length of time to tune all six strings from start to completion.
- For accuracy analysis, an Intelli IMT-301 was used to measure the deviation of the note from a reference pitch derived from an A at 440hz. Instead of measuring this value for all six strings, two strings were chosen at random for each trial.
- It should be noted that this is by no means a 100% accurate metric of the device's real-world performance. The small sample size and other environmental factors certainly may have influenced the result of this study. However, one can ascertain certain trends through this data.
- All participants were in the immediate family of the conductors.

Points of interest:

- The child had the largest time difference between the conventional tuning and tuning with the device (83.4 seconds).
- The most experienced string player (Ben) was slightly faster when using the conventional tuning method over tuning with the device (14.9 seconds).
- All two amateur musicians experienced similar time differences between conventional tuning and tuning with the device (39.6 and 35.4 seconds, respectively).
- Accuracy of all players was nearly proportional to their tuning time (ie. fastest tuner = most accurate tuner).
- All players had nearly the same accuracy with the device.

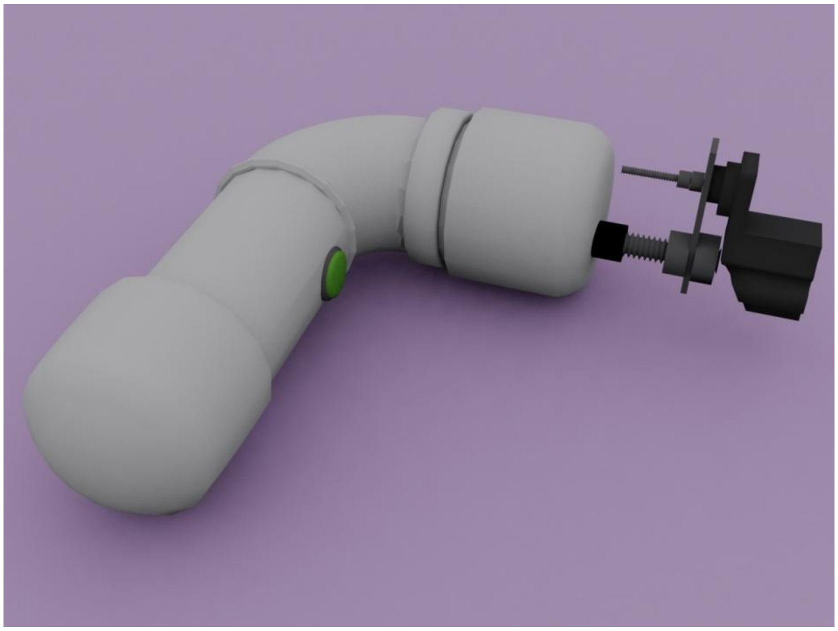
8 Cost Analysis

We estimate the following would be the costs of producing the device on a large scale:

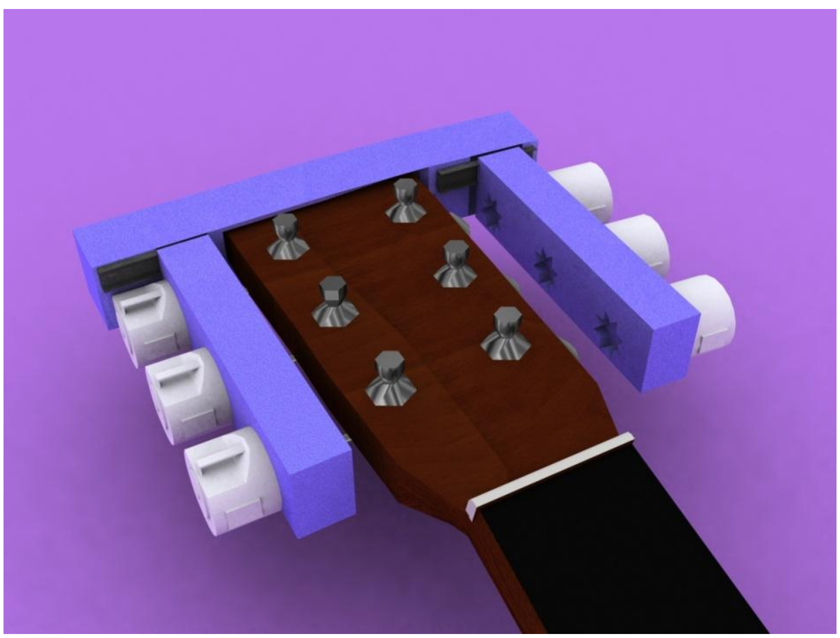
- Circuit board and microcontroller: $15 (includes logic and motor controller as well as other basic circuit components)
- Motor: $20
- Housing and chassis materials: $5
- Input and output devices (switches, LED's, buzzers, LCD screen): $5

Total estimated cost: $45

9 Future Implementations



L-shaped design of motor housing for improved ergonomics



This envisioned prototype represents the implementation of the technology seen in prototype 2. A user would place it over the top of their guitar's headstock and motor arms would slide on tracks and fit snugly over tuning pegs. A vibration sensor in the cap would serve as a pick-up for analyzing the string's pitch.

10 Conclusion

We successfully constructed a working prototype of our device which allows a user to tune any type of string instrument with ease and accuracy. The entire device, if produced on a large scale, is estimated to cost around 45 dollars, which puts it well within the reach of an average consumer.

In our limited trials, we observed that amateur and experienced players alike both benefitted from the device's capabilities. Specifically, amateurs saw a consistent reduction in the time needed to tune a six-string guitar. Furthermore, the device improved the tuning accuracy of all participants.

The technology in this device can be extended to all instruments, not just those with strings. For example, future versions could potentially tune woodwind, brass and percussion instruments. Furthermore, section 9 (see previous page) describes potential extensions of our technology to help streamline the tuning process.

In implementing our final prototype, we successfully fulfilled all of our engineering goals.

11 Acknowledgements

We would like to thank our chemistry teacher, Dr. Kumar, and our advisor, Ed Moriarty for their council. Also, we would like to thank our parents for funding our project and for providing tools and a space in which to build it.

12 Works Cited

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