ECE 445

Spring 2025

Design Document

Automatic Guitar Tuner Project Proposal

Team 65

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1. Introduction

1.1 Problem Statement

For many guitar players, keeping their guitar in tune can be a hassle. Looking at the tuners currently on the market, the most common type of guitar tuner is a clip-on tuner where the player is required to manually tune each string using the attached tuner as a pitch guide. There also exist automatic guitar tuners but these are limited by either the number of strings that can be tuned at once, the price of the tuner, or the amount of work needed to be done by the player (i.e. the player still has to move the tuner around the pegs or strum the strings) [1].

1.2 Solution

Our solution is to develop a portable automatic guitar tuner that attaches to all six tuning pegs of the guitar and can tune each string to the standard 6-string guitar tuning (EADGBE). So, the user will intermittently strum all six strings until an LED flashes which indicates that all strings are correctly tuned - an attached Piezo Disk Transducer will be used to determine the real-time frequencies and vibrations within the guitar. To accomplish this overall task, we will introduce 4 essential subsystems: a power subsystem, motor subsystem, processing subsystem, and a vibration-sensing subsystem.

1.3 Visual Overview

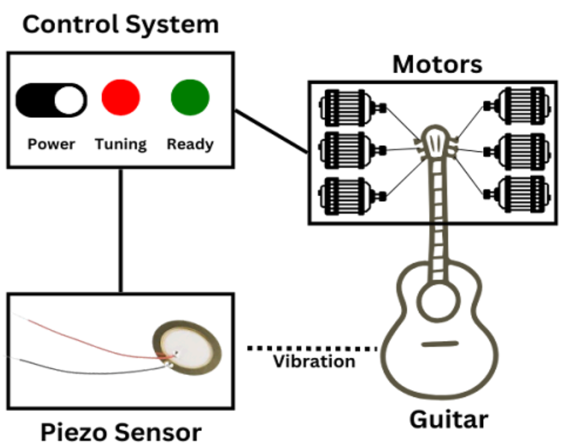
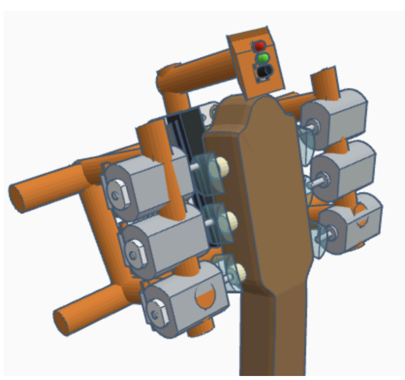


Figure 1: High-Level Visual Overview of the Automatic Guitar Tuner System



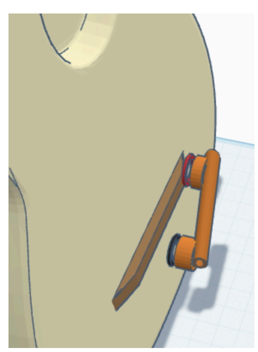


Figure 2 (left): Motor Mount with Control System and PCB
Figure 3 (right): Piezo Sensor Mounted at Bridge of Guitar with Magnets

1.4 Criterion For Success

- Ability to attach and remove the system within two minutes total
- Ability to tune all six strings within ±12 cents of the set tone per string (the value where people can start to detect when something is out-of-tune)
- Ability to finish tuning all strings within a minute, flashing an LED to visually signify completion

2. Design

2.1 Block Diagram

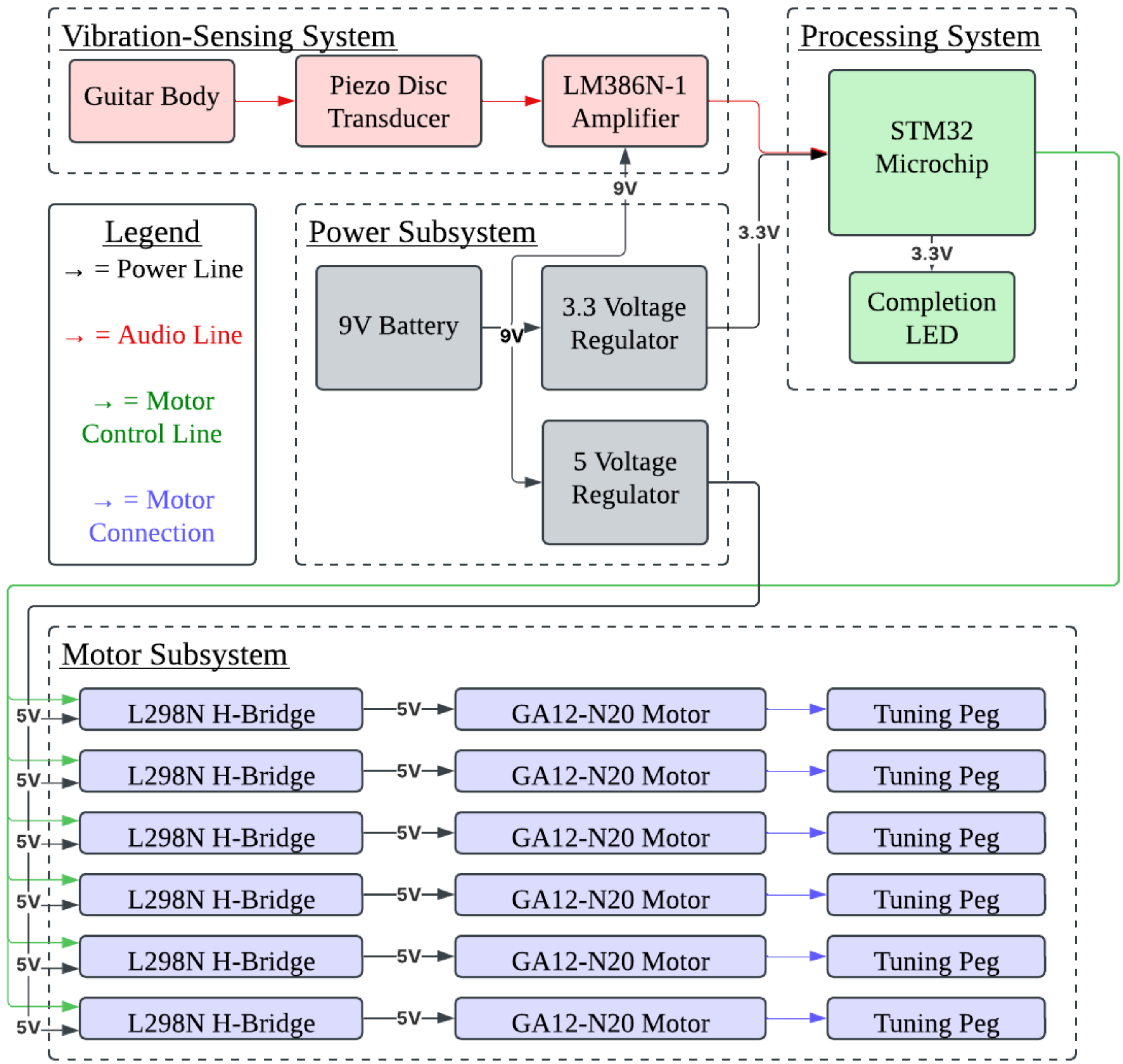


Figure 4: Block Diagram of the Automatic Guitar Tuner System

2.2 Subsystem Overview

2.2.1 Subsystem 1: Power System

The power system will provide power for the motors and processing system. As the design will be portable, it will be run from a 9V battery (233) and require a step down voltage regulator (LM2937 and μA7805) to get the power to an acceptable level for our motor and processing systems. We will also have a battery control system to ensure all our components receive appropriate power.

2.2.2 Subsystem 2: Motor System

The motor system will be responsible for turning the tuning pegs based on the processing system output. There will be 6 motors (GA12-N20), one for each tuning peg, and will be driven by H-bridges (L298N) on the PCB. They will also have limited torque and power in order to ensure the system will not damage the guitar.

2.2.3 Subsystem 3: Processing System

The processing system is the heart of the project, as it will take input from the vibration system, distinguish between all six strings, process which direction to tune each string, and finally send power to the motor system to tune the guitar. We will utilize the STM32H7B0RBT6 microcontroller to run DFT/FFT techniques on the signal from the vibration system in order to identify the six strings' individual frequencies. This will be done by having predetermined ranges for each string and sweeping through that range for the peak. Once the frequencies are separated, we will utilize a tuning algorithm to determine the direction the motors need to tune the guitar.

2.2.4 Subsystem 4: Vibration-Sensing System

This system will take input from a piezo disk transducer (TXJ-055-US) which will read the vibrational frequency from the guitar body and amplify (LM386N-1) it to an acceptable level for the processing system to handle. This system may also take input from multiple transducers placed at multiple locations on the guitar and combine them for a more accurate and reliable input.

2.3 Subsystem Requirements and Verifications

2.3.1 Subsystem 1: Power System RVs

Requirements	Verifications
1. Must be able to supply a continuous 5V±0.25V and 3.3V±0.2V for all system components	1. Connect 9V battery to battery clip and ensure power switch is turned on 2. Connect jumper wire to ground, and another to either the 3.3V or 5V power rail 3. Measure voltage with a voltage sensor and verify that it is within 3.1V-3.5V and 4.75V-5.25V respectively
2. Output voltage should not decrease by more than 5% when motors are under load	1. Connect 9V battery to battery clip and ensure power switch is turned on 2. Connect jumper wire to ground, and another to the 5V power rail

	3. Attach the piezoelectric sensor to the guitar without connecting the motors to the tuning pegs 4. Ensure at least one string is out of tune on the guitar, then strum the guitar 5. Verify the motors are on, measure the voltage, and verify it is above 4.5125V

2.3.2 Subsystem 2: Motor System RVs

Requirements	Verifications
1. The motor system must be able to adjust pitch within 15 seconds per strum to meet the overall tuning time requirement	1. Assemble automatic guitar tuner, with all subsystems connected and power on 2. Ensure at least one string is out of tune on the guitar, then use an external tuner to note the pitch of each string 3. Strum the guitar and start a timer for 15 seconds 4. At 15 seconds, or when tuning completes, turn off the automatic guitar tuner and note the pitch of each string again 5. Verify all strings have adjusted pitch by at least 1 Hz.
2. The motor system must rotate tuning pegs with a torque limit of ≤ 0.5 N·m to prevent damage to the guitar	1. Attach arm of known length to motor 2. Power motor from H-bridge at full operating conditions 3. Use a scale to measure the force at the end of the arm 4. Calculate the torque using the measured values and verify that it is within the stated limit

2.3.3 Subsystem 3: Processing System RVs

Requirements	Verifications
1. Use the STM32 chip to run real time FFTs to analyze the frequency within 50 ms of the start of the strum	1. Assemble automatic guitar tuner, with all subsystems connected and power on 2. Use a signal generator to create a sine wave of a known frequency 3. Connect signal generator to the STM32's ADC input test points 4. Simulate a guitar strum using a short burst of the signal generator 5. Read the output from the STM32's built in hardware timer and verify it is within 50 ms

2. The processing system must analyze frequencies with at least ±3 Hz precision in the 80 Hz – 350 Hz range	1. Assemble automatic guitar tuner, with all subsystems connected and power on 2. Strum all six strings of the guitar and obtain the 6 transformed frequency outputs from the microcontroller (one for each string) 3. Verify that the frequency output for each string is within ±3 Hz of the standard guitar tuning (82.41 Hz - E, 110 Hz - A, 146.83 Hz - D, 196 Hz - G, 246.94 Hz - B, 329.63 Hz - E)

2.3.4 Subsystem 4: Vibration-Sensing System RVs

Requirements	Verifications
1. Must be able to amplify the vibrational signal with a gain of 20dB	1. Attach the piezo disc transducer to the guitar bridge 2. Connect an oscilloscope to the transducer's leads 3. Strum the guitar and collect a non-amplified transducer output 4. Connect the output leads of the transducer to the signal amplifier 5. Connect the oscilloscope to the amplified output 6. Strum the guitar once more and collect an amplified transducer output 7. Verify that the amplified transducer output has a gain of 20dB compared to the non-amplified output
2. Must be able sense to vibrational frequency of the guitar and accurately output a signal within ±12 cents of the original frequency	1. Attach the piezo disc transducer to the guitar bridge 2. Connect the output leads of the transducer to the signal amplifier 3. Connect an oscilloscope to the output of the amplifier 4. Strum the low E string and measure the outputted frequency from the transducer 5. Use an external tuner to also measure the frequency of the low E string 6. Verify that the outputted frequency from the tuner is within ±12 cents of the frequency measured by the external tuner

2.4 Tolerance Analysis

The most precise part of the project is to tune the guitar to within ±12 cents of the set tone per string. This accuracy will be determined by two factors, the accuracy of the piezo transducer and the accuracy of the motors. The piezo transducer we selected has a resonant frequency around 4.6 kHz. As the typical tuning frequency of a guitar is between 80-350 Hz (from the low E string to high E string), this resonant frequency sits far above the top range, resulting in a flat frequency response from the transducer for our tuning range. Our motors will also be accurate enough to turn the tuning peg to within 12 cents due to their high torque, low RPM nature. Since the motor is a DC motor without steps, there is no concern over missing the target frequency because of large steps in the motor.

2.5 Linear Regulator Analysis

2.5.1 Voltage Regulator (3.3V) - LM2937-3.3

Part	Worst Case Current @ 3.3 V	Comment
Processor	140 mA	Total output current sunk by all I/O and Control Pins
LED (2)	15 mA (30 mA total)	Assuming 100% on rate, based on resistor and LED voltage drop values
Total	170 mA	

Table 1: Current Calculation at 3.3 V

Variable	Value	Comment
$max(T_i)$	125 C	Maximum operating junction temperature
i_{out}	170 mA	Maximum current draw of 3.3 V components
v_{in}	9.6 V	Maximum voltage of a 9 V battery
v_{out}	3.3 V	Operating voltage of components
Θ_{ja}	65 C/W	Thermal resistance of junction to ambient per datasheet
T_a	38 C	Hot day

Table 2: Variable List for 3.3 V Voltage Regulator

$$T_j = i_{out}(v_{in} - v_{out})(\Theta) + T_a \approx 108\ C < max(T_i)$$

2.5.2 Voltage Regulator (5V) - µA7805

Part	Worst Case Current @ 5 V	Comment
L298N H Bridge (3)	70 mA (210 mA total)	Max assuming: Ven = H; Vi = H; IL= 0
GA12-N20 Motors (6)	30 mA (180 mA total)	Current consumed under load at 500 rpm
Total	390 mA	

Table 3: Current Calculation at 5 V

Variable	Value	Comment
$max(T_i)$	150 C	Maximum operating junction temperature
i_{out}	390 mA	Max current draw of 5 V components
v_{in}	9.6 V	Maximum voltage of 9 V battery
v_{out}	5 V	Operating voltage of components
Θ_{ja}	19 C/W	Thermal resistance of junction to ambient per datasheet
T_a	38 C	Hot Day

Table 4: Variable List for 5 V Voltage RRegulator

$$T_j = i_{out}(v_{in} - v_{out})(\Theta_{jc}) + T_a \approx 72\ ℃ < max(T_i)$$

2.6 Battery Analysis

To analyze the battery life of our design, we first will estimate the current draw of each component/subsystem. This is shown in the table below:

Component	Quantity	Voltage	Current per Unit	Total Current
STM32 Microcontroller	1	3.3V	100mA	100mA
L298N H-Bridge	3	5V	70mA	210mA
GA12-N20 Motors	6	5V	40mA	240mA
TXJ-055-US Piezo Transducer	1	N/A	N/A	N/A
LM386N-1 Amplifier	1	9V	8mA	8mA
LED Indicator	2	3.3V	10mA	20mA
LM2937-3.3 Voltage Regulator	1	9V-5V	10mA	10mA
µA7805 Voltage Regulator	1	9V-3.3V	8mA	8mA

Table 5: Current Draw Component Breakdown

Thus, our estimated total current draw is about 600mA. An average 9V battery contains 500mAh. So, we can calculate the battery life using the following equation:

$$Battery\ Life = \frac{Battery\ Capacity\ (mAh)}{Total\ Current\ Draw\ (mA)} = \frac{500mAh}{596mA} \approx 0.83\ hours\ or\ 50\ minutes$$

Based on these calculations, since it takes 1 minute to tune all 6 strings, our device can be used 50 times before having to replace the 9V battery.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Parts/Materials Costs

Part Description	Part Number	Vendor	Quantity	Total Cost
3.3V Voltage Regulator	LM2937-3.3	DigiKey	1	$1.81
5V Voltage Regulator	µA7805	DigiKey	1	$1.16
H-Bridge	L298N	E-shop	3	-
Motors	GA12-N20	Amazon	6	$44.94
Microcontroller	STM32H7B0RBT6	DigiKey	1	$9.31
Piezo Disc Transducer	TXJ-055-US	Amazon	15	$6.99
Signal Amplifier	LM386N-1	Mouser	1	$0.93
LEDs	RED/GREEN LED	E-shop	2	-
Guitar	First Act Guitar 222	Facebook	1	$55
9V Battery	Energizer MAX	Amazon	4	$11.88
Battery Holder	9V-Switch	Amazon	2	$5.99
				Total: $138.01

Table 6: Parts/Materials Cost Breakdown

3.1.2 Labor Costs

Engineer	Circuit Design	Soldering	Tuning Algorithm	Prototype and Testing	Documentation and Write-Up	Total Hours
Ethan Lin	15	15	30	50	30	140
Nathan Kim	10	10	40	50	30	140

Table 7: Labor Breakdown by the Hour

Given that an average ECE graduate makes a starting yearly salary of $98,472.50 [4], we can use an estimated hourly rate of $47.34 to calculate the labor costs of this project.

Overall Total Hours	Hourly Rate	Total Cost
280	$47.34	**$13,255.20**

Table 8: Labor Cost Breakdown

3.1.3 Grand Total Cost

Section	Costs
Parts/Materials	$138.01
Labor	$13,255.20
Grand Total	**$13,393.21**

Table 9: Grand Total Cost Breakdown

3.2 Schedule

Week	Tasks	Responsibility
3/3/2025	1. Finish Design Document 2. Sign up for Breadboard Demo 3. Order all parts for Breadboard Demo	1. Both 2. Both 3. Ethan
3/10/2025	1. Complete Breadboard Design for Demo 2. Complete PCB Design for PCBWay 3. Create rough physical design and mounting system	1. Both 2. Both 3. Ethan
3/17/2025	1. Spring Break	1. Both
3/24/2025	1. Solder PCB 2. Tuning Algorithm Development 3. Prototype Motor Subsystem	1. Both 2. Nathan 3. Ethan
3/31/2025	1. Individual Progress Report 2. Prototype Vibration-Sensor Subsystem 3. Prototype Processing Subsystem	1. Both 2. Both 3. Both
4/7/2025	1. Fine Tune PCB design 2. Unit Test All Subsystems 3. Test Subsystem Integration	1. Ethan 2. Both 3. Nathan
4/14/2025	1. Ensure High Level Requirements are Met	1. Both
4/21/2025	1. Present Mock Demo 2. Implement Feedback from Mock Demo	1. Both 2. Both
4/28/2025	1. Present Final Demo 2. Give Mock Presentation 3. Implement Feedback from Mock Presentation	1. Both 2. Both 3. Both
5/5/2025	1. Give Final Presentation 2. Complete Final Paper 3. Lab Checkout	1. Both 2. Both 3. Both

Table 10: Future Schedule

4. Ethics and Safety

One potential ethical or safety issue that would arise from this project would be potential harm to people's property [2]. Automatic guitar tuners are not a new idea, but consumers are generally skeptical about them due to their history of damaging the guitars they tune. In order to prevent this, our design limits the power and torque the motors can produce, removing the possibility of damage. Another possible issue would be to respect the work required to produce new ideas [3]. Previous ECE 445 groups have created automatic guitar tuners, and our work aims to build on their designs. To prevent issues, we will clearly document our ideation and creation process to clarify our sources and references.

5. References

[1] “TronicalTune PLUS - Guitar Tuner AI full automatic for almost any Guitar,” Guitar tuner professional. full automatic guitar tuner that fits almost any guitar like Fender, Gibson, Ibanez Yamaha, Oct. 14, 2024. https://www.tronicaltune.net/tronicaltune-plus/

[2] “IEEE Code of Ethics,” @IEEEorg, 2019. http://www.ieee.org/about/corporate/governance/p7-8.html

[3] Association for Computing Machinery, “ACM code of ethics and professional conduct,” Association for Computing Machinery, 2018. https://www.acm.org/code-of-ethics

[4] G. E. O. of M. and Communications, “Salary Averages,” ece.illinois.edu. https://ece.illinois.edu/admissions/why-ece/salary-averages