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RotatingElves

ROTATING ELVES

082100461, Embedded Systems and Design
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Group SharpShooters

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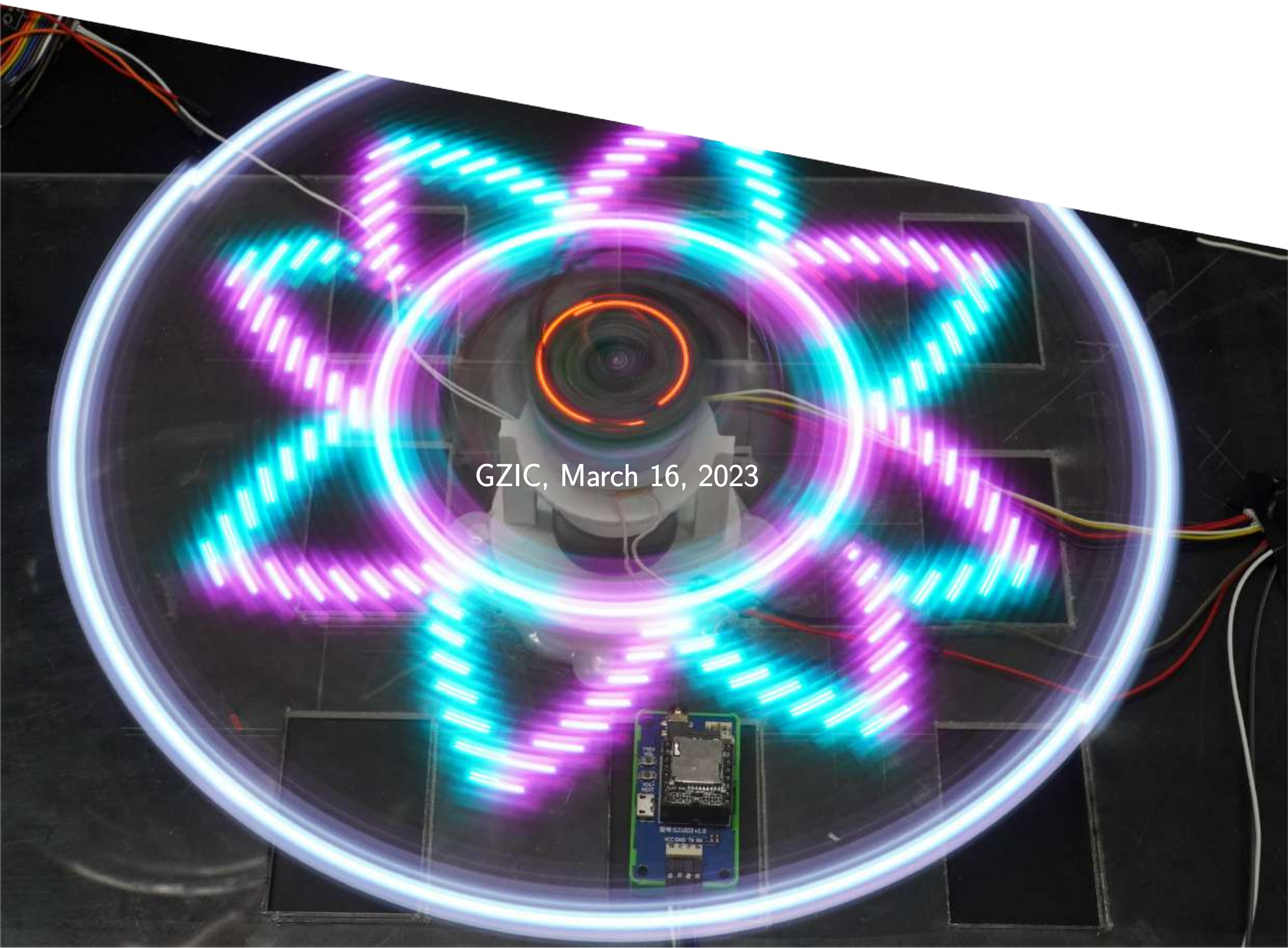


GZIC, March 16, 2023

Contents

1 | Introduction

1.1 | Project Background

A rotating LED is a LED display where many individual LEDs are arranged in a matrix and rapidly cycled through different lighting patterns to create the illusion of movement. Rotating LED displays are often used for advertising billboards, decorative lighting, and other applications where an eye-catching visual effect is desired. The LEDs can be programmed to display customized animations, text, and graphics, as depicted in Figure 1.1. The principle of displaying patterns using rotating LED will be discussed later.

(a) Graphics (b) Animation (c) Text

Figure 1.1: Examples of rotating LED applications

1.2 | Project Requirements

Here, the tasks required in this project and the corresponding section(s) talking about these tasks in this report are summarized as follows,

- Using a motor to rotate a plate where LED and LED drivers are mounted. (Section 4)
- Using a transmitter coil fixed with the stator of the motor to supply energy to the receiver coil mounted with the rotating plate to achieve energy transfer wirelessly. (Section 2)
- Within a minute, the plate should alternatively rotate clockwise and anticlockwise twice. (Section 4)
- The rotating LED should display some animations that are expected to be stationary, colorful and smooth. (Section 3, 5)
- Sound effect is integrated into this system. (Section 6)

1.3 | Our Works

In our project, we build several sub-systems to achieve the required tasks. These sub-systems are discussed in detail in the following sections. The overview of the structure of our prototype is depicted in Figure 1.2.

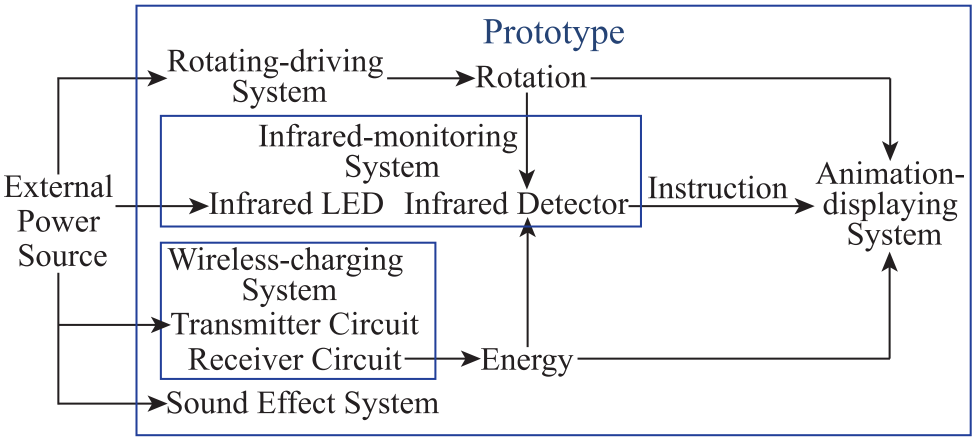


Figure 1.2: Overview the structure of prototype

2 | Sub-system 1: Wireless-charging System

2.1 | Common Types of Wireless-charging

Required by the project, components on the rotating plate should be powered wirelessly. In order to separate the power supply system from the rotating system physically, we need to use wireless-charging technology. At present, there are four main technologies that can be used for wireless-charging, namely electromagnetic induction, magnetic resonance, radio wave and electric field coupling.

2.1.1 | Electromagnetic Induction

This kind of charging system is mainly composed of two coils, the primary coil and the secondary coil. By applying alternating current with a certain frequency to the primary coil, a certain current will be generated in the secondary coil due to electromagnetic induction, so the energy will be transferred from the transmitting end to the receiving end. This charging method has high conversion efficiency and relatively simple technology, but it needs to be close to the emission board and accurately aligned to charge, so it is generally used for short-distance charging. Some relevant details can be found in the web page of this patent.[7]

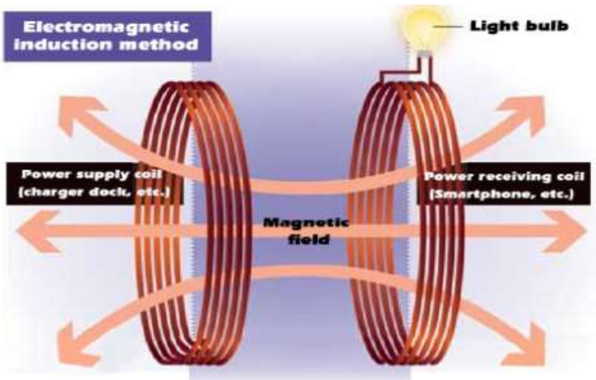


Figure 2.1: Principle of electromagnetic induction

2.1.2 | Magnetic Resonance

Magnetic resonance wireless-charging needs to use two coils in the energy transmitting device and the energy receiving device as resonators, which are composed of large inductance coils made of small capacitors in parallel or series, and transmit energy through resonance effect, and the two devices need to be adjusted to the same frequency. Compared with electromagnetic induction, resonance can extend the transmission distance of energy, and it is not necessary to completely match the positions of coils, but it is difficult to achieve high efficiency and miniaturization

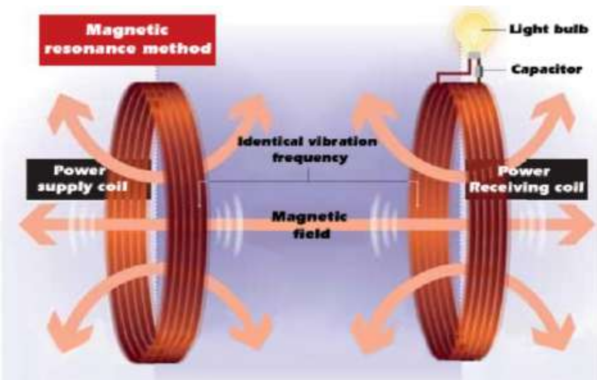


Figure 2.2: Principle of magnetic resonance

2.1.3 | Radio Wave

This technology is to convert electromagnetic waves into current, and then transfer the current through the circuit to charge. Radio wave power transmission system is mainly composed of microwave transmitter and microwave receiver. The microwave transmitter emits radio waves, and the microwave receiver captures the energy of the radio waves and makes adjustments with the load to obtain stable direct current. This power supply mode can be charged anytime and anywhere, but the charging efficiency is low, so it is mainly used for long-distance low-power charging.

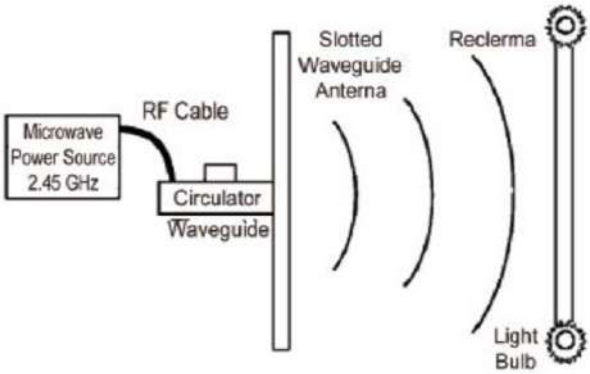


Figure 2.3: Principle of radio wave

2.1.4 | Electric Field Coupling

This technology does not use coils for electromagnetic induction, but directly transmits power through the high-frequency electric field in the capacitor formed between the charging base and the appliance to be charged, that is, by using the induced electric field generated by coupling two groups of asymmetric dipoles in the vertical direction [3]. This charging method has low cost, low alignment requirements, but low energy efficiency.

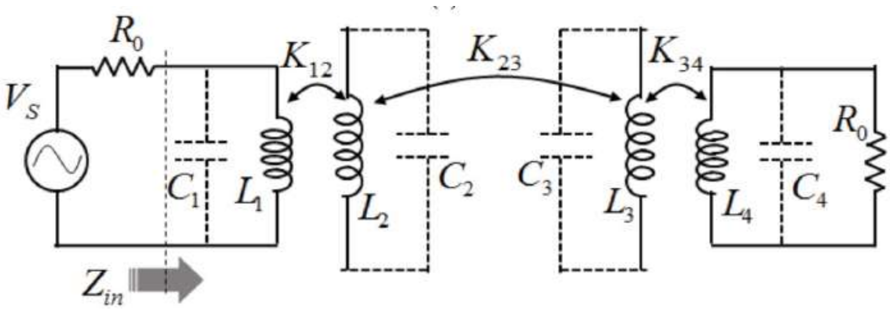


Figure 2.4: Principle of electric field coupling

In our prototype, conversion efficiency and the stability of the voltage supplied to the rotating plate are mainly two concerns, since the voltage supplied by the external source is required around 12 V and the stability of the wireless-charging affects the stability of the animation-displaying. Hence, electromagnetic induction is chosen for wireless-charging.

2.2 | Principle of Wireless-charging Circuit

We use the principle of electromagnetic induction to realize wireless-charging. As shown in Figure 2.5, the specific approach is to use an inverter circuit to convert direct current (DC) into alternating current (AC), which flows through the transmitter coil to produce electromagnetic signals. The receiving coil then induces an electromagnetic signal to produce an alternating current. Finally, alternating current is converted to direct current by rectifying circuit, which acts as the power source for the animation-displaying system.

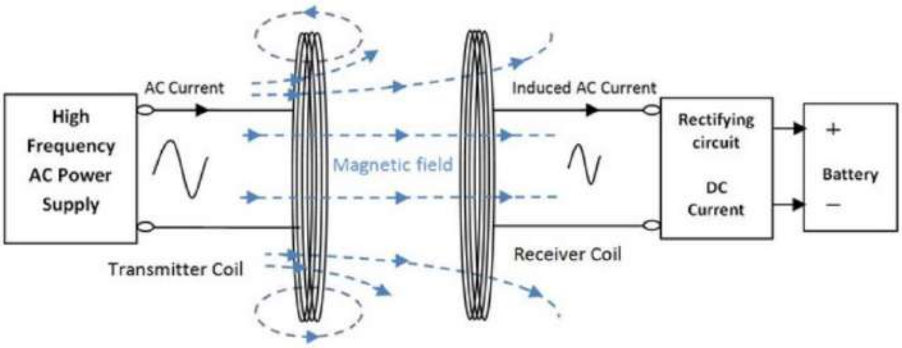


Figure 2.5: Schematic diagram of circuit used in our prototype

2.2.1 | Inverter circuit

We use a NPN type triode Q1, a PNP type triode Q2, a capacitor C1 and several resistors to construct a self-excited oscillation circuit to convert direct current into alternating current. The circuit diagram is shown as follows.

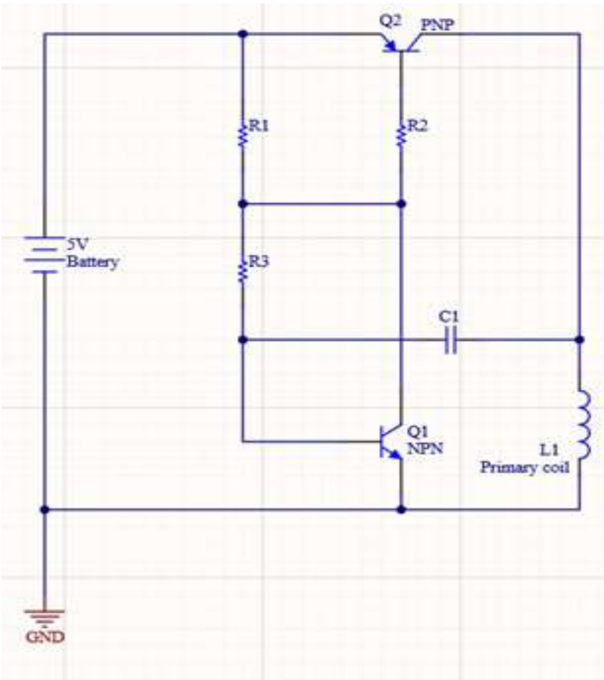


Figure 2.6: Circuit diagram of inverter circuit

The operation of the circuit is mainly divided into the following two stages.

1. Power supply: Current flows from the battery through R1, R3 to Q1's base and capacitor C1, charging capacitor C1. As the voltage of capacitor C1 rises, the voltage of the base of Q1 always is equal to voltage of the capacitor C1. When the voltage is large enough to make triode Q1 conduct, current flows through the emitter and the base of Q2 to the collector and emitter of Q1, and then to the ground.

2. Triode Q2 conduction: The current flows through the collector of Q2. A part of the current reaches the coil L1 and the current through L1 rises. Another part of the current reverses the polarity the capacitor, so that the voltage of the capacitor drops, until Q1 to be cutoff, then Q2 to be also cutoff and the current through L1 drops.

These two stages occur alternately so that the DC voltage output from the power supply is converted to the AC voltage across the coil L1, producing a varying magnetic flux intensity.

2.2.2 | Rectifier circuit

The rectifier circuit is mainly composed of several ordinary diodes, a filter capacitor and a 5V voltage regulator diode. The function of the rectifier circuit is to convert the AC voltage induced by the receiving coil into a stable 5V DC voltage. The circuit diagram is shown as follows.

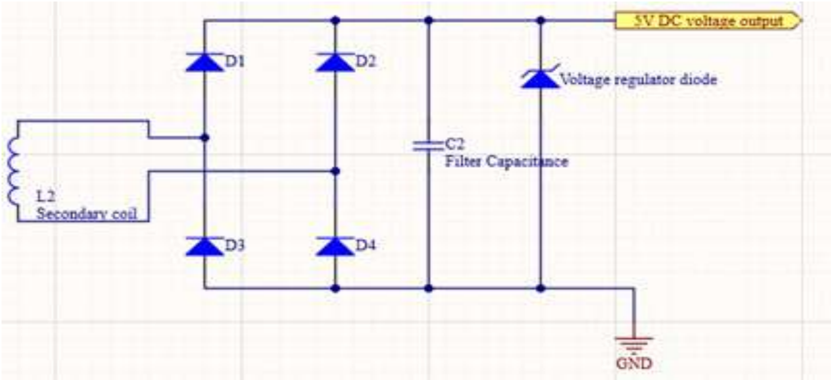


Figure 2.7: Circuit diagram of rectifier circuit

The rectifier circuit uses multiple diodes to limit the direction of current. The filter capacitor C2 is used to limit the direction of the voltage. The voltage regulator diode is used to stabilize the voltage around 5 V. With these components work together, the final output is a stable DC voltage around 5 V.

2.3 | Embodiment Process

At last, XKT412-26 is selected to perform the wireless-charging task due to its stable performance and suitable dimensions. Specifications of this module is listed in the table below, and the physical display is shown in the Figure 2.8.

Table 2.1: XKT412-26 technical specifications

Item Name	**XKT412-26**	
Parameter	**Value**	**Unit**
Input Voltage	9∼12	V
Coil Dimension	$\Phi 44\times\varphi 13\times 3$	mm
Max Load Current	1.1	A
Optimum Distance	3∼6	mm
Cost	23	RMB

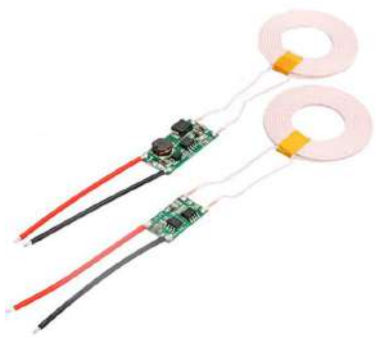


Figure 2.8: Physical display of XKT412-26

3 | Sub-system 2: Animation-displaying System

3.1 | Persistence of Vision

The principle of displaying patterns using rotating LED is utilizing the persistence of vision (POV) of human eyes. The principle of POV is that when the object is moving rapidly, the human eyes can still retain its image about 0.1~0.4 seconds after the image disappearing seen by the human eyes, which is explained in detail in Principle of POV. So that we need LED to light in the same position within 1/24 second which means the frequency of rotation need to be at least 24 Hz.

3.2 | Image and Animation Displaying

3.2.1 | Color and Resolution

There are two main aspects we need to concern when we design the image or animation displayed, i.e. color and resolution. WS2812B light is employed as light and Table 3.1 lists its technical specifications. WS2812B light can produce various colors with different brightness. Six hexadecimal numbers (refer to Section 3.3) are utilized to determine one color for WS2812B light, which means that total 256^3 kinds of colors can be generated. The abundant colors ensure the colorful pattern could be displayed. As for the resolution, the number of pixels in the image or animation is the main factor and more pixels mean higher resolution. Hence, we design a two-arm structure, which has 32*16 pixels in total, as shown in Figure 3.1.

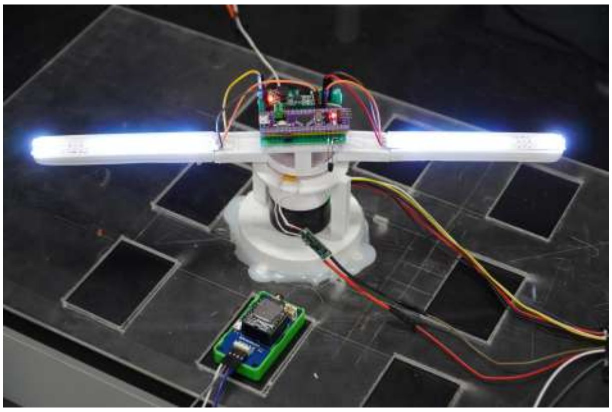


Figure 3.1: Physical display of two-arm LED strips

Additionally, this two-arm structure can reduce the requirement of rotation speed to achieve POV, which reduce the requirement of the motor. Higher rotation speed causes larger centrifugal force, which will damage our structure. Hence, this two-arm structure will also enhance the stability of the prototype.

3.2.2 | Color of pixels

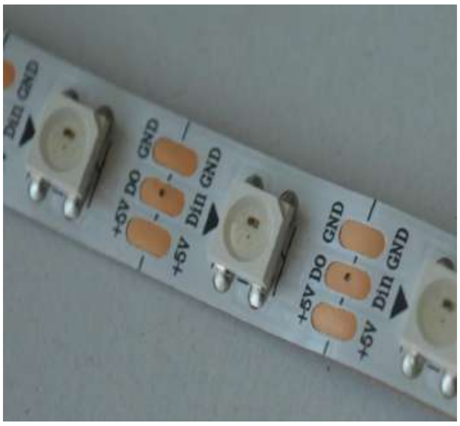
POV Converter is utilized to transform the resolution of given image into 32*16. The color of each pixel is also computed through this tool. The GUI of POV Converter is shown in Appendix A.1.

3.2.3 | Animation Generating

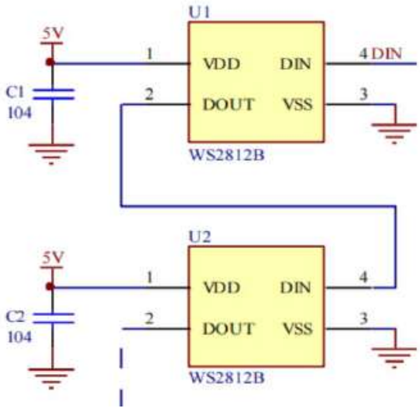
Now, we can set the color of every pixel, but the time when each pixel is on or off determines the completeness and smooth of the animation displayed. Firstly, rotation speed of motor should be stable. Then, we use the delay function to adjust the lighting time of each pixel, which should be consistent with the rotation speed.

3.3 | Control WS2812B Light with PWM

STM32f103c6t6 is employed to act as the MCU for the rotating plate, controlling the animation-displaying system and receiving the signal from the infrared detector. As for the animation displaying, if we use one IO port to control one WS2812B light, we'll need to use 32 IO ports, which exceeds the maximum number of IO ports equipped on the chip. In order to relief the IO port resources, we utilize the technique of PWM to use one IO port to control all WS2812B lights. As shown in Figure 3.2a, every WS2812B light has 4 ports that are VDD, VSS, DIN, DOUT. Since the DOUT port transmits signal to the next WS2812B light, we can connect one WS2812B light's DOUT port to the DIN port of the next WS2812B light to complete the data transmission through all WS2812B lights in series. This cascade connection method is depicted in Figure 3.2b.



(a) Physical display of WS2812B in series

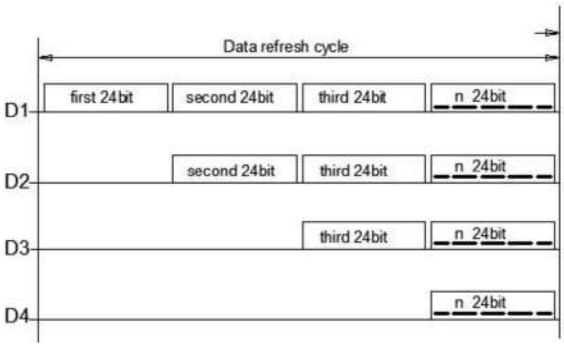


(b) Series connection of WS2812B lights

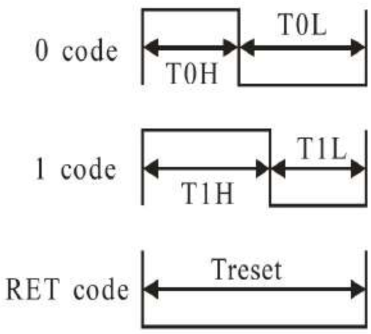
Figure 3.2: Physical display and the circuit diagram of WS2812B in cascade connection

The data transmission method is that the MCU on STM32f103c6t6 sends n 24bit data encoded into PWM signal to control n WS2812B lights. Assume that D1, D2, D3, D4 represent 4 WS2812B lights connected in cascade. As shown in Figure 3.3a, D1 accepts n 24bit data. The first 24bit data is remained and the rest data is transferred to the next light, i.e. D2. The WS2812B light has a built-in ADC to change analog signal to digital data and stores it in its memory. The "0", "1" and "reset" are decoded according to different duty cycle of the received PWM signal, as shown in Figure 3.3b. The whole process to generate the animation is listed as follows.

1. Decide an image or video to show;
2. Use *POV Converter* to obtain the RGB data of 32*16 pixels;
3. Configure IO port and DMA channel;
4. Update the RGB data in hexadecimal form to STM32f103c6t6;
5. Send the corresponding PWM signal to WS2812B lights



(a) Data transmission method



(b) PWM codes of WS2182B

Figure 3.3: Data transmitted in cascade connection and illustration for the PWM codes of WS2812B

3.4 | Embodiment Process

The official website for WS2812B employed in our prototype is here. As for the connection of STM32f103c6t6 and WS2812B, we choose PA1 on the chip as the output port. Besides, DMA channel also is used to accelerate the data transfer. TIM2 channel 2 is enabled and the data is saved into the RCCx register.

Table 3.1: WS2812B technical specifications

Item Name	WS2812B	
Parameter	**Value**	**Unit**
Input Voltage	3.5~5.3	V
Logic Voltage	±0.5	V
Transmission Delay	300 (MAX)	ns
Transmission Speed	800 (MAX)	Kbps
Cost	0.5	RMB per unit

4 | Sub-system 3: Rotation-driving System

In this section, we talk about the building process of our rotation-driving system. At first, we introduce several different kinds of motors, which are widely employed in industry to complete specific tasks. We compare these motors and select the brush-less DC servo motor due to its strong functionalities and stability. Then, we design two closed-loop control strategies to apply the motor in our Prototype. At last, the embodiment process of our rotation-driving system is briefly discussed.

4.1 | Motor Selection

In industry, there are several different types of motors which are widely used, such as brushed DC motor, brush-less DC motor, stepper motor and DC servo motor, as shown in Figure 4.1. The difference between brushed motor and brush-less motor exists in how the commutation of the windings is achieved. Brushed motors use physical brushes that slide over the armature to energize the windings, while brushless motors use an electronic controller to energize the windings. Brushless motors do not have the friction and wear of brushes, so they tend to be more efficient and durable. They can also often operate at higher speeds. However, brushless motors require a more complex speed controller, so they tend to be more expensive. A DC servo motor is a DC motor with speed feedback and torque feedback. It can accurately control speed and torque according to speed commands and torque commands to achieve high-precision speed regulation and torque control. Hence, DC servo motor has the advantages of fast speed response, wide speed regulation range, high speed regulation stability and fast torque response. It is widely used in automatic control fields. The comparison of these different types of motors are summarized in Table 4.1.

Table 4.1: Comparison of different types of motors

Type	Speed	Torque	Control Method	Cost
Brushed Motor	Low	Low	Open-loop	Low
Brush-less Motor	High	Low	Open-loop	Middle
Stepper Motor	Low	High	Closed-loop	High
Servo Motor	High	Controllable	Closed-loop	High

(a) Brushed Motor **(b)** Brush-less Motor **(c)** Stepper Motor **(d)** Servo Motor

Figure 4.1: Four types of commonly used motors

Considering the requirements of the Rotation LED Project, we select the DC servo motor to complete desired tasks. The logic of selection follows the procedure below:

1. Since the phenomenon, Persistence of Vision, which is the critical principle, requires that the rotation speed or the angular velocity of the LED can not be smaller than 1440 RPM, the maximum speed of our motor should be relatively higher than the commonly used motors. Hence, brushed motor and stepper motor are not appropriate.
2. Considering the stability of the animation displayed by the rotating LED, the speed of our motor should be able to maintain at some specific values stably. Thus, the closed-loop control of speed is also crucial.
3. Additionally, the closed-loop control of torque will not only improve the control performance of closed-loop speed control, but also boost the operability of forming patterns.

Overall, we choose the DC servo motor as our driving actuator, due to its high maximum speed and built-in closed-loop control system.

4.2 | Closed-loop Control

Closed-loop control is one widely used control strategy in practice, which monitors the output of a system and adjusts the input to obtain the desired output. In our project, the desired stable motion of LED and the desired varying pattern require that the speed and torque output from the driving motor are controllable. Hence, PID controller is utilized in our project to build the closed-loop control system. The PID control schematic is illustrated in Figure 4.2. For example, reference is the speed we want the motor to reach, that is, the expected speed; output is the actual speed of the motor; the error between them will be the input of the PID controller, and the output result of the PID controller will be output after the transfer function G. The closed-loop control helps to keep the speed of the motor stable, and the speed changes more smoothly when the speed change is adjusted, so that the display effect is better. The control procedure for torque is the same if we set the desired torque as our reference of this control loop and set the output as the actual output torque.

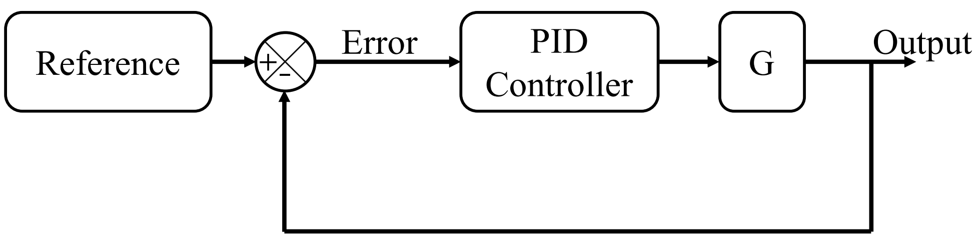


Figure 4.2: Block diagram of general PID controller

The principle of PID controller is briefly explained in the following, also as shown in Figure 4.3. PID stands for proportional, integral, derivative, which are the three components of PID control. Proportional control produces an output proportional to the error signal. Integral control produces an output proportional to both the magnitude and duration of the error. Derivative control produces an output proportional to the rate of change of the error. By combining these components, PID control can provide control action designed for specific requirements. Equation 4.1 shows the mathematical form of PID controller. More information about how to design a PID controller can be found in *System Dynamics*, Ogata[5].

$$Output\ signal = K_p e(t) + K_i \int e(t)dt + k_d \frac{d[e(t)]}{dt} \tag{4.1}$$

In our prototype, two PID controllers are employed to achieve the desired tasks:

- One PID controller is designed to fulfill closed-loop torque control. With this torque controller, we can impose a constant torque to accelerate the rotation motion from static state or to decelerate the motion to static state, which ensures that the duration of accelerate or decelerate process is controllable. Besides, with a constant torque imposing to the rotation motion, we can make the pattern displayed in the steady state to be gradually displayed, which means that we can display different patterns during our transient state and the pattern will changes continuously change until the rotation motion is stable.

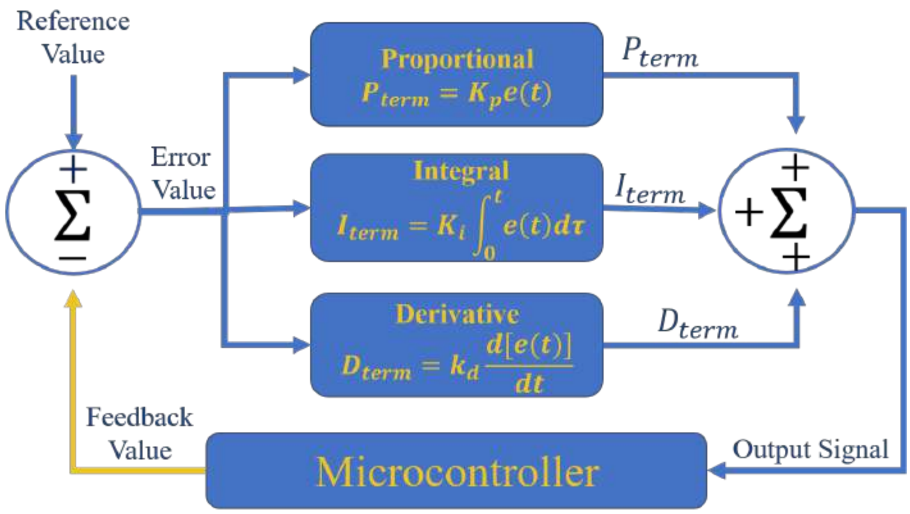


Figure 4.3: Flow chart of the principle of PID controller

- The other PID controller is used to form the closed-loop speed control. We employ this controller to ensure the stability of the speed of the rotation motion in steady state, since the final pattern should be fixed for a while.

Therefore, the control strategy designed for displaying patterns can be summarized as:

1. Impose a constant torque to accelerate the rotation motion from static state so that different patterns will be gradually displayed during this transient process and the pattern will be fixed once the maximum rotational speed is reached.
2. The constant rotational speed in the steady state will be maintain for a while with a fixed pattern displayed.
3. A constant torque will be imposed to decelerate the rotation motion from the steady state to static state. Different patterns displayed in the acceleration process will be displayed again with inverse order.

4.3 | Embodiment Process

At last, RMD-L-4005 is selected as our driving motor, which integrates servo motor, encoder, drive board and chips for torque and speed closed-loop control, greatly simplifying the developing process. Besides, the supporting debugging software developed by its manufacturers simplifies the tuning process for PID parameters of motor. Some critical electrical parameters are listed in the Table 4.2 and the screenshot of the GUI of the supporting software is given in Figure 4.4.

Table 4.2: RMD-L-4005 rechnical specifications

Item Name	RMD-L-4005	
Parameter	**Value**	**Unit**
Nominal Voltage	12	V
Nominal Torque	0.06	N·M
Nominal Speed	700	RPM
Max Speed	1300	RPM
Max Instant Torque	0.12	N·M
Line Resistant	4.3	Ω
Encoder Resolution	14	bit
Communication	CAN BUS	
Cost	218	RMB

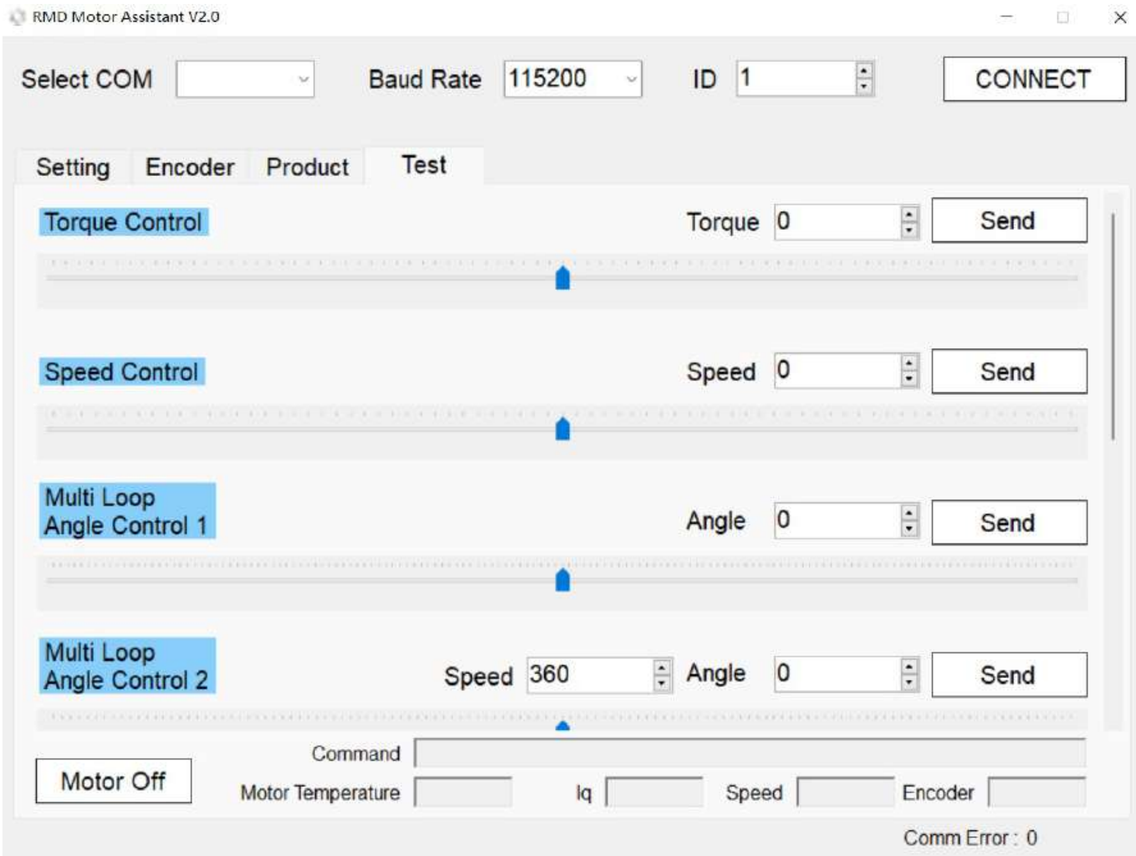


Figure 4.4: GUI of the supporting software of RMD-L-4005

5 | Sub-system 4: Infrared Monitor

In this section, the most critical sub-system of our prototype is discussed, which couples the rotation-driving, animation-displaying sub-systems and makes them work as a whole, which means that one of these two sub-systems can perform some specific tasks according to the instructions given by the other sub-system. With this coupler, the prototype is capable of achieving complex tasks, e.g. changing patterns along different rotation states.
In the following, we first talk about the working principle of our coupler, infrared monitor. Then, the principle of how these cub-systems are coupled together is explained in detail. The embodiment process of the infrared monitor is given at last.

5.1 | Working Principle of Infrared Monitor

Infrared monitor is selected to implement the coupler, due to its lots of advantages, e.g. low energy consumption, high sensitivity, contact-less interaction and simple structure. The Infrared monitor is composed of one infrared emitter and one infrared detector. Working principles of these two components are explained as follows:

- Infrared emitter is capable of producing infrared radiation through the conversion of electrical energy into light in the infrared spectrum. It contains LEDs or lasers that emit light in the range of 700 nm to 1 mm wavelength, which is invisible to the human eye but can be detected by infrared sensors. The most common type of infrared emitter is the infrared LED, as shown in Figure 5.1a. It works similarly to a normal LED, but emits infrared light instead of visible light. When current passes through the LED, the electrons release energy in the form of infrared photons. By controlling the amount of current, the intensity of the infrared light can be varied. Infrared emitters require a power source to convert electrical energy into infrared light. They are used in a variety of applications like infrared communication, heaters, and motion sensors. By pulsing the infrared emitter, it can also be used to transmit data over short ranges.

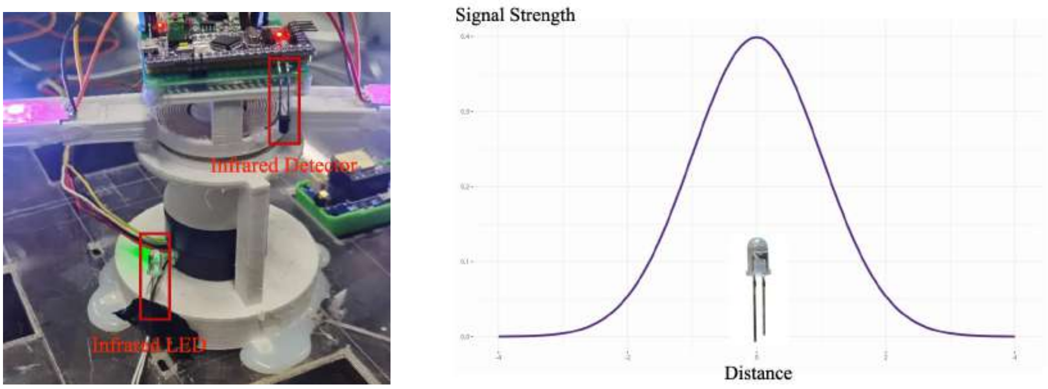
- Infrared detector works by detecting the infrared radiation emitted or reflected by objects. It contains infrared sensors that can measure the intensity and wavelength of incoming infrared light. The most common types of infrared detectors are thermal detectors and photodetectors. In our prototype, photodetector is selected since we use the infrared LED as the infrared emitter, as shown in Figure 5.1b. Photodetectors contain semiconductors that can absorb infrared photons and convert them directly into an electrical signal. Materials such as indium gallium arsenide and germanium are used. Infrared detectors requires a power source to operate the infrared sensors and supporting circuitry. They are used in applications such as night vision, temperature measurement, gas analysis, and motion detection. By analyzing properties of the infrared radiation like intensity and wavelength, the infrared detector can determine information about the emitting or reflecting object like temperature, composition, and motion.

(a) Infrared LED **(b)** Infrared Detector

Figure 5.1: Illustration of infrared LED and infrared detector used in our prototype

5.2 | Coupling of Rotation-driving, Animation-displaying Sub-systems

As shown in Figure 5.2a, the infrared LED is mounted with the base and the infrared detector is fixed with the rotating plate. The infrared detector is able to detect the infrared light signal from the infrared LED when the infrared detector reaches certain regions. These two components are aligned in the vertical direction, which ensures that the strength of the infrared light signal received by the infrared detector is maximum when it's located directly above the infrared LED. This phenomenon is depicted in Figure 5.2b, the signal strength received by the infrared detector increases when it closes to the infrared LED. Therefore, we utilize this property to determine if the infrared detector passes the infrared LED.



(a) Physical display of infrared monitor **(b)** Signal strength in different positions

Figure 5.2: Physical display of infrared monitor in the prototype. The infrared LED is mounted with the base and the infrared detector is fixed with the rotating plate. The signal strength received by the detector increases when it closes to infrared LED.

With this infrared monitor, we can obtain when the infrared detector passes the infrared LED. Since the infrared LED is mounted with the base, which stays static, the information of rotation can be computed.

$$\omega = \frac{2\pi}{\Delta t} \tag{5.1}$$

where ω is the instantaneous angular velocity of the rotating plate, Δt is the time interval to finish one cycle, which equals to the difference between two adjacent time instants when the infrared detector passes the infrared LED.

$$\Delta t = t_i - t_{i-1} \tag{5.2}$$

The value of instantaneous angular velocity is constantly computed and recorded, so that the MCU mounted with the rotating plate can determine the state of its rotation, i.e. the rotating plate is accelerating, decelerating or maintaining constant speed. Hence, the rotating MCU can compute different signals to change patterns displayed by the LED according different states of rotation. In our prototype, we set the patterns displayed when the LED is accelerating or decelerating are flowers with different number of petals. When the rotating plate is accelerating, the number of flower petals increases and it decreases when decelerating. When the rotating plate is maintaining a constant speed, the pattern is changed to individual letters. The final results are shown in Section 7.

5.3 | Embodiment Process

In our prototype, F5 Infrared Monitor is employed to perform the infrared-monitoring task. Its relevant technical specifications are listed in Table 5.1. Its low-cost and appropriate strength of signal make its coupling functionality work well, which is shown in Section 7.

Table 5.1: Infrared monitor technical specifications

Item Name	**F5 Infrared Monitor**	
Parameter	**Value**	**Unit**
Input Voltage	3.3∼5	V
Emission Wavelength	940	nm
Power Dissipation	75	mW
Cost	0.165	RMB

6 | Sub-system 5: Sound Effect System

Sound effect system is an individual system, working independently, regardless of the rotation of LED. In this section, we introduce the VS1053 Module at first, talking some specifications of this module, which employed to complete the sound effect task. Then, the embodiment process of sound effect system is discussed, where we'll explain how to use this VS1053 Module in detail.

6.1 | VS1053 Module

6.1.1 | Function Introduction

VS1053 MP3 MODULE is a high performance audio codec module. The module adopts VS1053B as the main chip, supports MP3 audio format decoding and EarSpeaker space effect Settings. Its powerful function is owing to the powerful resource on the module, which is depicted in Figure 6.1.

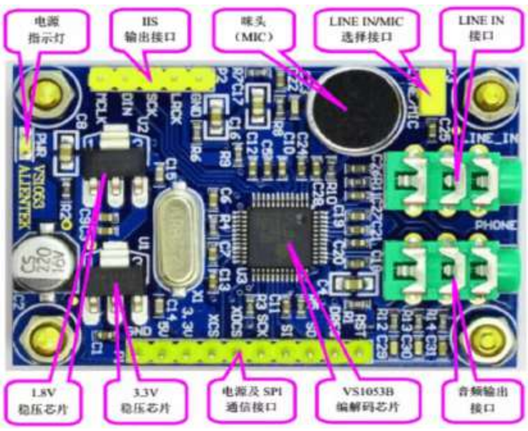


Figure 6.1: Illustration for the module resource on VS1053

6.1.2 | VS1053 Technical Specifications

In the following two tables, Table 6.1 and Table 6.2, some relevant technical specifications are listed. More information can be found on its official website.

Table 6.1: ATK-VS1053 MP3 MODULE analog circuit characteristics

Item	Value	Unit
DAC Resolution	18	bit
THD	0.07% (Max)	Dimensionless
Dynamic Range (A-weighting)	100	dB
Signal-to-noise Ratio	94	dB
Channel Isolation(crosstalk)	80dB@600Ω+GBUF 53dB@30Ω+GBUF	
MIC Amplify Gain	26	dB
MIC THD	0.07% (Max)	Dimensionless
MIC Signal-to-noise Ratio	70	dB
LINE IN Signal Amplitude	2800 (MAX)	mVpp
LINE IN THD	0.014% (Max)	Dimensionless
LINE IN Signal-to-noise Ratio	90	dB
LINE IN Impedance	80k	Ω

Table 6.2: ATK-VS1053 MP3 MODULE electrical characteristics

Item	Value	Unit
Operating Voltage	DC 3.3 or 5.0 (5.0 recommend)	V
Operating Current	15∼40	mA
Voh	2.31 (Min)	V
Vol	0.99 (Max)	V
Vih	1.26 (Min)	V
Vil	0.54 (Max)	V

6.1.3 | Pin Description

VS1053 MP3 MODULE has three sets of pins: P1, P2, and P3. The row of pins P1 is the power supply and communication interface of the module. The detailed description of each pin in P1 is shown in Table 6.3.

Table 6.3: Power supply and communication interface P1 port each pin function table

Serial number	Name	Description
1	GND	Ground
2	5 V	5 V power supply port
3	3.3 V	3.3 V power supply port, when using a 5 V power supply, a voltage of 3.3 V can be output for external use
4	XCS	Slice selection input (low is effective)
5	XDCS	Data slice selection/byte synchronization
6	SCK	SPI bus clock line
7	SI	SPI bus data input line
8	SO	SPI bus data output line
9	DREQ	Data Requests
10	RST	Reset pin (Hard reset, low is effective)

The row of pins P2 is the IIS output interface of the module. The detailed description of each pin is shown in Table 6.4.

Table 6.4: IIS interface P2 port each pin function table

Serial number	Name	Description
1	MCLK	Master clock
2	DIN	Data output
3	SCLK	Bit clock
4	LRCK	Frame clock
5	GND	Ground

The row of pins P3 is the selection interface for LINEIN/MIC. The detailed description of each pin is shown in Table 6.5.

Table 6.5: LINE IN/MIC selection interface P3 port each pin function table

Serial number	Name	Description
1	MIC	Positive signal of the microphone
2	MICP/LINE1	Positive input of the microphone/line input 1

6.2 | Embodiment Process

6.2.1 | Working Flow

First of all, we download the audio in MP3 format to the SD card, and connect the MCU to the SD card and VS1053 MP3 MODULE respectively. The MCU reads the audio file in the SD card and inputs the audio data into VS1053 through the SPI port. The module decodes the audio data automatically, and then outputs the music to the output channel. We can hear the music playing by wearing the headset.

6.2.2 | Hardware Connection

Module communicates with external MCU through SPI interface, and the module can be directly connected with 3.3V MCU system. VS1053 is connected to the MCU through 7 signal cables, which are XCS, XDCS, SCK, SI, SO, DREQ, and RST, in which RST is the reset signal line of VS1053 and the low level is valid, DREQ is a data request signal to inform the host whether VS1053 can accept data or not, SCK, SI, and SO are SPI interfaces of VS1053. They perform different data communications under the control of XCS and XDCS. Figure 6.2 shows the connection mode between VS1053 MP3 MODULE and MCU.

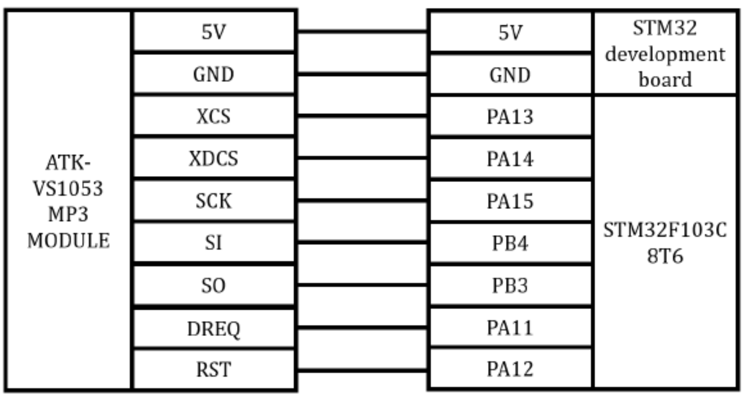


Figure 6.2: Illustration for VS1053 and MCU connecting

The connection between the SD card interface and the MCU is shown in Figure 6.3.

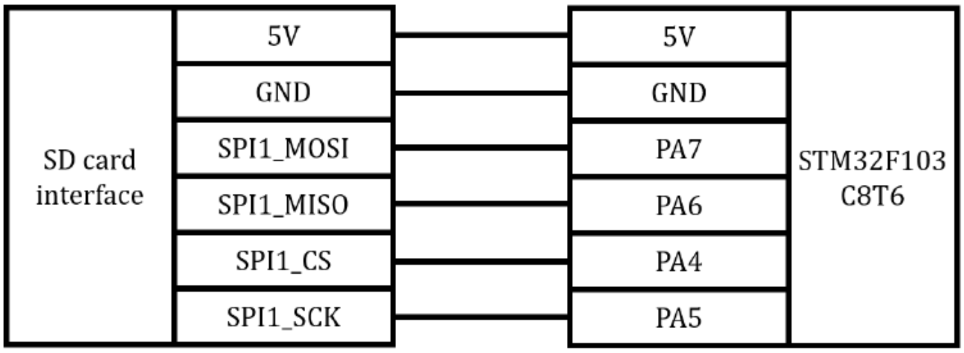


Figure 6.3: Illustration for SD card interface and MCU connecting

6.2.3 | Power Supply

The module has its own voltage regulator chip, so the external voltage only needs to be 3.3 V/5 V.

6.2.4 | Play Audio Files

The procedure of playing audio files with VS1053 is summarized as follows.

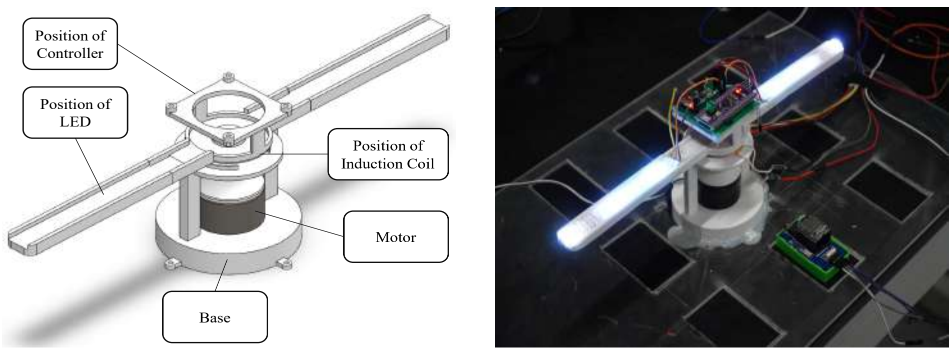
1. Reset VS1053: Including a hard reset and a soft reset to return VS1053 to its original state, ready to decode the next song.
2. Configure the relevant registers of VS1053: We need to configure the mode register, clock register, tone register and volume register, etc.
3. Send audio data: Select an audio format supported by VS1053. When the DREQ becomes high, send 32 bytes to VS1053. Then continue to wait for the DREQ to become high until the audio data has been sent.

7 | Experimental Evaluation

In this section, we provide the experiment results of our prototype completing the tasks mentioned in Section 1.2. Besides, we evaluate and discuss our results. The results provided in this section are divided into four aspects according to their belonging sub-systems.

7.1 | Structure of Prototype

Figure 7.1a shows the 3D model of the structure of the prototype and Figure 7.1b is the physical display of the final prototype.



(a) 3D model of the structure of the prototype **(b)** Physical Display of the prototype

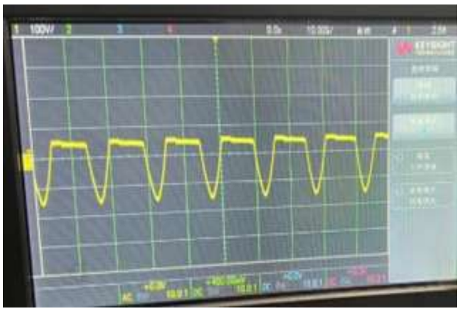
Figure 7.1: 3D model and physical display of the prototype

7.2 | Wireless-charging System

7.2.1 | Inverter Circuit

The designed function of the inverter circuit is to convert DC voltage to AC voltage. We impose a 5 V DC voltage on the input terminals of the inverter circuit, and then use the oscilloscope to measure the voltage at the output terminal, which is connected with the primary coil (transmitter coil). The input 5 V voltage provided by the power source under the constant voltage mode is shown in the Figure 7.2a. And the output AC voltage is shown in Figure 7.2b, where the voltage is alternating, producing a varying magnetic flux intensity in the the secondary coil (receiver coil).

(a) Photo of the input 5 V DC voltage from power source

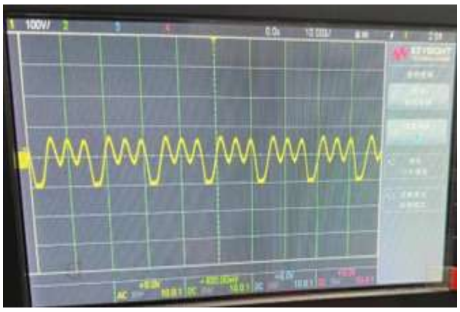


(b) Photo of the output AC voltage measured by oscilloscope

Figure 7.2: Photos of the experimental results of the inverter circuit

7.2.2 | Rectifier Circuit

For the rectifier circuit, we want it to be able to convert the AC voltage induced by the secondary coil (receiver coil) into a 5 V DC voltage which supplied to the animation-displaying system and the MCU mounted on the rotating plate. We used an oscilloscope to measure the voltage imposed on the secondary coil, which is shown in Figure 7.3a, and a multi-meter to measure the output voltage of the rectifier circuit, as shown in Figure 7.3b.



(a) Input AC voltage

(b) Output 5V DC voltage

Figure 7.3: Photos of the experimental results of the rectifier circuit

The output voltage of the rectifier circuit is slightly above 5V, but it's stable on this level, which can be utilized as a stable power source for the components on the rotating plate.

7.3 | Animation-displaying System

7.3.1 | PWM Control

The delay time used in the delay function mentioned in Section 3.2.3 is set as 500 ns to fit the rotation speed. The PWM signal sent by the MCU to the WS2812B lights is shown in Figure 7.4, with the hexadecimal code of the color 0xff0000.

Figure 7.4: PWM signal sent to the WS2812B lights

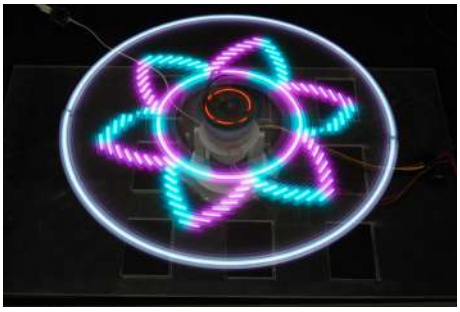
7.3.2 | Animation Displayed

In the experiment, we set the desired animation as follows:

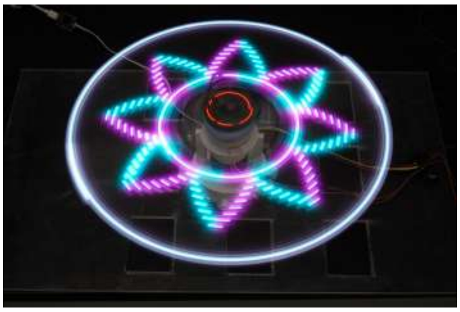
1. While the rotating plate is accelerating or decelerating, the patterns displayed are flowers with different number of petals. In the accelerating process, the number of petals begins from 14, reduced to 12, 10, 8, 6 during acceleration, and ends up with 4 when the rotation speed reaches the maximum threshold. This change is reversed in the of case deceleration.

2. When the rotation speed of the rotating plate reaches the maximum threshold, the plate will maintain this speed for a while. And during this time period, the pattern is set as letters, I and K, which is repeated four times.

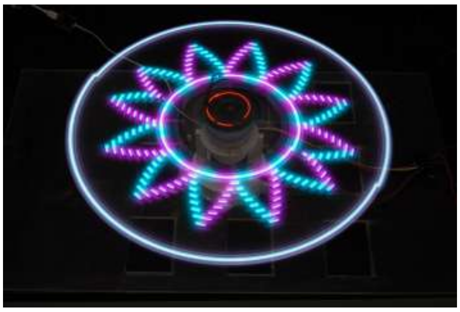
Figure 7.5 shows four flowers with different number of petals photographed at four time instants and Figure 7.6 is photographed at the steady state of the rotating plate. These colorful and different patterns displayed in this animation verify the success of the prototype.



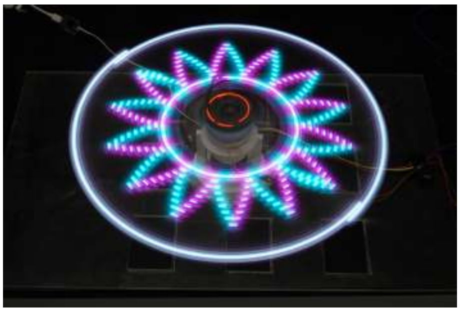
(a) Flower with 6 petals



(b) Flower with 8 petals



(c) Flower with 12 petals



(d) Flower with 14 petals

Figure 7.5: Photos of instantaneous pattern in transient state of the animation

Figure 7.6: Photo of instantaneous pattern in steady state of the animation

7.4 | Sound Effect System

In the experiments, we use the VS1053 Module to play a Chinese Music externally, named The Dark Plum Sauce composed by Ronghao Li[4]. The sound effect system works well and the music is played successfully. It's cool that the animation displayed by the rotating LED is changing along with a music.

8 | Conclusion

As for the tasks listed in Section 1.2 required by the project, our final prototype is capable of completing all tasks successfully. How these tasks are completed and the corresponding section talked about the results are summarized as follows.

- RMD-L-4005 is employed to rotate the rotating plate where the LED, the infrared detector and the MCU used to control the animation are mounted. (Section 7.1)
- XKT412-26 is employed to achieve the function of wireless-charging, with input 5 V DC voltage from the power source and output 5.3 V DC voltage supplied to the rotating plate. (7.2)
- Within a minute, the plate is alternatively rotated clockwise and anticlockwise twice by the RMD-L-4005.
- Colorful and smoothly changing animations are displayed by the rotating LED in the transient process and stationary pattern is displayed in the steady state. (Section 7.3.2)
- Sound effect is equipped in our prototype using VS1053 Module. (Section 7.4)

As for the cost, total cost of our final prototype is around 350 RMB, which is relatively expensive since RMD-L-4005, a brushless DC servo motor, is employed in our prototype with cost around 218 RMB, but the smooth animation is mainly owing to this motor.

Finished this project, we've progressed a lot, not only our personal skills in many aspects, e.g. embedded design, circuit design, poster design and report writing, but also the team coherence. Better performance in future could be expected.

9 | Acknowledgement

All work of this project is finished by the team *SharpShooters*, supported by SHIEN-MING WU SCHOOL OF INTELLIGENT ENGINEERING, Dr.Zhicong Huang, Dr.Hongjie Jiang, and all people who provided valuable assistance. Lots of online open-source websites provides useful materials, e.g. CSDN[1], Stack Overflow[6]. The photos of this report are mainly from Google Images[2]. The open-source software, POV Converter, gives this project huge assistance.

10 | References

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A | Appendix

Figure A.1: GUI of POV Converter