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Working with Electrons

21 May 2020

Music Wheel

1. Project Title

Music Wheel

2. Project Description and Significance

Usually, music boxes are powered by spiral springs while the plectrums make the sound. However, we are thinking of the possibility of combining the concept of music box with that of the Ferris wheel. Our plan is to create an unusual music box that not only play out a piece of music but also has mechanical motions externally. In our project, we build a special music box that rotates like a Ferris wheel, which is also how its name, "music wheel", comes from.

To turn our design into reality, a comprehensive understanding of circuit and electromagnetism is required. Also, this project contains a lot of handcrafting work that needs careful research and design beforehand.

3. Literature and Art, Perspectives and Contexts

3.1. Sky Wheel

The outlook of our music wheel is basically based on the structure of sky wheels. As a spinning object, sky wheels are something that involves both art and science. By learning about the sky wheels, we could understand how art is combined with science, and how to design our own structure. By researching on architecture *The Yongle Bridge Tientsin Eye*, a famous sky wheel located in Tianjin, China, as well as other world-famous sky wheels, we analyzed the framework of the sky wheels.

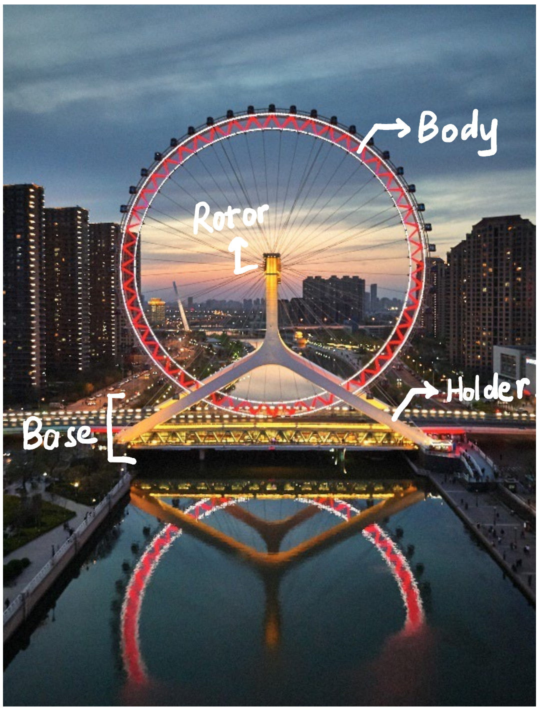


Figure 1 Picture of The Yongle Bridge Tientsin Eye in Tianjin.

The basic structure of a sky wheel can be concluded into 2 parts – the base and the body. To make the architecture stable, two holders stand by each side of the body part. And the two holders are connected to the rotor of the sky wheel, as well as the bottom. As for the body part, it is can be described as a large circle whose center is connected to the rotor between two holders. The body has several branches, supporting the large circle outside. Besides the skeleton, sound and light effects are also crucial to a sky wheel. Designers usually add light strips to the outline and branches of the sky wheel to make it more elegant in the night.

$$p = 69 + 12 \times \log_2 \frac{f}{440\ Hz}$$

3.2. **Phonograph and CD**

When thinking of “rotation” and “sound”, the first machine that come into our mind is the phonograph. To make our wheel producing sound, the phonograph is something we could consider. As a result, we started on researching the theory behind this old invention.

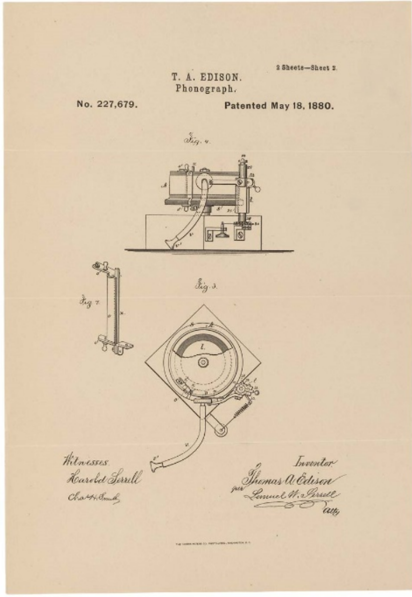


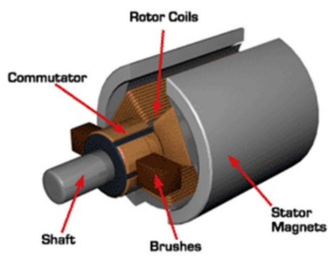
Figure 2 Patent drawing for Edisons phonograph, May 18, 1880

The basic components of a phonograph are a disc, a stylus and a speaker. Tiny grooves are engraved on the disc in a spiral order, the series of the grooves in different depth represents the waveform of the sound. By connecting the stylus to the vibrator of the speaker, we can turn the grooves into the sound that we can hear. In the model of phonograph, the disc has turned the sound into some physical structure, via the convey of motion, this physical structure finally turned into the sound.

4. Project Design, Experiments, and Production

4.1. Research

4.1.1. Maxwell’s Equation and Stepper Motor



One of the primary components of our project is electromotor. Electromotor is closely related to Maxwell’s equations. Maxwell’s equation can explain its essential principle. Though there are various types of electromotors with different internal structure, all electromotors consist of permanent magnets and electromagnets (or, coils). The picture on the right side illustrates the structure of a typical DC brush motor.

The fourth equation in Maxwell's equation explains how electromotors works. The fourth equation in Maxwell's equations defines the quantified relationship between changing electricity and magnetic field.

Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial \Sigma} \mathbf{B} \cdot \mathrm{d}\boldsymbol{l} = \mu_0 \left(\iint_{\Sigma} \mathbf{J} \cdot \mathrm{d}\mathbf{S} + \varepsilon_0 \frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{E} \cdot \mathrm{d}\mathbf{S} \right)$	$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$

From the differential equation, we can see that if a constant current J is given, a constant magnetic field will be generated. Thus, when current passes through the coils, the coils generate a magnetic field. And that magnetic field interferes with the magnetic field of the permanent magnets and pushes the rotor to rotate.

Some electromotors can detect rotating speed and rotating position. Maxwell's equations can explain it as well.

Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial \Sigma} \mathbf{E} \cdot \mathrm{d}\boldsymbol{l} = -\frac{\mathrm{d}}{\mathrm{d}t} \iint_{\Sigma} \mathbf{B} \cdot \mathrm{d}\mathbf{S}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$

In Maxwell's third equation, we can see that a changing magnetic field B can produce an electric field E. Therefore, when the rotor rotates, the relative position of the coils and permanent magnets are changing, which means the magnetic field passes through the coils are changing. The corresponding electric field will generate a current in the coil. If there is an external circuit detecting that current, the information about the rotating speed and rotating position of the motor could be fetched.

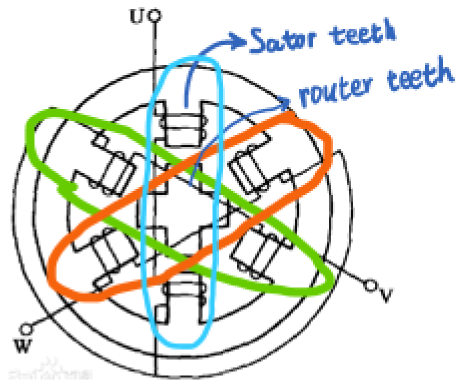
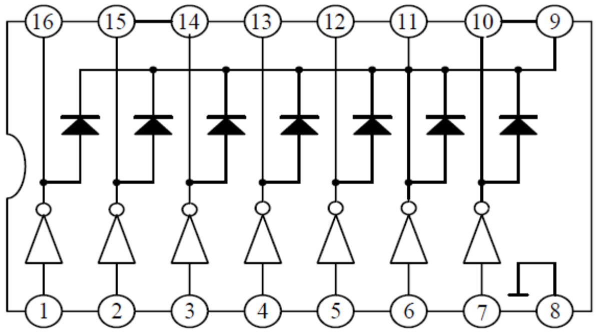


Figure 3The Internal Structure of Stepper Motor

While ordinary motors are cheap and easy to drive, stepper motors work more silently and support more precise speed control. In our project, we want to precisely control the rotating speed of the motor and get rid of its noise, so we particularly focus on the stepper motor, whose working noise is low and speed can be controlled. Basically, a stepper motor is a kind of motor that can rotate certain steps in response to the electric signal given to it. There are many kinds of stepper motors, one of the simplest kinds, however, is the three-phase variable reluctance stepper motor, as shown in the picture. This motor has six stator teeth and can be energized with three separate DC power sources, and also four rotor teeth. When we energize one pair of stator teeth, the router could turn in to the position corresponding to the sator teeth under the attract of the magnetic force. And when we dis-energize this pair of sator teeth and energize the next pair, the router would spin into the next position. As we continue this process, the router would spin endlessly.

4.1.2. **ULN2003 IC**

Unlike ordinary motor, which can be directly driven by DC power source, stepper motors must be driven by a motor controller. In our project, we chose to use Arduino UNO together with ULN2003 IC. Basically, the ULN2003 is designed to amplify the current and increase the drive capacity. Its internal diagram is as follow:



The ULN2003 is a high-voltage, high-current-composite transistor array consisting of seven silicon NPN composite transistors (Darlington tube). It is also a 7-way inverter circuit, i.e. when the input is high, the ULN2003 output is low; when the input is low, the ULN2003 output is high. The driving current of each unit can go up to 500mA. The current on the Arduino's output ports is far from enough to drive the motor, so we need ULN2003 to amplify the current.

4.1.3. **Conductive Slip Ring**

In our project, part of the circuit is fixed on the wheel and rotates with the wheel, while the others are static. In order to connect the two-part circuit, we must do so in a way that is not affected by relative motion. If we simply use wire connections, the wires get tangled together in the rotation and eventually stop the movement. Inspired by the drone gimbals, we came up with the idea of using a conductive slip ring. Drone gimbals can usually be rotated infinitely horizontally. This is because it uses a conductive slip ring to connect two parts of the circuit that move relative to each other, avoiding the problem of connecting with wires. Here is an illustration of how conductive slip ring works:

Figure 4 Drone Gimbal

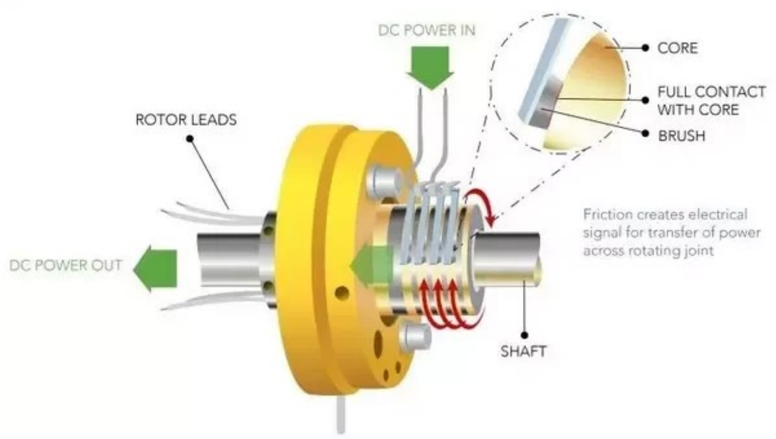


Figure 5 Internal Structure of Conductive Slip Ring

4.1.4. **Frequency and Pitch**

With the NE555 oscillating circuit, we are able to generate a square wave, or PWM signal, with a specific frequency. A speaker converts such an electronic signal into sound signal. According to our previous research, we know that the time interval of each pulse can be calculated by the following formula:

The high time interval of each pulse is given by:

$$t_{high} = \ln(2) \cdot (R_1 + R_2) \cdot C$$

The low time interval of each pulse is given by:

$$t_{low} = \ln(2) \cdot R_2 \cdot C$$

In other words, the frequency of the sound signal can be precisely calculated when the capacitance and resistance are given. However, when we speak about music, we use the term pitch rather than frequency. Therefore, if we want to build a music box from an ordinary oscillating circuit, we have to find a way of converting between pitch and frequency.

Indeed, frequency describes the oscillating speed from the perspective of waveform, whereas pitch tends to describe it from human perception perspective. Since human ears' perception to frequencies are log-linear, the relationship between frequency and pitch can be depicted with a logarithmical function. One octave up in pitch is equivalent to doubling the frequency. In accordance with established practice, we defined A4 to be 440Hz. And so on, we can do calculation to know that C is approximately 261.63Hz. Furthermore, we can have a more general formula:

$$p = 69 + 12 \times \log_2 \left(\frac{f}{440\ \mathrm{Hz}} \right)$$

With it, we can easily decode a piece of music from its score into a sequence of circuit parameters.

4.2. Experiments

4.2.1. First Test on Arduino

Since Arduino is a new component that we haven't used before, it took us some time to figure out how could we let the Arduino to work properly. As a trial, we tested the example from official Arduino document, building up a blinking LED. Basically, the Arduino uses C or C++ as its programing language. And as least two functions are necessary. 1) The *setup()* function. it runs as Arduino initializes – it runs only at the first time. 2) The *loop()* function, this function runs after the *setup()* function and goes over and over again if not being forced to stop. In the experiment below, we set pin D13

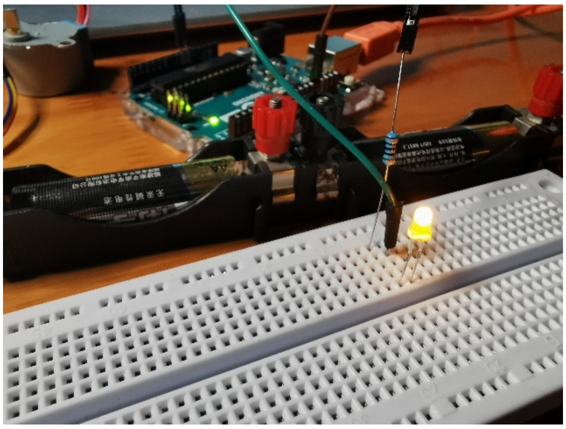


Figure 6 Sub-experiment with Arduino. The LED is blinking.

to the output in the *setup()* function; in the *loop()* function, we firstly set the output to give out high voltage and delay for 1000 milliseconds, then we set it to low voltage and delay for 1000 milliseconds; after that, the program loops, making the LED blink. Below is the code for this experiment.

```
void setup() {
  pinMode(LED_BUILTIN, OUTPUT);
}

void loop() {
  digitalWrite(LED_BUILTIN, HIGH);
  delay(1000);
  digitalWrite(LED_BUILTIN, LOW);
  delay(1000);
}
```

4.2.2. **Make Stepper Motor Work**

This experiment is the key step for us to realize our design. To make the stepper machine work, we need to connect Arduino, ULN2003, the stepper motor and the power together. The basic idea for this experiment is to let Arduino produce a series of pulse signal, then, let the ULN2003 to magnify the signal, making the power strong enough to drive the stepper motor. As shown in the circuit at the right side.

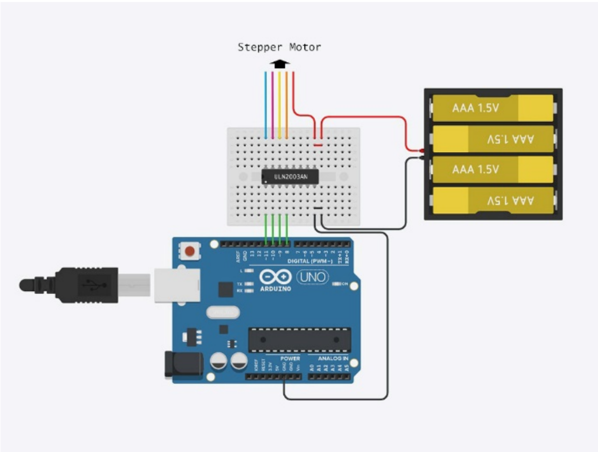


Figure 7 Our design for driving the stepper motor.

For Arduino, we use a built-in package called Stepper.h to help us work more conveniently. The whole code is shown below:

```
#include <Stepper.h>

const int steps = 64;
Stepper myStepper(steps, 11, 9, 10, 8);

void setup() {
  myStepper.setSpeed(240);
}

void loop() {
  myStepper.step(steps);
}
```

In this program, we firstly set up a Stepper object, assigning pin 11, 9, 10, 8 to be the sequential output ports; then, in the setup() function, we set 240 to be the initial speed of the motor; finally, in the loop() function, we let the stepper motor to go one step each loop. Here is the outcome of our experiment.

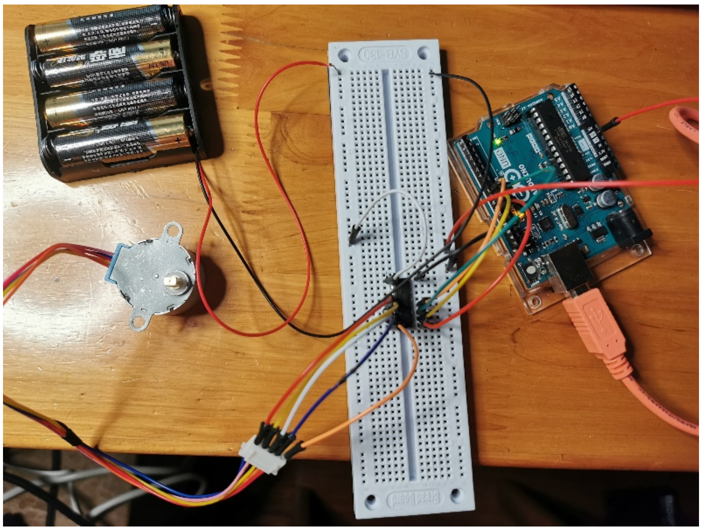


Figure 8 Connecting all the components to make the stepper motor work.

4.3. **Production**

4.3.1. **Wooden Structure**

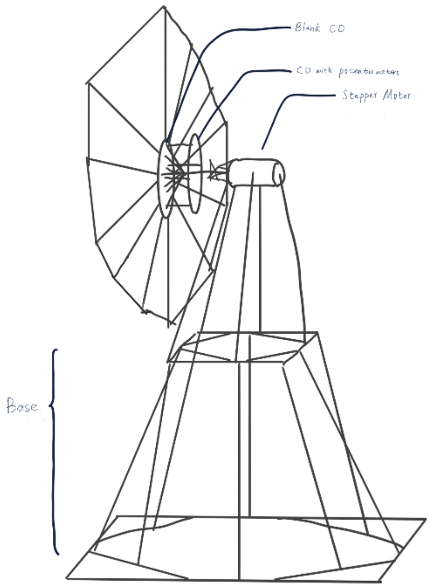


Figure 9 The draft for our wooden structure design.

Our wooden structure's design was basically based on the structure of the sky wheel. However, instead of using 2 holders by each side of the rotor, we just used one – this might be a little unstable, but enough for our current work. We used hot melt glue to connect the stickers and other components. One thing to mention is that due to the hand-made process is not always accurate and precise while we cannot guarantee all the components we have are in the same size, in our exact building process, we dynamically adjusted this structure when needed – sometimes we add more sticks to support one point, sometimes we change the direction or position of existing stick to balance the object.

4.3.2. **555 Circuit**

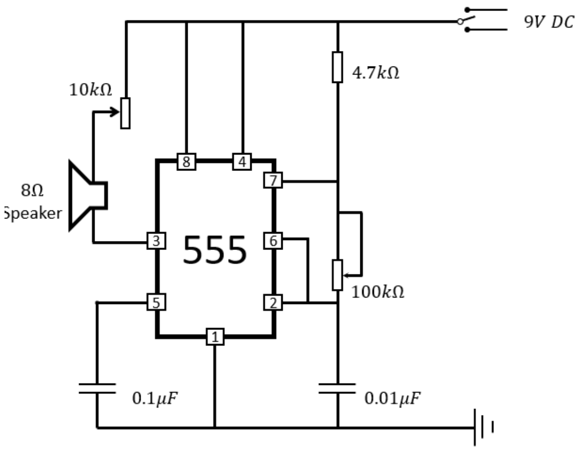


Figure 10 The circuit for producing sound.

We adapted our 555-circuit used in the midterm project. Different from our midterm project in which the prank box needs a high frequency, we need a lower and more musical range of sound frequency to produce sound. As a result, after several test, we decided to change the value of the capacitor connected to pin 5 from 0.01 μF to 0.1 μF. After this change, the sound is more comfortable to hear.

4.3.3. **Note Encoder**

Inspired from the phonograph, we decided to add a CD in the center of the music wheel to store the note information. However, it might be a little tricky for us to make such a delegate phonograph with soft wooden structure. As a result, we designed our own CD (as shown in the picture). Our CD has 2 separate annuluses covered with aluminum foil. The inner one is a complete circle while the aluminum foil in the outer circle is equally divided into 16 sections. We used knife to cut off a thin line between each section, making them in insulation. After that, we glued and soldered one 100k potentiometer between each section and the inner annulus. Once we finished checking all the solder points, we used the 555 circuit to test the sound and modify the resistance of each potentiometer to make the full music.

Figure 11 The back of our CD

4.3.4. **Final Work**

Here is what our final project looks like. To hear the sound and see the motion, click the link to view our final presentation and live demo:

https://www.youtube.com/watch?v=wtYCK3cwIN0

Figure 12 The outlook of our final project.

5. Improvement

5.1. Using PCB for Better Connection

Currently, we use a CD with tinfoil on it as the note encoder. However, this solution does have several severe problems. One of them is that the connection is not good. Since the tinfoil is cut into sections by hand, the surface of the tinfoil is not very smooth. Consequently, when the note encoder rotates, the brush sometimes detaches from the tinfoil, causing the oscillating signal to be unstable. Another problem is that the tinfoil has to be cut by hand, whose precision is very limited.

In order to solve these two problems, we came up with the idea of substituting the CD with a PCB. Inspired by the connection fingers on the GPU and RAM, we imagine a circular PCB that has several connection fingers on the border and a whole round piece of conductive metal in the middle. The PCB is manufacture by machines with high precision, therefore the above two problems can be solved.

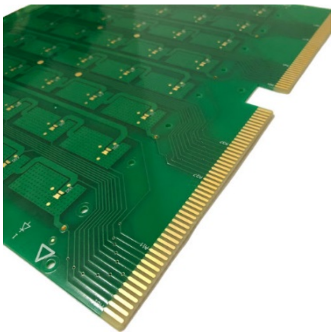


Figure 13 Connection Fingers

6. **Reflection**

6.1. **Feedback from Audiences**

Neil Jiang, Freshman in NYU Shanghai: The machine?? gadget is really creative. They definitely hooked my eye when introducing the idea to give music a physical shape. And the function of the machine/gadget is presented clearly in the video. However, I guess a small hook at the start of the presentation would be more effective. (i.e. have you ever heard of music that moves?) Besides, the second presenter definitely needs a virtual background.

Barry Wang, Sophomore in NYU Shanghai: It is such a well-done project with bold ideas and immense work you put in. The idea of Ferris wheel structure adds aesthetic value and great entertaining effect to the final outcome. The user can easily enjoy a piece of music or interact with it simply by rotating the Ferris wheel. For future improvements, it would be more interesting and attractive to users if you consider turning the wooden structure into a real beautiful Ferris wheel. It will definitely add a lot to the user experience.

Yuhe Lu, a high school senior 2 student: The spinning wheel music box is really cool and looks so complicated that I don't think I could never figure out a way to make it. The music, if I'm not wrong, you used Ode to joy, right? I think the rhythm is a little bit inaccurate, and also, if you could improve the sound (a little bit creepy), then it will be perfect! But overall, I love y'all's ideas and how you explained it!

6.2. **Conclusion**

Deciding on the idea for this project was a difficult task, from the idea of the perpetual motion machine, to the Ferris wheel, to the music box, to the CD player, we combined technical and artistic concerns to get to the final idea. Theres no doubt that our final idea is not only artistically meaningful, its technically challenging as well . This project is the product of our study and research throughout the entire semester. We either spent lots of time on designing the structure and solving technical problems or handcrafting and building the project. Nevertheless, our plan is proved to be too ambitious that we cannot turn everything we have in mind into reality. Several improvements can be done to this project, such as replacing the CD with PCB, hiding all circuit part inside, refining and decorating the external outlook to make it more enjoyable. In short, the process of doing this project has been enjoyable and fulfilling, and if time allows, we will certainly get closer to perfection!

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