uTune: An Automated Guitar Tuning Solution

EE41430 Senior Design: High Level Design

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1. Introduction

Stringed instruments have long been utilized to create music by manipulating the properties of the strings to control pitch. These instruments range from lyres and guitars to violins and pianos, and they incorporate a number of different elements in order to control pitch and thus create music. Three key factors that affect pitch are string length, linear mass density, and tension. While linear mass density remains constant in a particular guitar string and the length is used to change pitch while playing, the tension in the string changes the pitch of the open string and thus changes the reference point for all fretted notes.

Many different guitar tuning systems have been developed throughout the course of history. Standard tuning is known as EADGBE from low string to high string, and this is the common tuning used in many mainstream guitar songs of all genres. However, this is not the best tuning system for other playing styles, like fingerstyle, and many particular songs use unique tunings. General and song-specific tunings such as DADGBE (known as "drop D"), DADGAD for fingerstyle, D#G#C#F#A#D# or DGCFAD for a half or full step down, CGDGBD for Constellations by Jack Johnson, C#A#D#G#A#D# for Barcelona by Ed Sheeran, EABGBD# for Yellow by Coldplay, DADF#AD for The Cave by Mumford and Sons, EBEF#BE for In Your Atmosphere by John Mayer, and many others are prominent in the music world and required in a guitarist's repertoire today.

2. Problem Statement and Proposed Solution

In order to incorporate these various tunings into playing and performance, a guitarist must allocate significant effort to the tuning process. To tune the guitar, the musician must rely on the guitar's built-in tuning pegs as the mechanism by which to adjust the pitch of each string. Six pegs, one for each string, are situated on the headstock of a guitar, and each can be rotated in one of two directions to either increase or decrease the tension in the guitar string, subsequently increasing or decreasing the fundamental vibrational frequency of that string. Thus, much time must be spent by the guitarist turning pegs and checking frequencies until all strings have reached the proper tuning—a tedious process that requires a high degree of precision, and one that must be repeated frequently as the guitar goes out of tune or alternate tunings are required. The overall subject of this is one of performance and/or practice management, as currently a user must complete tuning as menial task unrelated to the intended activity, which is playing a song or a musical excerpt on the guitar.

This project proposes to automate the tuning process through the use of frequency identification and motor control of the pegs on a guitar in a feedback control loop. The process is as follows: when the performer needs to tune the guitar, they will attach the tuning device onto the head of the guitar and select the desired tuning via the LCD control buttons or a wireless phone app which will communicate with an onboard LCD screen user interface to display current settings and relevant real-time frequency information. Next, the user will strum their guitar, and the microphones embedded in the tuner will record the overall sound containing the six string pitches (the performance of the microphones will be assessed based on signal-to-noise ratio and frequency resolution to determine an appropriate number of microphones and spacing, as well as whether balanced audio signal transmission should be implemented). An onboard microcontroller (such as an ESP-based device) will analyze time-based data to compute the current frequency of each string using the Fast Fourier Transform (FFT), subsequently determining if each string needs to be tuned up or down. The results will be communicated with the mobile app in real time. The tuner will then begin controlling all six motors to adjust the frequency in the proper direction by engaging in a feedback loop — continuously recording sound, determining the current frequency, and controlling the motors based on the position of the actual frequencies relative to the desired frequencies. It will cease when each string has been correctly tuned or is no longer producing a loud enough sound to determine its frequency. In the latter scenario, the tuner will indicate to the user that another strum is required. Through the use of frequency analysis, a feedback-loop control system, and high-torque motors, this project will successfully solve the problems of tuning faced by guitarists - this system will save time and provide precise tuning with minimal effort required by the guitarist.

3. System Requirements

In this section, a general set of requirements are outline for each major component of the uTune device.

3.1 Motors

Torque: Each motor must provide sufficient torque to turn a guitar peg, with string attached, to three notes above its standard tuning pitch (i.e. must be able to turn E string up to a G).

Speed: Each motor must be able to complete a full rotation in under 10s.

Weight: The guitar player must be able to individually support the guitar with tuner attached. Each motor must weigh no more than 75g.

Accuracy: Each motor must be able to turn to within 0.5 degrees in order to meet pitch accuracy requirement.

Current: Each motor must draw no greater than 1 amp (stall current).

Attachment: Each attachment must connect securely to the motor and peg and require no more than ¼ turn of the peg when attaching.

Cost: Each motor and connector combination must cost less than $15.00.

3.2 Batteries

Power: Device must be able to run entirely on battery power. Batteries need to have sufficient ability to power 6 motors in tandem, LCD screen, microphones, wireless chip, and microcontroller.

Charge: Batteries must be rechargeable or easily replaceable when burnt out.

Weight: Batteries must collectively weigh less than 100g.

Cost: Rechargeable batteries must cost less than $5.00 each. Non-rechargeable (i.e. replaceable) batteries must cost less than $1.00 each.

Time: Rechargeable batteries must be able to provide no fewer than 100 full tunes before charging. Replaceable batteries must be able to provide no fewer than 1000 full tunes. The device must be able to remain powered on for no fewer than 6 continuous hours on new or fully charged batteries.

3.3 Microcontroller

Abilities: The microcontroller must be able to:

- read analog microphone signals, convert to digital data, perform frequency analysis (i.e. FFT), and run algorithm to find local peaks and determine current string frequency
- interface with mobile app and LCD screen to determine user-selected string frequencies
- decide based upon user selection and current string frequency how to control the motors
- send a signal to an amplified power source to turn the motors such that they tune the string according to the user's input

Size: The microcontroller and accompanying circuit components must fit on a PCB smaller than the head of the guitar in all dimensions.
Weight: The microcontroller and board assembly must weigh no more than 70g.
Cost: The microcontroller must cost no more than $20.00.

3.4 Physical Build

Weight: Device must weigh little enough that the guitar player is able to comfortably support the guitar and tuner setup while standing. Entire apparatus must weigh less than 500g.
Assembly: Device must be relatively simple to put-on and take-off. Either procedure must be possible for an experienced user to complete in under 1 minute.
Robustness: Assembly must be constructed from materials that will allow the device to survive normal operation for at least two years of frequent usage.
Cost: Assembly for device (i.e. not including components such as motors, PCB,, etc.) must cost less than $30.00.

3.5 LCD

Size: The LCD screen must be large enough to display 6 characters for the tuning selection and several lines to indicate menu options and settings, but must be no wider than the head of the guitar.
Weight: The LCD screen must weigh no more than 50g.
Visibility: The LCD screen must have resolution greater than 8 pixels per character.
Buttons: The LCD screen must have three connected buttons, to control up and down selection and an “enter” or “next” button to change selections. These must be between 0.5 and 1 cm in diameter, and must weigh no more than 5g.
Cost: The LCD screen must cost no more than $10.00. The buttons must cost no more than $0.50 each.

3.6 Mobile App

Devices: The app must be able to connect to a minimum of one device at a time.
Range: The tuner must be able to connect to the mobile device up to a distance of at least 10 ft.
Bluetooth Chip: The bluetooth chip must be low-energy (BLE), smaller than 2 square centimeters, and easy to program and interface with the microprocessor.

3.7 Frequency Detection System

Size: The frequency detection system (e.g. microphones) must be no larger than 1 cm in diameter, such that they can fit in the corners of the guitar head of another location that is optimal for detecting pitches.
Weight: The frequency detection assembly must weigh no more than 40g.
Placement: The microphone assembly must be built into the device such that the user does not need to place them at all, other than simply clipping the device onto the guitar head.
Quantity: No more than 6 frequency detection devices must be utilized.
Cost: The frequency detection assembly must cost less than $20.00.

3.8 Safety

Exposed electricity: There must be no exposed metal or wires, such that there exists no possibility of shock or electrocution during normal, safe operation.
Heat: There must be no exposed components which become very hot, such that the user may manipulate the device and put it on the guitar or take it off with no possibility of burning

their hand, and so that there is no risk of fire.

Shut-off: The device must include a shut-off button or switch that is easily accessible, easy to operate, and will immediately shut-off the device, stopping all operations immediately. This is to prevent a scenario in which the device malfunctions and continuously operates a motor such that there exists a possibility of a string snapping, which could injure the user.

4. System Block Diagram

4.1 Overall System:

Fig. 1 - uTune "Black Box" Inputs and Outputs

On a high level, the user is designed to have two methods of controlling the turner settings. Either they will choose the LCD screen optimized for performance-time operation and expediency, or the iPhone app which will offer greater functionality into customized preset-tunings, feedback information, and useful historical data. The only other input that the device needs to be capable of inputting is audio data in a manipulatable electrical format. It must be interpretable such that it can be used to efficiently control the motor system, and provide the user with accurate information on the LCD display and iPhone application.

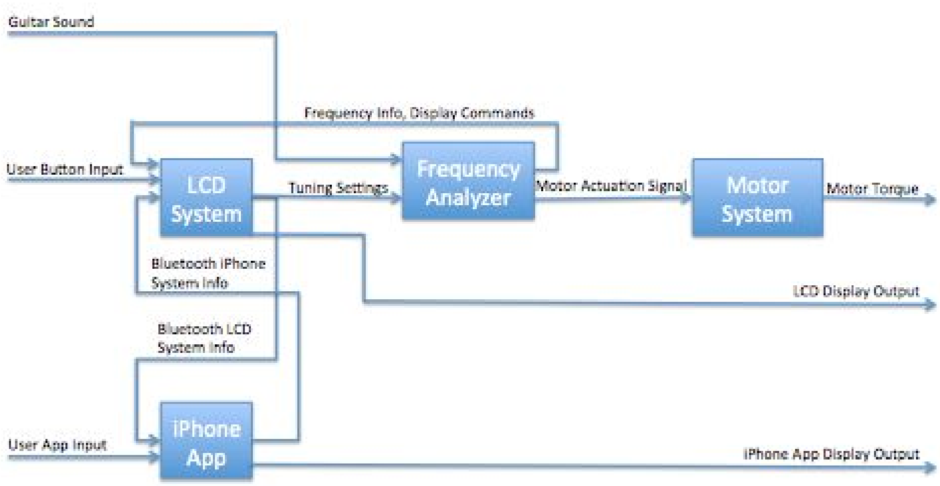

Fig. 2 - uTune Overall Block Diagram

The second figure breaks down the core functionality into explicit subsystems including the user's I/O on the LCD system and the iPhone app as well as the core FFT computational software that must be implemented in the frequency analyzer in order to intelligently move the motors to turn the guitar peg to the in-tune position.

4.2 Subsystem and Interface Requirements:

4.2.1 Frequency Analyzer

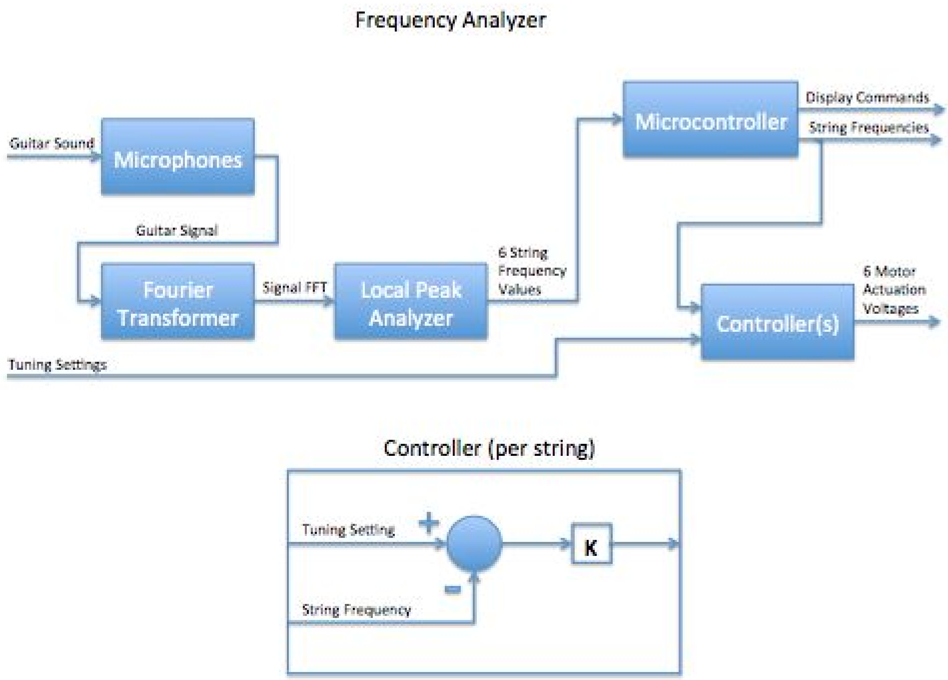

Fig. 3 - uTune Frequency Analysis and Control System Block Diagram

The frequency analyzer is the part of the system that converts the acoustic input signal into an electrical signal and finds the most efficient way to extract the necessary information from it. The robustness of the microphones is critical, as this is the interface upon which the rest of the analysis and tuning will be based. Accordingly, the fidelity, bandwidth, resolution, and noise factors of the converted electrical signal from the microphone sensor will be considered when designing a software-based fast-fourier transform algorithm of the proper length. Since the result of the FFT will be a number of "bins", an efficient search can be done for the local peaks, assessing their relative amplitudes to determine the number of peaks, and how to proceed correspondingly. This middle section is all about minimizing the low-level operations that the microcontroller must perform, also saving battery life in the process. Finally, with adequate information, the microcontroller can relay to the user the current settings and tuning conditions via a wirelessly-connected iPhone application. As for the control algorithm, the goal is to keep it as simple as possible, which would ideally be a motor setting proportional to the error in the frequency term.

Additional Requirements:

- Microphone Placement: The microphones must be placed in a location such that physical coupling does not substantially alter the input. At the same time, the microphone must be placed where it can receive the highest broadband acoustic sound pressure levels.
- Efficiency of Fourier Transform: The microcontroller must offer hardware-level bit manipulation in its IDE so that a customized time-saving FFT can be implemented. This could potentially involve

specific hardware designed to perform high-speed FFT operations. Regardless, will likely require a microprocessor with something on the order of 1 MFLOP.

- Controller Simultaneity: The microcontroller must be able to operate all six servos simultaneously, or at least pseudo-simultaneously such that the user would never notice a difference in operating time.
- Local Peak Analyzer: Must be capable of identifying the six fundamental frequencies either by amplitude or by local knowledge of the A440 tuning system. The nonlinear frequency components must be discarded so that they do not become the fundamental tuning frequencies.

4.2.2 Motor System

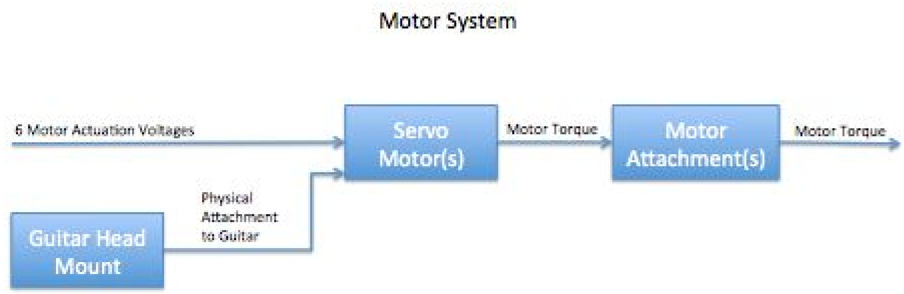

Fig. 4 - uTune Motor System Block Diagram

This subsystem is designed to receive a PWM input signal from the microcontroller and operate the servo motors in a manner that will adjust the motor attachments to turn the guitar pegs. The guitar head mount must be sturdy enough that the device remains stationary in the operation position as motor operation occurs. One of the concerns will be attaching the guitar head in the first place with the motors, and the simplest solution will be to move each peg individually to fit the set motor positions on the clip. However, there are also methods that would allow the head to be attached in a short period of time as the motors operate if they are simultaneously turning at different speeds; by spinning each motor slowly while applying small pressure to the device, pushing the motors towards the pegs, we can implement a “pairing” function that rotates each motor until it experiences a load torque from the peg, meaning it is connected in place.

Additional Requirements:

- Attachability of Guitar Head: Either by asynchronous motor motion and a button indicator, or by instructing user to turn the guitar pegs to a vertical position and simultaneously programming all six motors to the same position.
- Servo Motors: Must not protrude from the guitar head by more than 8cm on either side. Ideally, the apparatus will be contained under the head as much as possible.
- Weight Reduction of Attachments: The final design will implement lightweight HDPE material instead of the malleable prototyping material with unnecessary material removed from the structure.

4.2.3 LCD System

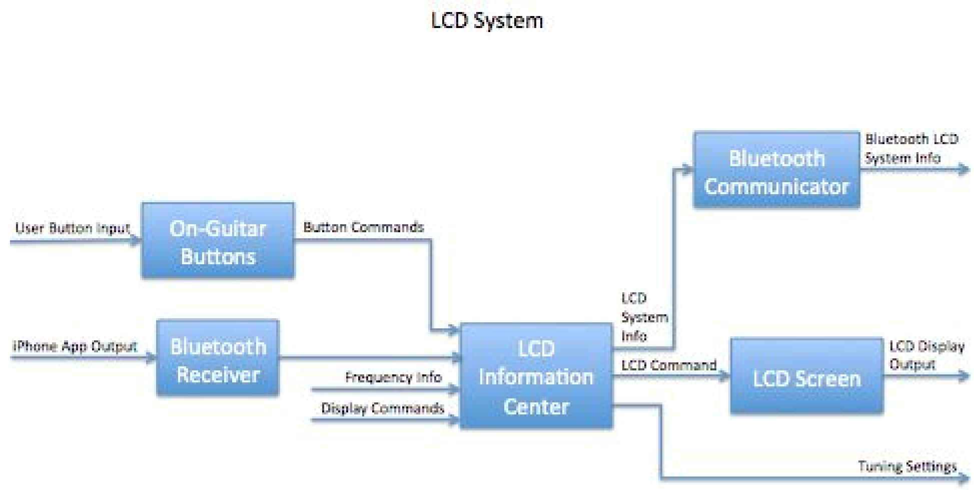

Fig. 5 - uTune LCD Display Block Diagram

The primary function of the LCD system is to provide on-board control and operability without requiring the user to take out their iPhone app (which will have additional features not required on a regular basis). The LCD display should allow the user to specify a string and a note to which it should be tuned, or a preset tuning system as inputted on the iPhone app at an earlier time. Additionally, the current frequency of a string being tuned should be displayable on the LCD screen at the user's request, and as a debugging mechanism. All of this information will further need to be communicated with the user's iPhone (single connectivity) via a Bluetooth transceiver.

Additional Requirements:

- Onboard Button/Switch Functionality: Must allow user to turn on/off, initiate tuning sequence, browse the LCD menu, and lock the LCD interface (for similar reasons why a cell phone lock screen is used).
- Bluetooth Transceiver: Must have a sufficient enhanced data rate (to transmit the necessary data to the iPhone app). Must also have a low-energy mode for when not in continuous operation that uses negligible power and does not drain the battery.
- Compliance with FCC Regulations: Though this is likely not an issue for such a small device, it should be confirmed that the operating range and power of the device do not violate any local regulations for RF transmission. It must also operate be able to operate on a frequency band not susceptible to intermodulation complications or desensitization from other communications being broadcasted.
- Information Display: LCD display should selectively display a tuning preset and/or the current frequency of a selected string.

4.2.4 iPhone App

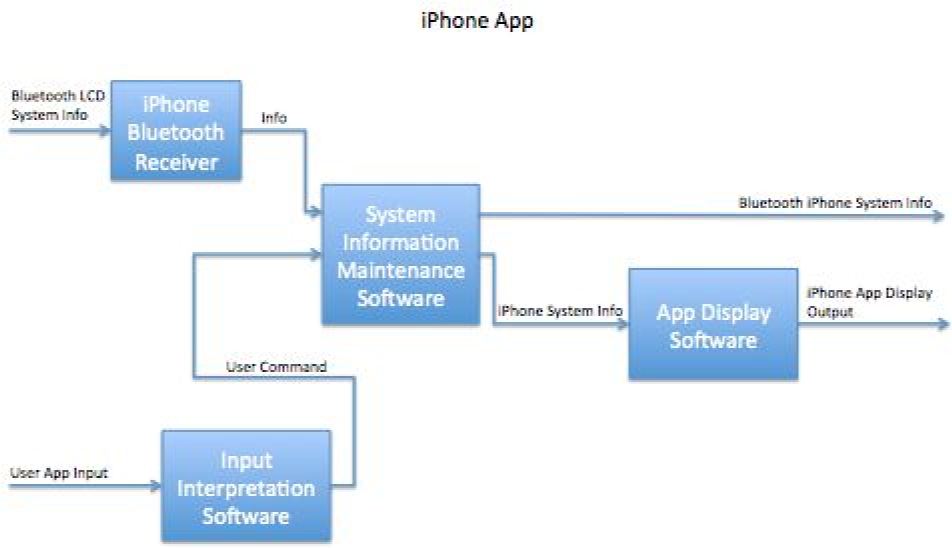

Fig. 6 - uTune iPhone App Block Diagram

The overall design of the iPhone app will require both frontend and backend design with the ability to push data fluidly and simultaneously in both directions. The user's inputs to their iPhone should be promptly stored or transmitted, then displayed. The information received by the iPhone's Bluetooth connection with the device should be displayed in real-time for the user.

Additional Requirements:

- Tuning Presets: Will allow user to create any number of custom tuning presets and name them. Each one can specifically define the note or frequency desired.
- Display of FFT spectrum: The app will be capable of displaying a real-time FFT at any time (even when the device is not being tuned) if requested on the iPhone app.
- Intuitive GUI: The app will have an intuitive user interface and allow the user to navigate between a number of menus for specific functions.

4.3 Future Enhancement Requirements

This section outlines a number of potential future enhancements to the guitar tuning system.

Enhancement 1: The uTune automated tuning device could be constructed with smaller motors and a build such that the device may be left on the guitar at all times. This model would be small, lightweight, and would rest behind the head of the guitar such that it would be inconspicuous and out of sight to the audience.

Enhancement 2: Faster motors (high-torque) could be utilized such that the device is able to tune a guitar much more rapidly, thus enhancing the user's experience and shortening gaps between song performances.

Enhancement 3: The current model under construction is designed to work with a single guitar. Future iterations of the model could include alterations to allow for a fit on multiple different guitar models, or specific uTune models could be created for unique guitar models such that customers could purchase the uTune model specific to their own guitar.

Enhancement 4: Due to the microphones and intelligence which are already embedded in uTune, future versions of the model could be adapted to continually record sound. This data could then be processed to determine notes and durations, and a program could write that information down as sheet music. This would be particularly useful for artists who are writing songs, providing a means for them to record spontaneously inspired music.

Enhancement 5: Future version of uTune could come with an installable strumming device, which would take the tuning automation a step further by strumming the guitar for the user. This would allow the user to tune the guitar completely hands-free.

Enhancement 6: Rather than using a microphone-based frequency analysis system, a second, miniature, self-contained mechanical pickup mechanism could be wirelessly connected to deliver real-time mechanically-read frequency information instead of airwave-based frequency information. This device would have to be inconspicuous and small enough that it could be installed on the bridge.

5. High Level Design Decisions

5.1: Frequency Analyzer

- Microphones (or pickup)
    - Sampling Rate: According to the Nyquist Theorem, the microphones used for this project must sample at a rate of greater than 40kHz in order to achieve the desired 20kHz bandwidth.
    - Type of Microphone: There are also a variety of available technologies including condenser, MEMS, and magnetic-based microphones. Some of the MEMS microphones will be smaller but potentially lack in accuracy.
    - Sensitivity: Ideally, the microphone should have a high enough sensitivity to detect the sound coming from the strings, even as the amplitude decays after each strum. This is essential in order to provide the control system with enough time to process and adjust the strings into position without requiring the user to strum an excessive number of times.
    - Analog/Digital Output: This consideration has a lot to do with signal-to-noise ratio and minimizing the noise that reaches the sampling input.
- Fourier Transform Algorithm
    - Number of Bins: Assuming a sampling rate of 40kHz, this leaves a 20kHz band for the audible range of human hearing. In order to achieve resolution to 1Hz, this requires 20k samples for the FFT size. This extrapolation of the sample rate and number of FFT bins will ultimately lead to a microcontroller requirement for calculation speed.
    - Microcontroller Computational Ability: Ultimately, this will tie into the processing power of the microcontroller needed. The user will experience a delay according to how quickly the sampling can be done, but also according to how quickly the FFT can be calculated and analyzed. Therefore, to avoid any unnecessary delay, the monetary cost of computing speed must be weighed against the time cost in executing the FFT.

- Motor System
    - Pulse-Width Modulation Control: The six motors will be individually implemented with simultaneous PWM signals that will determine the angular rotation and rotational speed of the motor pegs.
    - Power Usage: The motors should be designed to use as little power as possible to accomplish their assigned task in a short period of time. This means that they should draw minimal current, also aiding the battery in its ability to supply
- Ideal mount structure
    - Durability and Sturdiness: There will be a tradeoff (likely unobservable without specialized accelerated-durability testing) between minimizing weight of the structure that will connect the motor pegs to the system and extended durability (maintaining rigidity throughout the course of its lifetime to provide adequate grip strength).
- Motor type
    - Servo Motors: Currently, the most viable solution given the status of the subsystem demonstration is to use servo motors powered by a PWM signal to determine the distance which they turn. Likely, this will prove to be the best solution given the lightweight nature of the servos, and the ability to construct a sophisticated software-based control system.
    - Stepper Motors: An alternative plan would be to use stepper motors using motor controllers that allow for up to 1/16th step resolution. This would certainly meet the peg turning precision needed, but it might be an excessive solution, and potentially add unnecessary weight to the device.
    - Motor Attachments: These are designed to require no more than a slight turn of the peg to initially fit the attachment, and fit neatly and securely onto the servo motor propeller attachment. Note that a small hole could be added through the center to allow the attachment to be screwed onto the motor. A sample (not final) design is included below in Fig. 7 and Fig. 8. Further refinements will reduce material and create a more snug fit to the guitar peg.

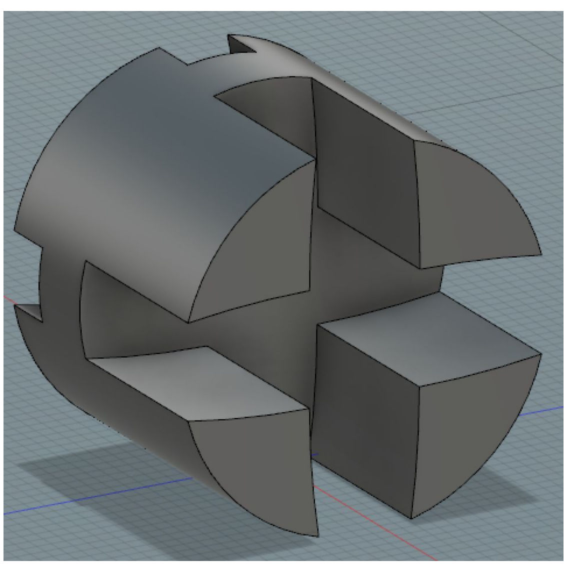

Fig. 7 - uTune Peg Clip Motor Attachment: Peg Side

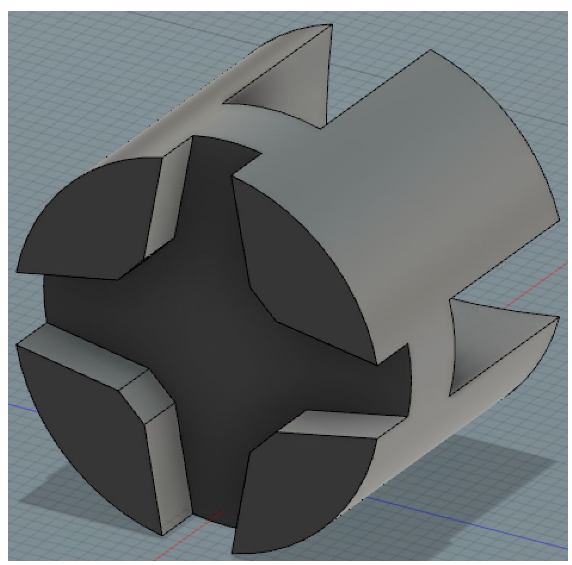

Fig. 8 - uTune Peg Clip Motor Attachment: Motor Side

5.2 LCD System

- Types of buttons
  - Low-Profile: Ideally, these buttons should be both provide a firm connection as they are pressed, but also remain unobstructive.
  - Long Lifetime: Choose a button which will be easily installable on the PCB board and avoid the risk of breaking off.
- Type of switch (for iPhone/LCD control)
  - Robust: Must be simple and instantaneous in signaling the user's desire to switch their input source. Must function for a long period of time, and must withstand consistent use.
- Bluetooth transceiver
  - Bluetooth Protocol: The specific Bluetooth protocol selected will be a major concern, especially in ensuring that the devices can communicate enough information in a short period of time while maintaining consistent connectivity.
- LCD screen type
  - Resolution of Display: After understanding the frequency resolution of the FFT, the number of digits to be displayed at once can be determined, and the number of LCD cells can be chosen accordingly.

5.3 iPhone App

- Swift programming
  - Depth of Functionality: When designing the iPhone application, it must be determined that this method is sufficiently low-level to control all of the incoming and outgoing information in a meaningful manner.
  - Availability of Developer Support: There must be an outlet to find developer support so that a single aspect of the project's functionality does not hinder the overall success if there isn't a clearly available and working software solution.
- User interface
  - Touch-Screen GUI: Standard and simple user interface with several menus for specific sections of the app such as tuning presets, frequency system selection, and FFT viewing.
- Data storage and processing
  - Stack and Operating Memory: Must allocate sufficient memory within the cell phone's software stack without storing unnecessary information longer than it needs to be stored.
- Bluetooth communication protocols
  - Microcontroller Integration: Must provide incoming data in a convenient format for interpretation by a microcontroller. The transceiver selected must provide a full solution to convert radio waves into a standard embedded protocol.

5.4 Power

- Batteries
  - The battery will be driving 6 motors, as well as powering the microcontroller; each motor is spec'd at less than 1000 mA of stall current, but the highest current draw happens when each motor is just starting / stopping to turn. Therefore, to mitigate any harsh current draw for short periods of time from the battery, we will control the start and end of the tuning process to ensure that peak current will not be drawn from more than one motor at the same time.
- Recharging
  - Lifetime of Batteries: It is well-known that many battery capacities will degrade over time. Therefore, it is necessary to choose a battery that will minimize the effect of this impact

on the user's operation, rendering the device completely operational for an extended period (i.e. several hours for a concert), even after this degradation has occurred.

5.5 Microcontroller

- Clock signal
    - External Crystal: It is possible that the microcontroller selected will require a specific external crystal that sets a particular operating frequency. This signal must be maintained and distributed throughout the device. It is also possible that this frequency must be slowed down via the microcontroller to be distributed throughout the rest of the device.
- Power and control signal to motors
    - Power Management to Motors: Microcontroller must manage motor start-up as they demand peak power consumption to avoid overdrawing current from the battery. As the motors are under operation, they must not draw more current than the battery can supply.

6. Open Questions

1) Guitar Signal Capture: Transducers

- We aim to use either microphones or a hexaphonic pickup as the input for the guitar sound. With either of these, the sound for each string would ideally be fed into the system as its own signal. Thus, each measured frequency could be attributed to its specific string.
- It is currently unknown how many microphones placed underneath the six strings would be required to accurately isolate six frequency peaks. Since it detects the sound waves, which are primarily resonant in and amplified by the whole guitar body, rather than just the string itself, it is unknown whether each microphone's slightly closer proximity to its respective string will allow it to pick up a signal primarily composed of that string's root frequency. It is quite possible that the use of six would take in a signal almost the same as one taken in by a microphone in front of the whole guitar, a signal whose FFT consists of the six major peaks for the fundamental string frequencies. This would require an interpretation process to attribute each frequency to a particular string, which would require additional processing after the FFT is calculated.
- With a hexaphonic magnetic pickup, there are guaranteed to be six individual outputs, each with a single string's vibration pattern. This is not susceptible to the previous air wave problem because the hexaphonic magnetic pickup operates based on the disturbance of magnetic fields by the metal string's vibrations, which are local to each string. This would take away the need to interpret one main signal to distinguish each string frequency.
- If the microphones cannot give individual string signals, the hexaphonic pickup would be a good solution, but cost may be an issue. Hexaphonic pickups sell for prices in the mid-hundreds, like the one below. This decision will be made once the microphones are assessed.
    - http://www.ubertar.com/hexaphonic/products.html

2) Specific Microcontroller

- One of the primary concerns will be the required computational speed in order to be able to execute the FFT in a manner fast enough that the user is not disturbed by any unnecessary delay. One potential solution could be hardware-specific FFT implementations that are optimized for speed on certain microcontrollers. However, there could be issues of cost.
- The microcontroller must also have sufficient GPIO, which would be a bare minimum of ten (6 for motor control, 1-2 for microphone input, 1-2 for transceiver information communication, 1-2 for LCD control, etc.). This will ultimately depend on the protocol that is implemented on the

microcontroller to control each of these other devices. Given the number of such devices, it might be ideal to implement the SPI protocol, as each additional device only requires a chip select pin on the microcontroller).

3) Bluetooth Transceivers

- There are so many different available options that this will likely come down to a specific library or functionality of the microcontroller we select in order to provide a streamlined data pipeline between the transceiver and the central processor. This could come down to the availability of a pre-programmed function library to send bytes of information, or it could come down to the hardware connectivity protocol that the transceiver implements (I2C, SPI, etc.).

4) Voltage Regulation

- A 5V battery is needed to control the servo motors sufficiently. This battery will be specified to handle high enough current output to supply all six motors in continuous motion. From there, there will likely be a number of required power levels to power the microcontrollers, sensors, and other active devices on the PCB. Ideally, they would all be specified to work at the same stepped-down voltage that would only require one regulator with sufficient current-handling capacity, but this might not be the case. As a result, it might be necessary to source multiple voltage regulators to serve different purposes, although only one necessary voltage regulator to bring the battery voltage to 3.3V to serve the microcontroller would be ideal.

7. Major Component Costs

Component Type	Parts	Cost per	Quantity	Total Cost
Motor	Motors	$8.49	6	$50.94
	3D Printed Clips	$0.00	6	$0.00
	Propellers	$0.00	6	$0.00
	3D Printed Guitar Head Mount	$0.00	1	$0.00
LCD	LCD Screen	$20.00	1	$20.00
	Buttons	$1.00	3	$3.00
	Switch	$1.00	1	$1.00
Frequency Analysis	Microphones	$3.00	6	$18.00
	(Alternative: pick-up)	($145.00)	(1)	($145.00)
Board	Bluetooth Transceiver	$15.00	2	$30.00
	Microprocessor	$20.00	1	$20.00
	PCB	$50.00	1	$50.00

Power	Rechargeable Battery	$5.00	4	$20.00
	Voltage Regulators	$0.50	4	$2.00
Total Cost - using Microphones: **Total Cost - using Pick-up:** **Total Cost of all Materials:**				**$214.92** **$314.94** **$359.94**

8. Conclusion

Tuning is an essential aspect of a musical performance, but it should not be a burden for a performer while they are in the middle of making music. A performer, especially an inexperienced one, can spend a significant amount of time focused on tuning. Additionally, the human ear is not as high resolution as modern microphones due to critical bandwidth perception limitations. Therefore, an automated guitar tuner is a desirable and useful item.

Through the use of the subsystems and functions specified throughout this high-level design, this automatic guitar tuner will utilize microphones to analyze the frequencies of each string, and based upon the user's selections, will control the motors in order to finely, accurately, and quickly tune the guitar. This will resolve the key problems we set out to address: going out of tune gradually over time and due to temperature changes, and requiring quick changes to different tunings during performances. Ultimately, this product will enhance the experience of performers and audience members, will make playing guitar a more accessible pastime for less-experienced musicians, and will present a high-value and much-needed system to a large audience.

References

https://www.digikey.com/
http://www.ubertar.com/hexaphonic/products.html