AUTOMATED CHINESE TRADITIONAL CHIMES WITH SONG

By

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Contents

1. Introduction

1.1 Purpose

Few people play Chinese traditional Chimes, and they're often stuck in traditional music, which seems to be a barrier of traditional instruments. Additionally, the lack of research on blending modern music with Chinese traditional genres is another challenge. By addressing these issues, the project contributes to the inheritance of Chinese culture in a modern context and innovatively researches the possible music style transformation between model music and traditional Chinese music. However, the chimes we can find can't meet the requirement of being able to play, out of tune and too widely spaced.

The project aims to revive the melody played by smartphones in the Chinese traditional Chimes. We will first recognize a melody from a smartphone and generate the adapted melody for chimes, then transform the melody to signals, and then control a mechanical design to ring the chimes with the motor. We intend to transform the instruments that would have been used to strike the chimes and their control system to control the striking of cups filled with water. Replace chimes that produce different tones with cups containing different amounts of water. The following references to cups filled with water still use chimes.

1.2 Functionality

1.2.1 Visual Aid

The project aims to revive the melody played by smartphones in the Chinese traditional Chimes. We will first recognize a melody from a smartphone and generate the adapted melody for chimes, then transform the melody to signals, and then control a mechanical design to ring the chimes with the motor. The diagram for visual aid is shown in Figure 1.

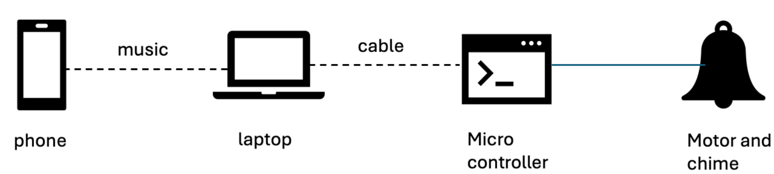

Figure 1 Visual aid

1.2.2 High-level requirements list

1. Generate an algorithm that can correctly recognize the melody from a smartphone (with noise). Apply the algorithm to adapt the recognized melody for chimes play.

2. Generating correct position and time signals and successfully controlling motor operation.

3. Make the adapted music pleasant and make the whole structure as simple as possible.

4. Achieve striking functionality through a structurally simple, efficient, and aesthetically pleasing design.

5. Ensure that the striking method produces a high-quality, crisp, and stable sound from the water cup.

6. Digital signals are converted into voltage signals and output through the microcontroller, and when the output pin is not sufficient to support one-to-one control, a logic circuit is used to realize one-to-many control.

7. Achieve auto-injection function, realization of automatic water injection to the target position.

1.3 System Overview

The block diagram of our design is shown in Figure 2.

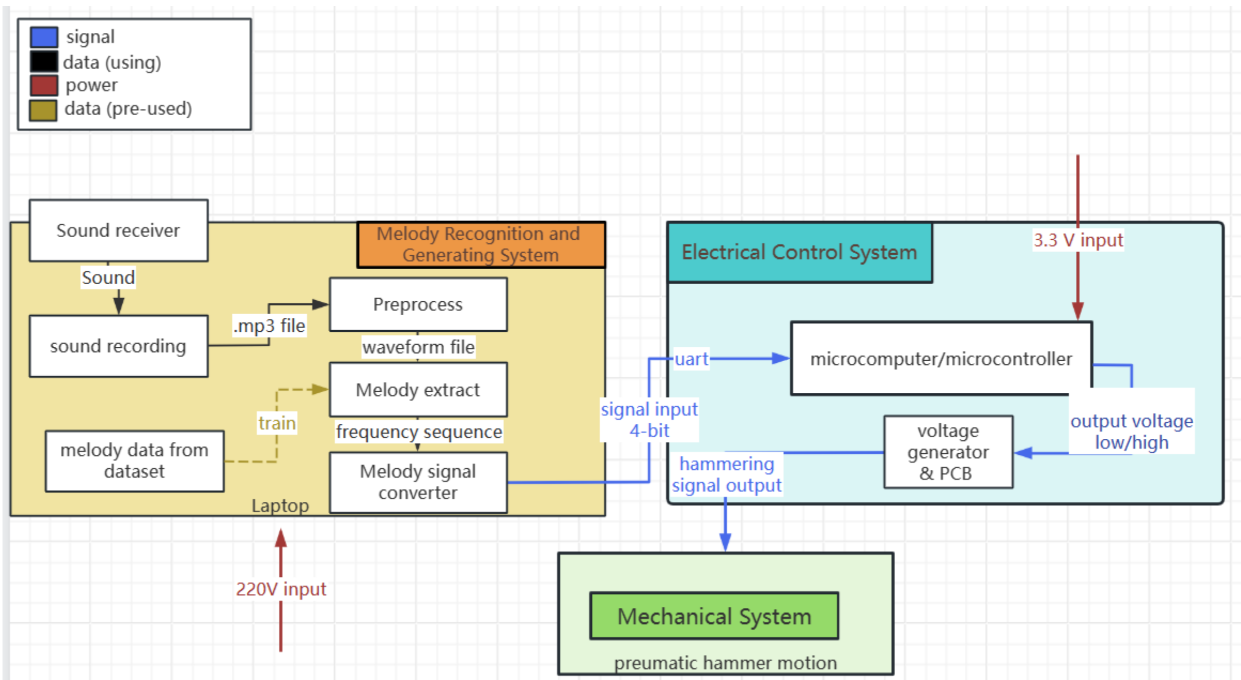

Figure 2 Block Diagram

The description of each subsystem is shown below.

1.3.1 Melody Recognition and Generating System

As shown in Figure 1, the phone is used for playing a piece of music then we use a laptop to record it. Then with salience-based method, a frequency series for the note performed at each time is obtained. Then by setting different thresholds, acquire the length for crotchet, minim, dotted minim respectively. Finally, considering the speed of motor and Baud rate of microcontroller, generate the control code for microcontroller.

1.3.2 Electrical Control System

We will also design a control circuit to transmit signals from the microcontroller to the mechanical part. There are 8 output pins with 3.3V- 5V output as logic “1” and 0V as logic “0”, and the microcontroller is duty for processing the location data and control the voltage at each pin, more specifically, low voltage for hitting and high voltage for other time. The pin is connected to the gate of an NMOS and a PMOS, which operates as a switch to control the motor.

1.3.3 Mechanical System

A hammer structure hanging horizontally at the top of a series of chimes (cups) controlled by a motor. It will ring the corresponding chimes controlled by the electrical control system. The primary design is shown below:

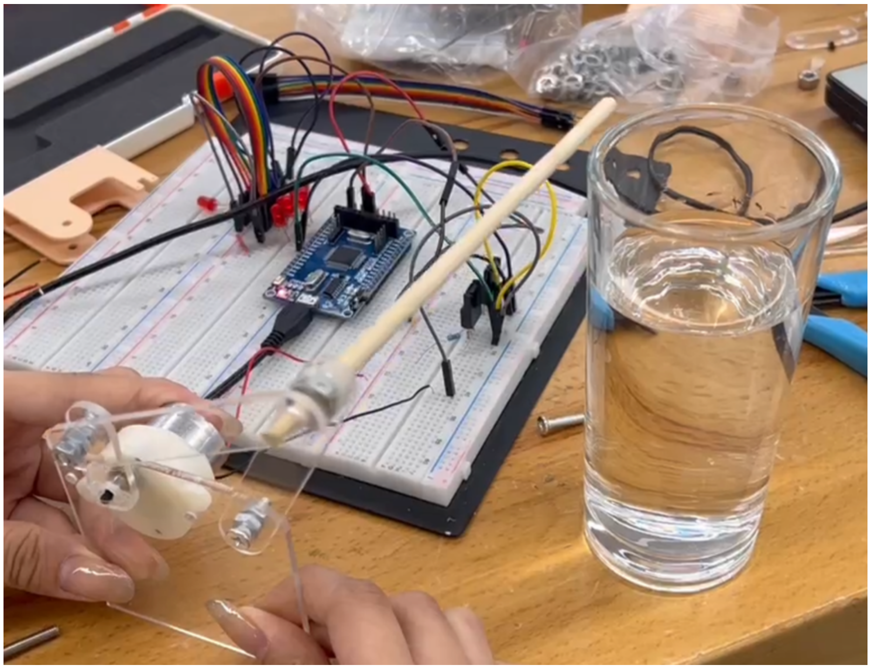

Figure 3 Fundamental Design of the Mechanical Part

For the whole structure, the water will be placed in two parallel lines and the striking part will be arranged between the cups. The motor will serve as the base and control the worm gear to rotate. Each motor will control two sticks, which are fixed in position. We apply siphon effect with pipes to achieve the function of automatically filling the water to the right level.

2. Design

2.1 Equations & Simulation

The speed of the motor is 100 rpm, and Baud rate of microcontroller is 9600 Baud. For the stricking of each note, it requires for a full cycle. Thus, calculate the number of symbols for one stricking:

$$n = 9600 * \frac{60}{100} = 5760 \tag{2.1}$$

We still need some time for flexibility. The choice now is 1240 symbols. Thus, for each note, we have the length of 7000 symbol, if there is a key to be stricked, the first 5760 symbols represents its location and the following 1240 symbols remain 0; otherwise, all 7000 symbols are 0.

As for the striking torque, we can calculate from the angular velocity and the motor power. We have:

$$T = \frac{P}{\omega} = \frac{1.65[W]}{91.667[s^{-1}]} = 0.018[N \cdot m] \tag{2.2}$$

Here are some tolerance calculations:

1. Error in extracting melody from the song.
   Suppose vector f is the calculated frequency sequence and F is the ground truth sequence. Suppose v and V are the voicing indicator vector, where $v_i = 1$ means frame i has a melody frequency f_i and $v_i = 0$ means no melody detected in frame i. Similar for F and V.
   An Overall Accuracy (OA) measures the ratio of frames that be correctly denoted pitches as [3]

$$OA = \frac{1}{L}\sum_i V_i \tau[\xi(f_i) - \xi(F_i)] + \overline{V_i}\,\overline{v_i} \tag{2.3}$$

   Where τ is a threshold function defined as

$$\tau[a] = \begin{cases} 1\ if\ |a| < const \\ 0\ if\ |a| > const \end{cases} \tag{2.4}$$

ξ describes frequency with a reference frequency.

   Then the error can be calculated as

$$Err = 1 - OA \tag{2.5}$$

2. Delay in hitting the hammer due to variations in signal transmission.

3. Loosening may occur, necessitating regular maintenance, due to frequent tapping and the connections between different materials.

4. For the microcontroller, 12M crystal baud rate is up to 2400, 9600 case will have 7.8% error, so it will produce garbled code, and 2400 baud rate in the case of the error is 0.16%. But after debugging our microcontroller due to performance limitations can only accept baud rate 9600 when transmitting.

2.2 Design Alternatives

2.2.1 Signal Processing Method

At the first glance, FFT is taken advantage of to obtain the frequency of notes. However, this could only generate the frequency spectrum for the whole piece of music, as shown is Figure 4 for the first sentence of “Twinkle twinkle little star”.

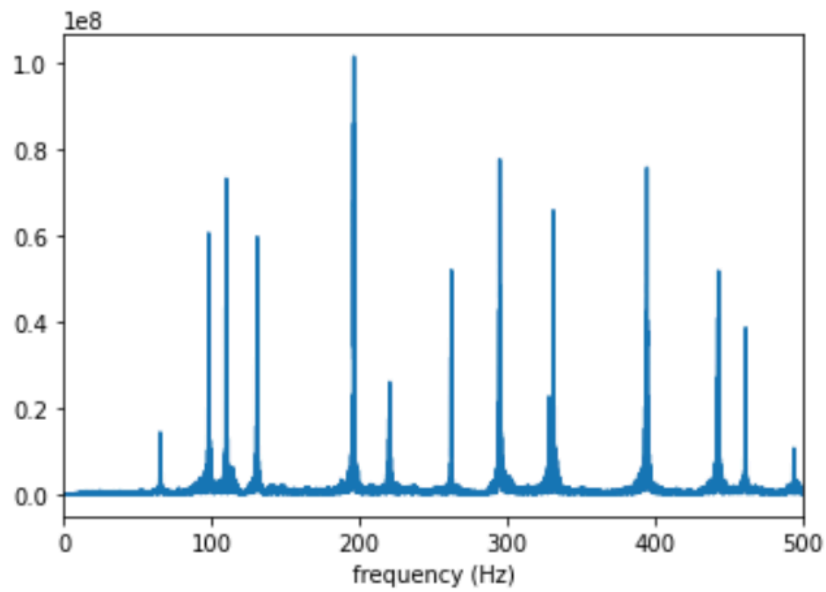

Figure 4 FFT result

To get the note frequency with respect to time, STFT is taken advantage of, and the frequency series is shown in Figure 5.

```
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 261.63, 261.63, 261.63,
261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 261.63, 261.63,
261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63,
261.63, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 415.3, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.
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440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 415.3, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0]
```

Figure 5 STFT result

2.2.2 Melody Extraction Method

Having the time, frequency, and magnitude information, the problem becomes two parts. Firstly, does a time frame contain a melody, that means does it voicing. Secondly, what should the pitch of the melody be in that time frame. To solve these questions, my first design was to use a deep neural network to automatically learn the character of the melody. However, due to the limitation of hardware, it is hard to run the model fast to recognize the melody, which does not align with our project goal: live recording and play the chimes. So, I decided to change my method to a more traditional way, mainly based on the salience function. According to my research, the salience-based method can also reach accuracy enough for our application with easier hardware requirements.

2.2.3 Motor Supply Voltage

Initially, the motor is connected to the I/O pin of microcontroller directly as both the operating voltage of motor and I/O pin output voltage is between 3.3 V and 5 V. However, this does not work as the output voltage of microcontroller is only about 2.5 V when the setting is 5 V. There are two assumptions about the output voltage: a) the output is a square wave with duty cycle of 50%. b) there is some problem with the output voltage.

For reason a, we tried to connect a capacitor in parallel with the motor, as shown in Figure 6. By this means, an output of 2.5 V with less ripple is generated. However, the motor still did not work.

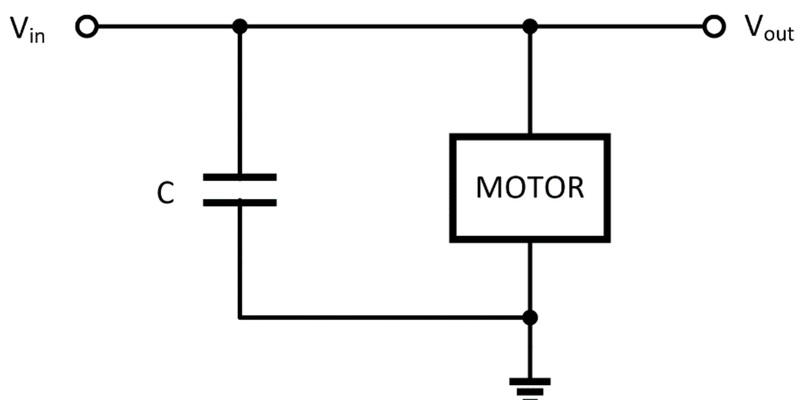

Figure 6 Design with capacitor

For reason b, we tried to connect the I/O pin with the gate of a set of NMOS and PMOS, then the output voltage to motor, as shown in Figure 7. In this way, the motor is connected to a higher voltage, e.g., 3.3

V, and the output voltage of microcontroller operates as the control volatage of a witch. But it worth noting that the voltage is set to low when there is a hitting, and it remains high for no actions.

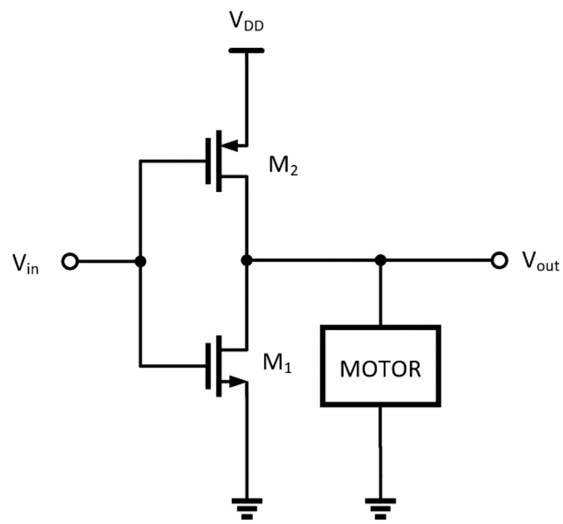

Figure 7 Design with CMOS

The actual circuit is shown in Figure 14.

2.3 Design Descriptions & Justification

2.3.1 Melody Recognition and Generating System

The model will be trained to automatically recognize the main melody from a period of sound played by the smartphone and adapt to Chinese traditional style for chimes.

The Subsystem has the following functions:

a. Sound Recording. We will record a 30s long audio through our laptop sound receiver and save it as an audio file. This function serves as the start of the interaction of this project.
   The recording parameters are set below:

```
CHUNK = 1024
FORMAT = pyaudio.paInt16
CHANNELS = 1
RATE = 44100
```

b. Preprocess. Then, we will use python to preprocess the audio file, reducing noise and cutting off empty periods in the audio. We calculated the volume peak of the audio and started from the time with the volume above one fourth of the peak volume.
c. Melody Extract. We will identify the melody by extracting the frequency sequence. We will use a combination of signal processing method and data driven method. The process shows as figure 8:

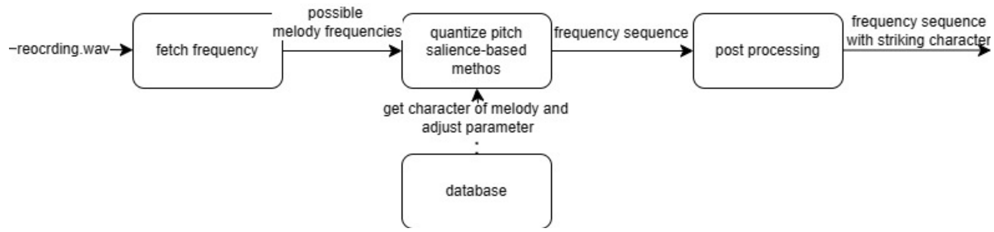

Figure 8 Procedure of melody extract

The melody extraction is a salience-based method. Firstly, we do frequency fetch. This step is to get the candidate melody frequency for each frame. We apply an STFT and keep frequencies with a magnitude larger than the threshold as the candidate frequencies.

Then, we quantize the pitch. This process will determine which frequency or none of the frequencies in a certain frame should be detected. We generate melody contours based on the frequency and magnitude continuity. We recursively searched frequencies with difference smaller than 1 Hz into the same contour and cut the contours if the magnitude difference is large. Finally, we select the contour using the equation ?:

$$score = avg(mag_c) \cdot \max\big(avg(mag_i)\big) \cdot Weight1 + match \cdot Weight2 \qquad (2.6)$$

Where mag is the list of magnitude of a contour, match is the percentage of the frequency has the maximum magnitude in that time frame. We choose the contour with larger score when contours overlapped time interval.

All the parameters of the above process are adjusted for a better performance of the following dataset.

Table 1 information of related public music recording dataset

Name	Sampling rate (in KHZ)	Pulse code modulation (in bit)	Genres	Duration (in seconds
Medley DB	44.1	16	Daisy, Jazz, Opera, MIDI, Pop	20

d. Finally, we do post processing. The post processing contains 2 steps. Firstly, we filter out notes with small magnitude, extreme large or small length. Then we continue some notes with several "0" intervals. Secondly, we do a tune switch, increase or decrease several half-tones so that more notes can be implemented by the chimes.

e. Melody Signal Converter. Finally, the frequency sequence will be converted to the signal. With certain interval, pitch frequency, and strength, the information of notes could be proceeded to the microcontroller digitally at certain frequency. This function served as a connection between Melody Recognition and Generating subsystem and Electrical Control subsystem. The first two bits are for controlling, with “00” no hitting, “01” indicating the number of notes in the following harmonica, “10” containing the key to be stroke. If it is in “01” mode, the following 3 bits show the number of notes to be performed together; if it is in “10” mode, the following 3 bits present the key location to be played and the 2 bits after that contain the strength of hitting. Then they will be transmitted to the microcontroller with certain frequency by a USB cable. There will be 8 keys (3 bits) and 4 strengths (2 bits) in total.

Here is the sample testing result for songs, we can see the program generate clear and recognizable notes:

The monophonic melody sequence result:

```
quantized_sequence is: [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 261.63, 261.63, 261.63, 2
61.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 392.0, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 2
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 0, 0, 0, 0, 415.3, 369.99, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0,
392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 4
40.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 440.0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 440.0, 440.0, 440.0, 440.0, 44
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392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 392.0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 369.99, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 3
49.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 0, 0, 0, 0, 0, 0, 349.23, 349.23, 349.23, 349.23, 3
49.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349.23, 349
.23, 349.23, 349.23, 349.23, 349.23, 0, 0, 0, 0, 349.23, 349.23, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 3
29.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 0, 0, 349.2
3, 349.23, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63, 329.63,
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3.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 293.66, 0, 0, 0, 0, 293.66, 293.66, 261.63, 261.63,
261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 26
1.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 261.63, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
```

Figure 9 monophonic melody sequence result

2.3.2 Electrical Control System

The system will transform the generated melody to location and time signals (for different pitches and rhythms) and build a microcontroller.

The plan is to use a microcontroller to convert the input signal (8-bit signal) into a switch to control the circuit, and to control the thyristor to realize the circuit on and off. By connecting eight mechanical hammers to each of the eight circuits, the signal input to the mechanical part of the conversion is realized by using controllable thyristors MOSFET to control the on-off time of the circuit. The control voltage of the microcontroller is in the range of 3.3-5V, which is smaller than it can be used by the hammer(6-12V), so we add an amplifier circuit to get higher output for the MOSFET to control the motors.

We use C language to control the microcontroller and the serial port communication is UART and we use Baud to be 9600 to convert signal, smaller or higher will both cause errors in transmission of information. And we use a state machine to control 8 outputs, using P20-P27 to be the output ports, when the 3-bit is 000-111, one of the 8 pins will be outputting high voltage. And then the voltage will control the targeted MOSFET (1-8) Gate, and all Source will be connected to the output of amplifier circuit which will be 6-12 V, according to the needed voltage of motors, and the Drain will be connected to the motors. (see figure 9 for the outside control circuit)

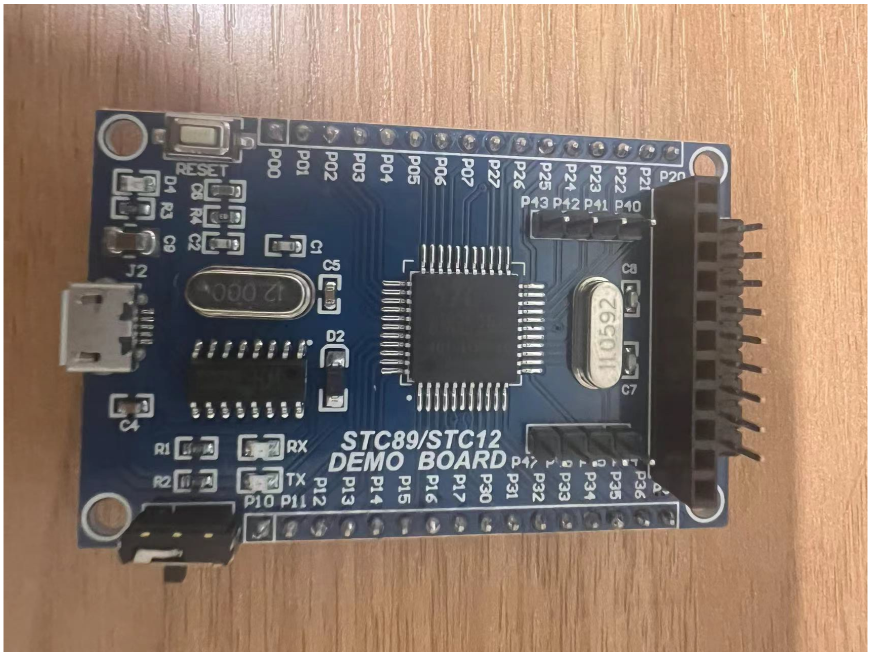

Figure 10   microcontroller system board

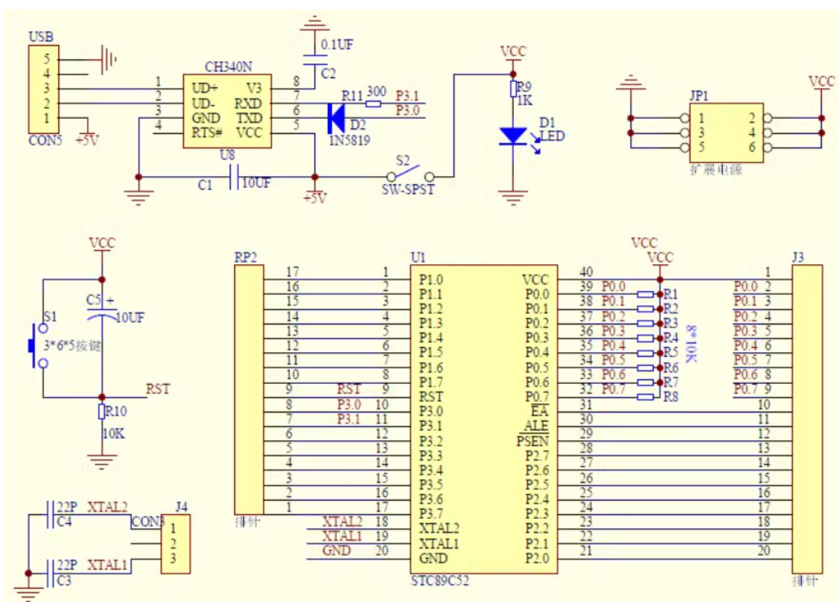

Figure 11   PCB layout for microcontroller

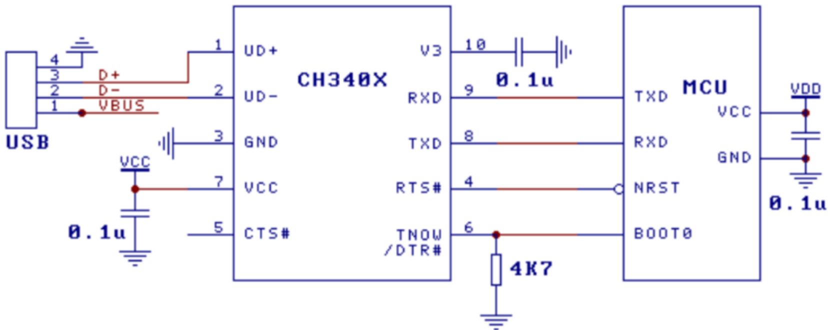

Figure 12 Data download circuit

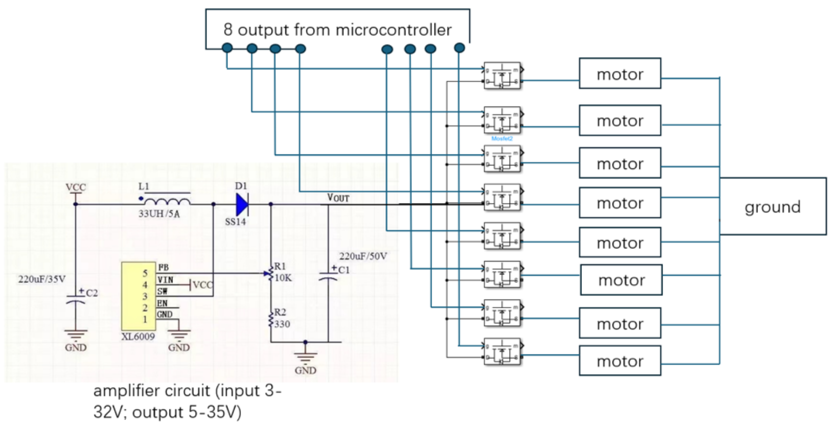

Figure 13 outside control circuit (LEDS and resistors are not shown in the diagram)

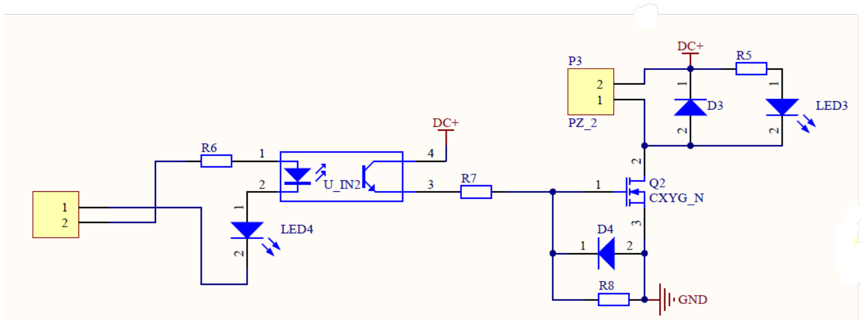

Figure 14 sample subcircuit in PWM board

2.3.3 Mechanical System

The main structure consists of a frame, a driving motor, and drumsticks. For aesthetic and practical considerations, the motor will be positioned between two rows of water cups, with one motor controlling two drumsticks, aiming to reduce the number of motors and the weight of the structure.

The precise emulation of human percussive actions using wooden sticks to strike the chimes constitutes the crux of the entire mechanical structure. To achieve this functionality, my focus is divided into two primary aspects: optimizing the trajectory and velocity of the wooden sticks.

Firstly, the essence of percussive strikes lies in the necessity for the velocity of the stick to increase as it approaches the target, followed by a gradual deceleration upon impact. Given the uniform rotational motion of the motor, I prioritize the utilization of a four-bar linkage mechanism[5][6][7] to accommodate this requirement effectively.

Secondly, in pursuit of identifying the optimal motion trajectory, I employ simulation tools to visualize the movement paths, facilitating the determination of the ideal relationships between the various linkages. This meticulous approach ensures the attainment of precise and efficient percussive actions, thereby aligning with the overarching objectives of the project. The optimal combination of four-bar linkage is shown as below, with the ratio of groud link, input link, output link and floating link is 10:5:16:20.

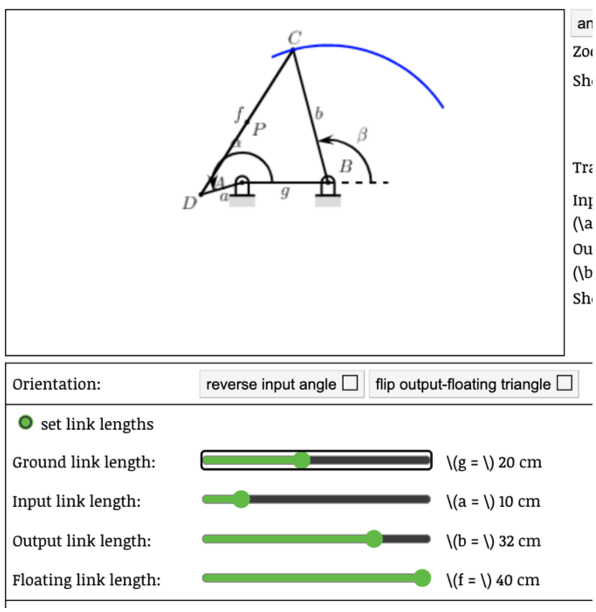

Figure 15 Simulation of Four-bar Linkage

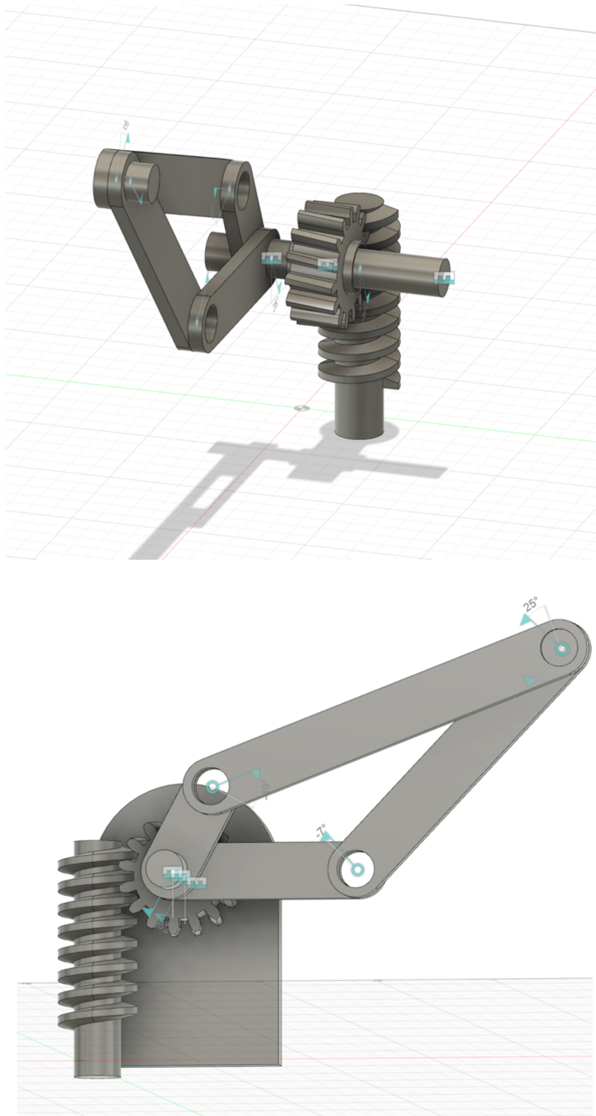

Figure 16 Screenshot of CAD Model

For the percussion structure, we will employ small-sized direct current (DC) low-speed motors for driving. The speed is around 90 rpm. Power Subsystem should contain relays, pulse control instrument and PLC, and be able to supply the rest of the system continuously at around 6V.

To ensure crisp and stable tapping sounds, we intend to utilize wooden rods as the material for the drumsticks, driven by a worm gear mechanism. The hammer should provide at least 5 N·m exciting force. The drumstick should be well controlled after the first strike to avoid redundant strike. We will control the signal time-step or the power supply time-step to limit the phase change of the stick.

Additionally, we utilize the siphon effect to add an automatic water filling function to the water cups.

2.4 Subsystem Diagrams & Schematics

2.4.1 Melody Recognition and Generation System

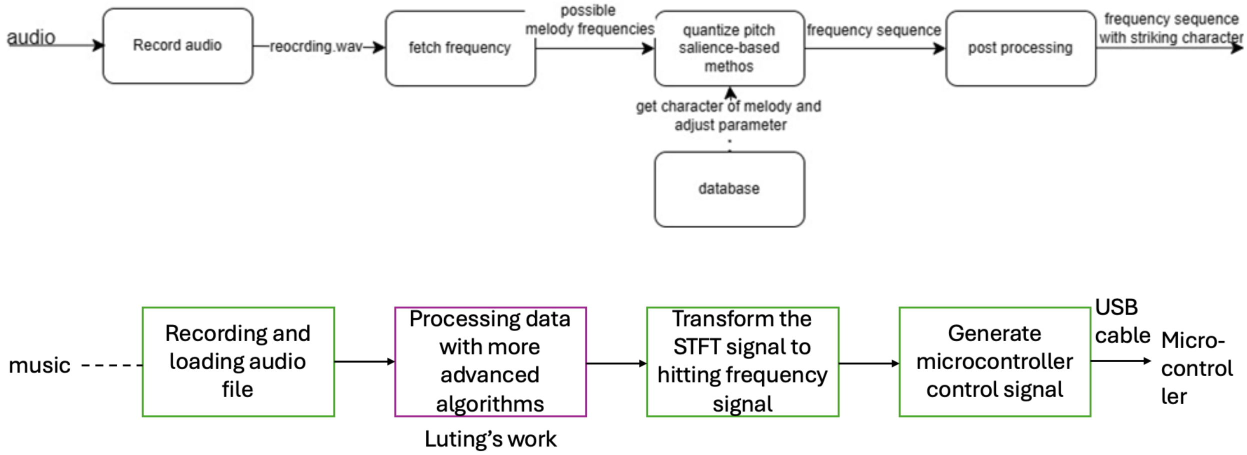

Figure 17 Melody recongnition and generation system diagram

2.4.2 Electrical Control System

Figure 18 Electrical control system diagram

2.4.3 Mechanical System

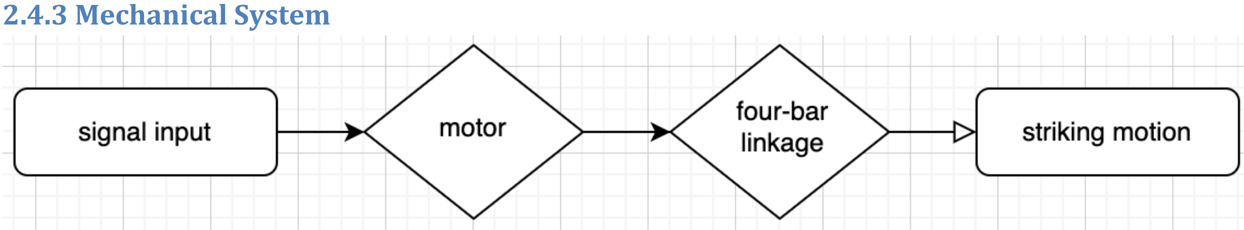

Figure 19 Mechanical system diagram

3. Cost and schedule

3.1 Cost analysis

Table 2 Cost Analysis of Labor

Name	Hourly Rate	Hours	Total	Total x 2.5
Tianle Wu	$37	10weeks * 10h/w	$3700	$9250
Luting Lei	$37	10weeks * 10h/w	$3700	$9250
Siyi Li	$37	10weeks * 10h/w	$3700	$9250
XiaoXiao Pan	$37	10weeks * 10h/w	$3700	$9250
Total			$14800	$37000

*We use an average EE engineer salary as an hourly rate.

Table 3 Cost Analysis of Materials

Part	Cost (prototype)	Cost (bulk)
Microcontroller system	￥18	￥18
Traditional Chinese Chimes	￥88	￥88
Cups	￥48	￥16 per 6 cups
Pneumatic hammer	￥10	￥10
fastening	￥200	￥200
Motor and	¥360	¥30 per motor set
Wood stick	¥3.33	¥3.33
acrylic plate	¥72	¥24 per (500*500*3mm)
battery	¥40.89	¥40.89 for 20 pieces

3.2 Schedule

Table 4 Schedule

Time\group task	Luting Lei	Tianle Wu	Siyi Li	Xiaoxiao Pan
Week 6	Finish the pipeline to generate signal for microcontroller, develop algorithm of monophonic as baseline		Testing on whether the Chimes can be used to perform, otherwise using some other objects like cups with water to replace.	
Week 7	Continuously develop algorithms of more complicated melody extraction		Adjusting the instrument we decide to work on, including the intonation and the force that needed to strike.	
Week 4/15	Optimize algorithms and research on melody recompose;	generating required rhythm and microcontroller control code	Got new microcontroller and working on the printed circuit board of the brought one.	Create primary model with CAD and manufacture the prototype

Mid-test	Testing on doing simple melody on the cups controlled by electronical part			
Week 4/22	Running on database, adjusting parameters, increasing the accuracy of the algorithm	Connecting control code with microcontroller	Coding on the new microcontroller and get the initialized output voltage control. And then work on the connection between the data file and the output signal.	Adjusting the prototype. Add the auto-injection function
Week 4/29	Combining the complete two parts for functions: recognition + performance. Doing test to make sure the system can work.			
Week 5/6	Adjust details for demo, add little chord or recomposition to make the melody more pleasant	Test the control code transmission in more advanced functions	Adjustment on signal control.	Final adjustment on prototype
Week 5/13	Final demo			

4. Requirements & Verification

The requirements and verification of melody recognition and generation system, electrical control system, and mechanical system are shown in Table 2, Table 3, and Table 4 respectively.

Table 5 Requirement and verification of melody recognition and generation system

Requirement	Verification	Verification Status
1. The environment for using our product should be in a quiet space and the song should be relatively loud. We define 54 db as the sound threshold, which means a sound louder than 54db will be considered as the song we want to identify. 2. Considering the data we used to adjust our parameter, we also limited the song to a limited length of 30s.	Procedure: (b) Run firstly a program to test whether the audio is good after the audio is recorded. (c) The program should detect the average volume of each time window, with a threshold of 54 dB. The window with an average volume larger than 54 dB will be considered as an audio part, while smaller than 54 dB will considered as an empty part. (d) If the program detects the audio part with a length larger than 10s and smaller than 30s, then the audio is considered good.	1. Y

The program successfully generates the right frequency sequence	Procedure: The control signal will be generated in particular frequency, especially a couple of times of the detected beat. If the signal showing there is a note appears periodically, it means the beats generation is successful.	2. Y
The program successfully generates the correct rhythm	Procedure: Comparing the generated durations between every two notes nearby with the original music, if they match with each other, the rhythm generation is successful.	3. Y
The program successfully generates the correct control code for microcontroller	Procedure: If the control code starting with "10" appears at the same location as that in frequency sequence, and there is always a control code starting with "01" leading it; the number of notes and note location match with the original song, the control code generation is successful. It can also be verified by inputting the control code sequence into the microcontroller directly and listen to the generated song.	4. Y
The chime generates correct notes which performs the regenerated song	Procedure: The melody performed by the chime could also be recorded, and then compare it with that performed by the phone in frequency domain with stft function.	5. Y

Table 6 Requirement and Verification of Electrical Control System

Requirement	Verification	Verification Status
1. Processing the input signal and then getting the output voltage from the microcontroller system. 2. Using the voltage signal, including the	To be specified, we plan to use the whole microcontroller demo board, including clock, LEDs, chips. (As figure 5 shown) We try to use Keil UVision4 to program the microcontroller, to implement this function. We use C language to program the microcontroller. We need first to get the input signal, which is supposed to be 8 bits signal in the text file or just can be copied to the transform area. So, we need to figure out how to identify text file using microcontroller, use CH340 chip to convert USB signal to the data that can be recognized by the microcontroller, and then use C language to make	Y

message of time and which pitch the machinal damp will strike, to control the machinal part.	state machine, getting output voltages from microcontroller and then sending them to control the motors. For the outside circuit: Use 8 MOSFET to control the circuit, and we got a PWM control board to manage the function, including 8 MOSFET and 16 LEDs and some resistors to control the whole circuit. Each load includes 1 MOSFET and 2 LEDs to show whether the MOSFET and motor is on.	

Table 7 Requirement and Verification of Mechanical system

Requirement	Verification	Verification Status
The automated infusion of water into a cup ceases upon reaching the specified height.	Procedure: The visual observation is conducted to ascertain whether the automatic water dispensing function halts precisely at the calibrated line. Subsequently, software designed for pitch detection is employed to assess the accuracy of the pitch emitted by the water-filled vessel upon reaching the prescribed level.	/
Whether the capacity to accurately simulate manual tapping actions is achievable.	Procedure: Initiate the motor and observe the trajectory of mechanical components. Utilize a glass cup to evaluate the efficacy of the tapping effect.	/

5. Conclusion

5.1 Accomplishments

We have basically finished the melody retrieving and performing on chimes for monophonic music. For the melody recognition and control code generation, we succeeded in obtaining the frequnce sequence and transform it to microcontroller control code. For the electrical control part, it successful enables the corresponding motor. For the machenical part, the wooden stick, together with the connections, could generate a clear sound. Though the chime is replaced by glass with water to perform a piece of music, it still has good performance in generating clear and precise pitch.

5.2 Uncertainties

The melody extraction step cannot recognize all the melody notes perfectly, so some wrong notes may be played by the chimes.

Due to the low performance of the microcontroller and the possibility of poor contact, there is some uncertainty about the existence of the signal that drives the motor to the signal in the tapping experiment.

5.3 Future Work/ Alternatives

1. Though there is still some implementations for harmonics and corresponding control code generation, it is still difficult to perform it as the reaction time of motor is less controllable than our imagination. In the future, we could deal with this technical problem and play more complex music.

2. There are only 7 notes in the current design, limiting the music to be performed. The thing to be done is to improve the melody recognition and control method, together with building more chimes, then it is more flexible in playing music.

3. Striking speed and frequency are limited since our design can only achieve striking one time per revolution of motor.

4. The melody extraction algorithm for polyphonic songs is not accurate enough, there are some notes not detected and some frequencies that do not belong to melody are detected. The accuracy can be improved in the future.

5. Using a PWM amplifier circuit instead of a separate MOSFET and adding LEDs to form the control.

5.4 Ethical Considerations

The IEEE Code of Ethics emphasizes the importance of protecting the public, so we will ensure the entire cups and the mechanical parts of its striking are capable of safe operation. However, there are still the following points worth noting:

1. The overall mechanical part of the false placed on the horizontal surface to prevent accidental fall damage, affecting safety.

2. The whole mechanical structure should be placed in a place that is not easily touched by children, to prevent children from accidentally ingesting or being injured.

3. It may not be suitable for people with impaired hearing to use it, and some of the chimes are too high-pitched, which may cause auditory impacts to some groups of people. When we change to cups with water, we can control the pitch to around C3-C4, not too high for people to preform.

4. The primary ethical concern would be ensuring the safety of individuals interacting with the structure. If the striking mechanism is too forceful or unpredictable, it could cause injury to users or bystanders. Improper tapping technique and force may cause the glass cups to topple, potentially resulting in dangerous glass shards and injury incidents.

5. Consideration should be given to potential malfunctions of the striking mechanism. For instance, if it is used inappropriately or lock itself, it could lead to unintended damage or harm.

At the moment, based on the materials we have purchased, the chimes themselves do not have the intonation we would expect, and to a certain extent they are not even playable in their entirety; the pitches the twelve bells can produce are not fully recognizable by professional software and are in a range of fluctuations that are not fully under control.

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