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ROTATING RGB LED TRUE-COLOR DISPLAYER DESIGN AND CONTROL METHOD

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Abstract. *A rotating red, green and blue (RGB) light-emitting diode (LED) true color displayer apparatus and its control methodology are proposed. The apparatus includes a base, a rotating circular bottom, a power supply unit, and an electrical control system. The upper plane of the circular bottom is assembled with control PCB, RGB LED strings, and power filter circuits. Also, the edge of the circular bottom is assembled with symmetrically RGB LED strings arranged in a cylinder or cone. The RGB LED strings are assembled with multiple high-brightness RGB LED lamps according to the specified length. The brightness of the RGB LED lamps is controlled by a constant current chip with a programmable PWM modulation scheme. The rotating seat is located in the upper center of a base constructed from multiple copper rings insulating each other. The necessary power is transferred to the rotating control board though the base by carbon brushes touching the copper rings. When the DC motor drives a circular seat to rotate at high speed, controlling the gray scale of RGB LED at specified position, a true color-like display function will be obtained.*

Keywords: RGB LED, Rotating displayer, PIC microcontroller, True color, Servo control

1. **Introduction.** In the past decade, LEDs have been used in many daily-life applications. Because of their high brightness, low power consumption, and long lifetimes, they are widely used for lighting, such as in table lamps, traffic signals [1,2], billboards, video walls, and LED TVs [3]. The first LED applications were single-color static displays. Traffic lights and text string displayer are the most common applications. Advances in chip technology enabled full color RGB LED displayers [4], which have been used for video wall, LED TV, and projection lamps [5] for various purposes, such as crossroads, sports events, and concerts. All these applications use static display schemes in which the display screen consists of numerous LEDs. Its resolution depends on the LED layout density. Because of the size limitation of the LEDs, however, a high resolution LED displayer is often difficult to achieve. How to develop an innovative, novel, and cool display scheme becomes a charming topic.

This study developed a rotating true-color RGB LED displayer consisting of a base, rotating circular panel, control board, and RGB LED strings fixed on a rotating circular panel. By maintaining the circular panel rotation at a constant speed, the RGB LED string follows the rotation. The LED rotating plane forms a specified surface depending on the shape of the RGB LED string. An example is arranging RGB LED strings vertically to form a cylindrical surface. Because color can be produced by mixing red, green and blue light, an RGB LED with PWM modulation scheme can display any color. Therefore, controlling the RGB LED string displays different patterns at different rotating locations, and due to persistence of vision [6,7], the rotating displayer can display any desired graphics or text.

Although its brightness is inferior to that of the static display type, the RGB LED requires substantially fewer LEDs, and the resolution in the rotation direction is superior. To achieve the desired objective, this study developed a novel electrical control system and a human-machine interface. The experimental results demonstrate the effectiveness of the proposed full-color RGB LED rotating displayer.

2. Mechanical Design of the Rotating RGB LED Displayer.

2.1. Architecture of the rotating RGB LED displayer. Figure 1 shows the architecture of the rotating RGB LED displayer, which includes the base unit, rotating unit, and power unit. The base unit is heavy enough to stabilize the displayer and load the rotating unit. The rotating unit mainly consists of the circular bottom, RGB LED strings, control board, carbon brushes, and power filter and regulator circuits. The power unit supplies the initial power source. The rotating unit is coupled to the base unit by ball bearings. The DC motor is embedded in the base unit to drive the rotating unit at a constant speed. The design details for each unit are given below.

2.2. Base unit design. Figure 2 shows the decomposition plot for the base unit. In the upper plane of the base, ball bearings are fixed to a circular base. The inner ring of the ball bearing can rotate freely. A hollow pillar axis is fixed perpendicularly to the upper plane and has multiple insulation gaskets and copper rings as arranged from top to down in order. The inner sides of copper rings are connected to the power unit by wires to

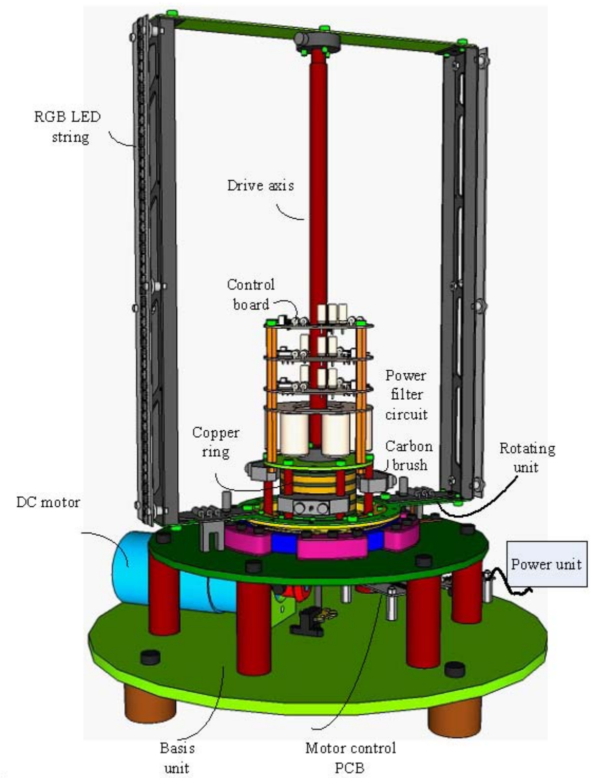

FIGURE 1. Mechanical structure of the rotating RGB LED displayer

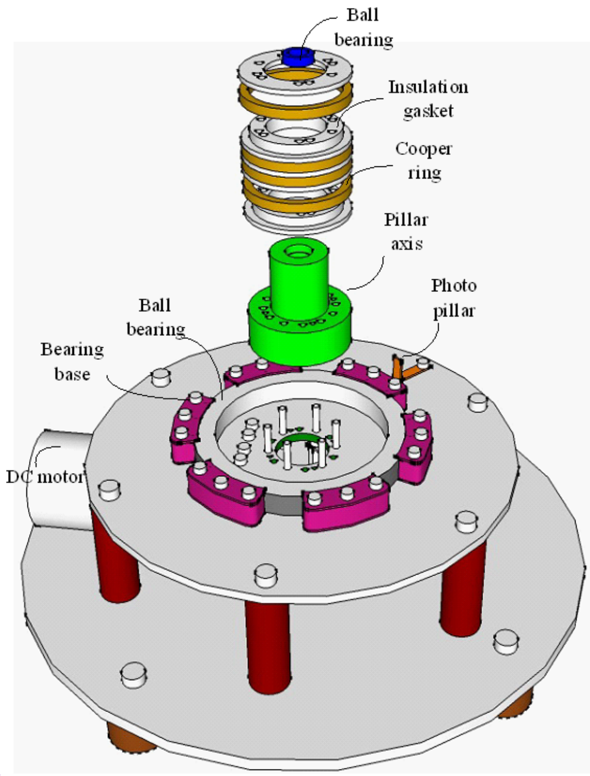

FIGURE 2. Decomposition diagram of the base unit for RGB LED rotating displayer

conduct the necessary power to the rotating unit. Two small ball bearings are set in the hollow of the pillar axis to benefit the drive axis rotation.

2.3. **Rotating unit design.** Figure 3 shows the decomposition plot for the rotating unit. First a bearing fixed ring is embedded in the inner ring of the ball bearing. The upper plane of the fixed bearing ring combines with a circle-like rotating bottom. Two terminals at the bottom are fixed with RGB LED strings and photo sensor circuits. Bearing fixed ring circular sets with multiple pillars are used to support upper components, including the loading hollow panel, power filter circuits, and control board. Multiple carbon brushes fixed on the pillars provide contact with the copper rings and conduct power to the upper circuit boards. Rotating bottom, fixed pillars and hollow panel construct the space to place pillar axis, cooper rings and insulation gaskets. The rotating unit is driven by a DC motor mounted in the base unit. Figure 4 is the schematic diagram for the drive system. A vertical bevel gear is inlaid in the output shaft of the gear box and coupled to another horizontal bevel gear located at the bottom of the drive axis. The rotation speed of rotating unit is indirectly controlled by the DC motor. The precise speed control is provided by the motor control board as described in the following chapter.

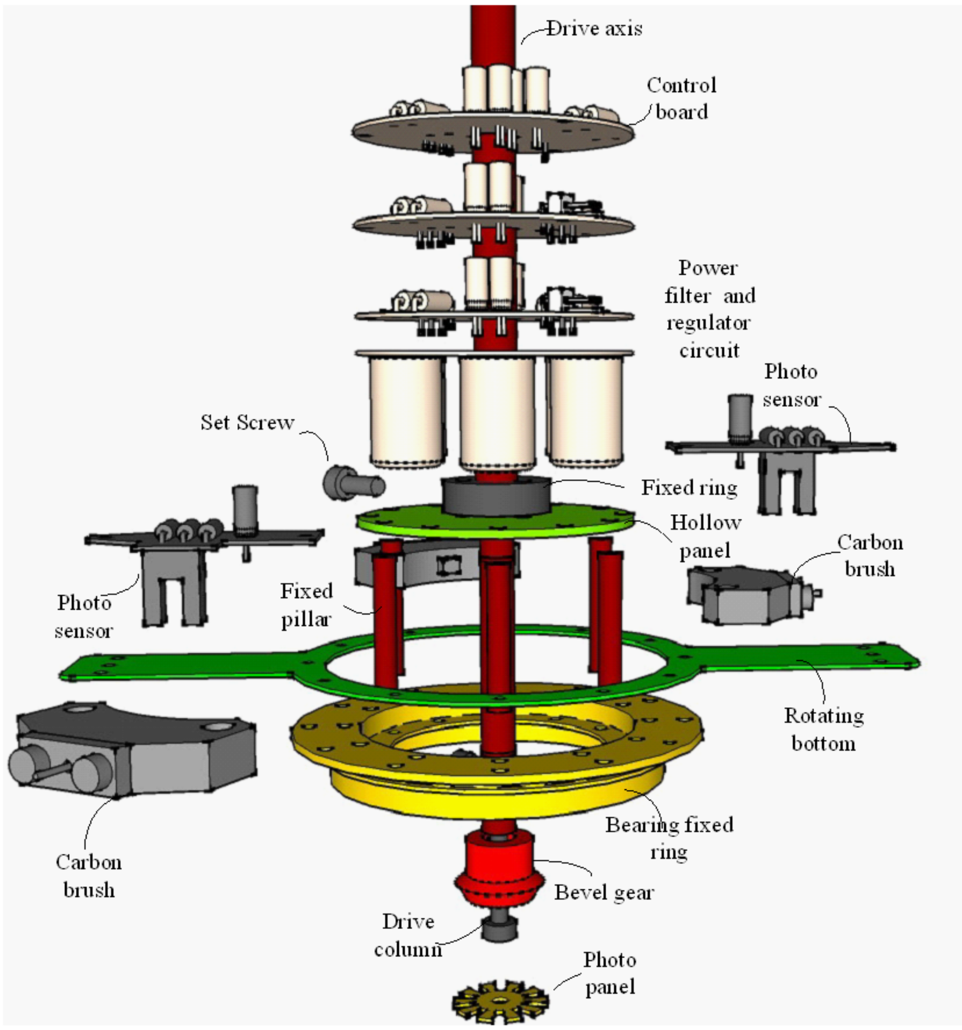

FIGURE 3. Decomposition diagram of the rotating unit for RGB LED rotating displayer

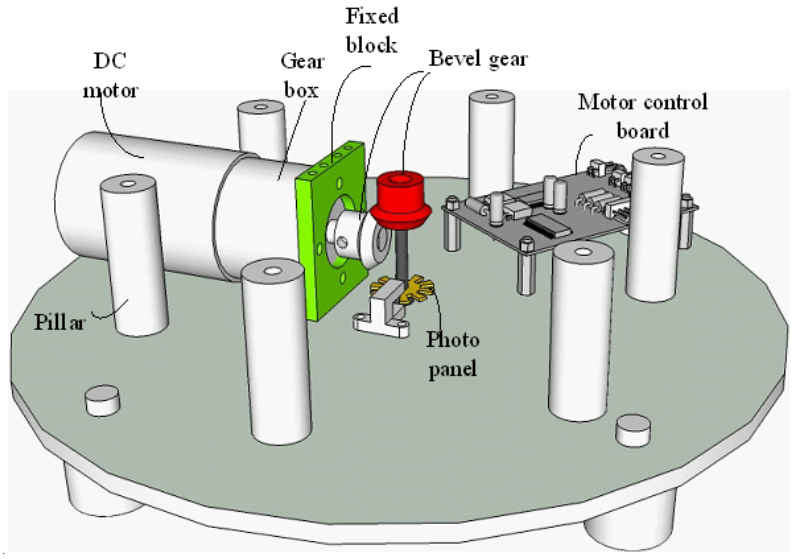

Figure 4. Schematic diagram of DC motor drive

Table 1. Parameters of DC motor

Rated volt (V)	12
Rated torque (g-cm)	700
Rated speed (rpm)	5700
Rated current (mA)	$\leqq$ 5500
No load speed (rpm)	7000
No load current (mA)	$\leqq$ 900
Rated output (W)	41.3
Weight (g)	360
Gear rated torque (kg-cm)	2.2
Gear rated speed (rpm)	1440
Gear ratio	1:4

3. **Electrical Control System Design.** The three parts of the electrical control system are the DC motor control unit, RGB LED control circuit, and power supply unit.

3.1. **DC motor control board design.** The DC motor only provides unidirectional power to the rotation unit. Figure 5 shows the simple design of the driver circuit. The figure shows how PWM and A/D signals are connected to a microcontroller. The PWM modulates the duty cycle of the DC motor to change rotation speed. The A/D monitors the current signal to avoid over current operation. Figure 6 is a schematic diagram of the integrated motor speed control system. The PIC18f8720 [8], which is used as the control kernel, has a built-in PWM, A/D, and capture modules, which satisfy the control requirements. The capture module captures the photo panel signals, as shown in Figure 4, to calculate feedback speed signal and to provide closed-loop control. Further details of the control method are given in the discussion of the software control unit below.

3.2. **DC motor control board design.** The RGB LED package has red, green, and blue LEDs and six pins [9]. As described above, any color can be obtained by mixing the red, green and blue light produced by the LEDs. Using PWM modulation scheme enables easy color modulation, and a constant current modulation chip DM632 [10] is used as a driver to simplify the control circuit. The DM632 is a 16-channel constant current sink

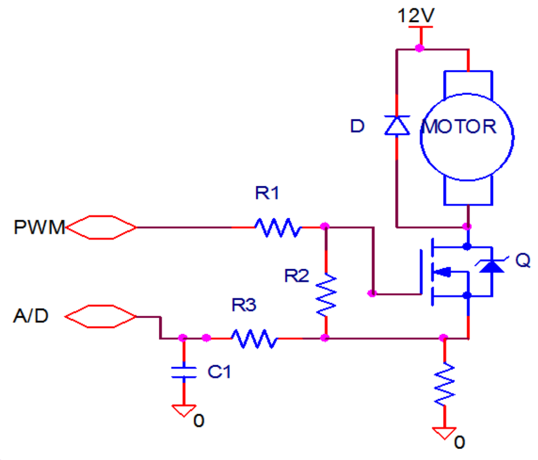

FIGURE 5. DC motor unidirectional drive

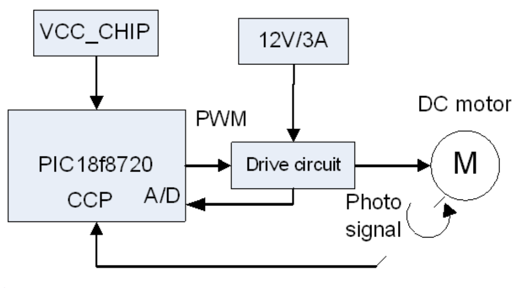

FIGURE 6. Schematic diagram of the motor speed control system

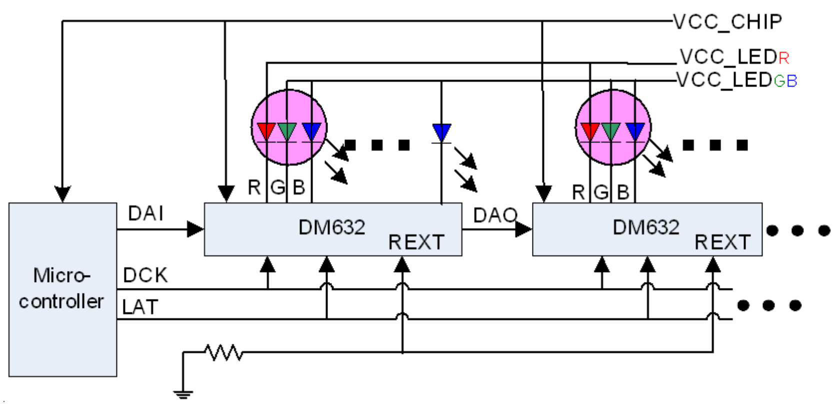

FIGURE 7. Schematic diagram of RGB LED drive circuit

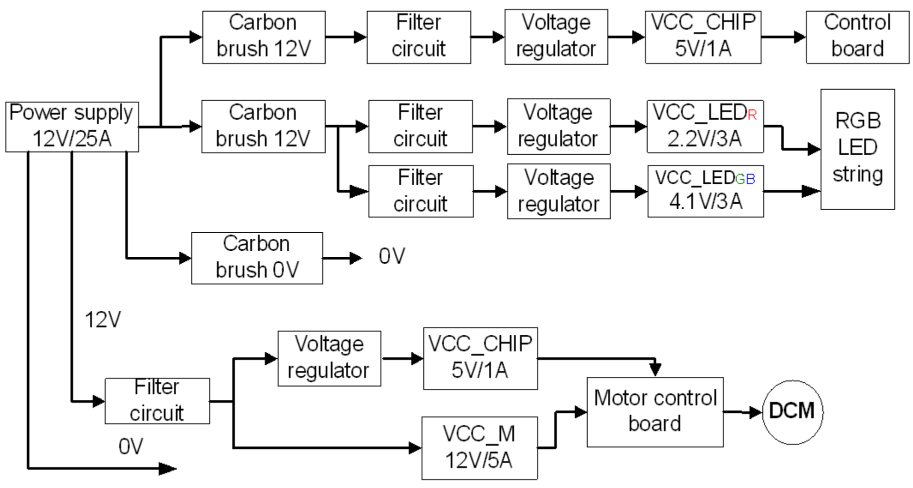

FIGURE 8. Block diagram of power source design

LED driver. Each channel has a programmable 16-bit PWM control current output. By connecting the LED control pins to the output channels of DM632, LED color can be controlled by simply programming DM632.

Figure 7 shows the schematic plot for the RGB LED drive circuit. The DM632 receives the serial data command. The serial-in data, DAI, is then clocked into 16×16 bit shift registers synchronized on the rising edge of the DCK clock. After receiving the serial-in data, a LAT command (HIGH) latches the data to the latch registers, and the duty cycle of each channel is controlled by the inner hardware of DM632. External resistors connected between REXT and GND control the output current. The VCC_CHIP is 5V, and VCC_LED is between 2.2V and 4.1V depending on the LED color. According to the specifications for DM632 and RGB LED, under maximum output current of DM632, VCC_LEDR and VCC_LEDGB are 2.2V and 4.1V respectively. An excessive voltage is likely to damage the LED.

Notably, to increase the serial transfer speed, the microcontroller uses SPI mode to send serial data to DM632.

3.3. **Power filter and regulator circuit design.** As described above, the displayer needs multiple power sources, including motor control units 5V/1A and 12V/3A and RGB LED drive boards 5V/1A, 2.2V/7A and 4.1V/7A. These power sources are drained from carbon brushes that make contact with copper rings connected to the 12V/25A

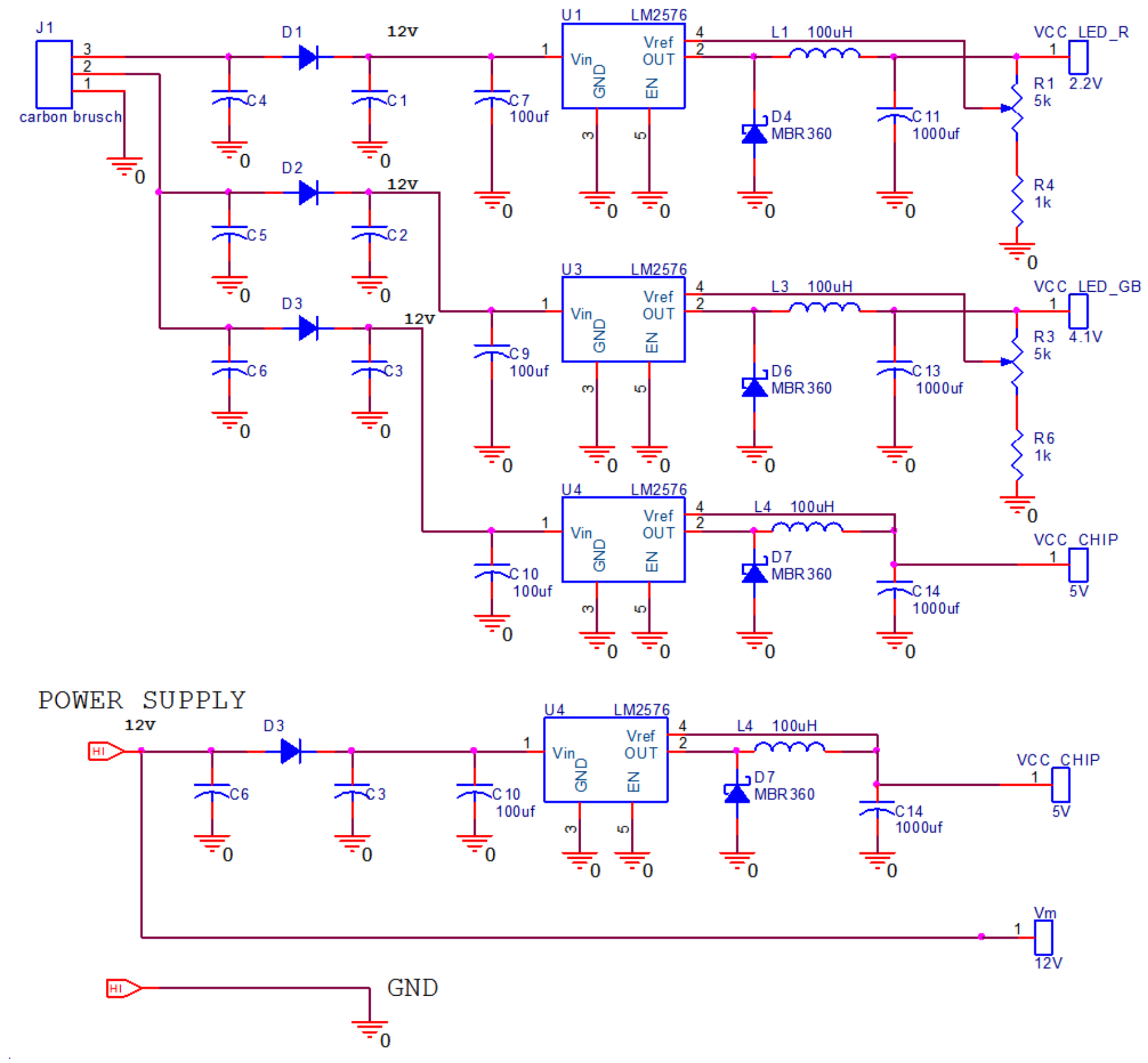

FIGURE 9. Detail power sources circuit

power unit. Figure 8 is a block diagram of the designed power sources. Figure 9 is a detailed circuit diagram of the power source. Resistors and capacitors are the main components of the filter circuit, and LM2576 [11] is the main regulator chip, which has a current rating of 3A. Adjusting the variable resistor as shown in Figure 9 enables easy adjustment of output voltage.

Because each DM632 channel has a 90mA maximum output current, the total consumption current across the copper ring and carbon brush generally exceeds 2A. To reduce the voltage drop, sufficient test running time between the copper ring and carbon brush is needed. Generally, testing time should exceed 6 hours.

4. **Software Control Method.** The software program consists of three parts, DC motor speed control, RGB LED string display control, and the graph/text pattern transformation program design.

4.1. **DC speed control.** Figure 10 is a schematic diagram of the DC motor [11]. The velocity loop mathematical model can be simplified as a first order system. Figure 11

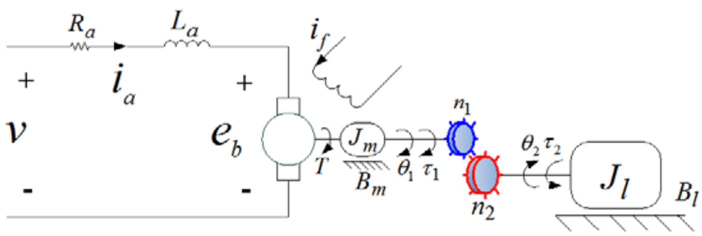

FIGURE 10. Schematic diagram of DC servo system

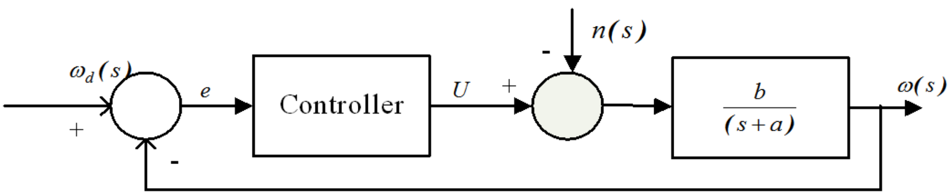

FIGURE 11. Simplified closed-loop DC servo system

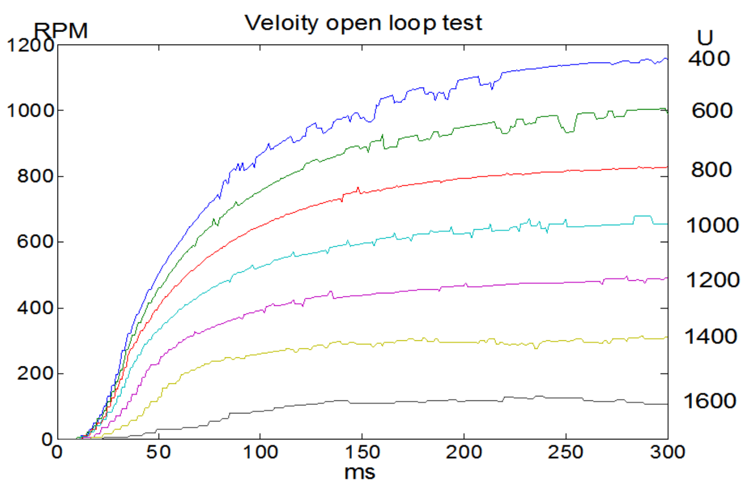

FIGURE 12. Time response curve for step input tests

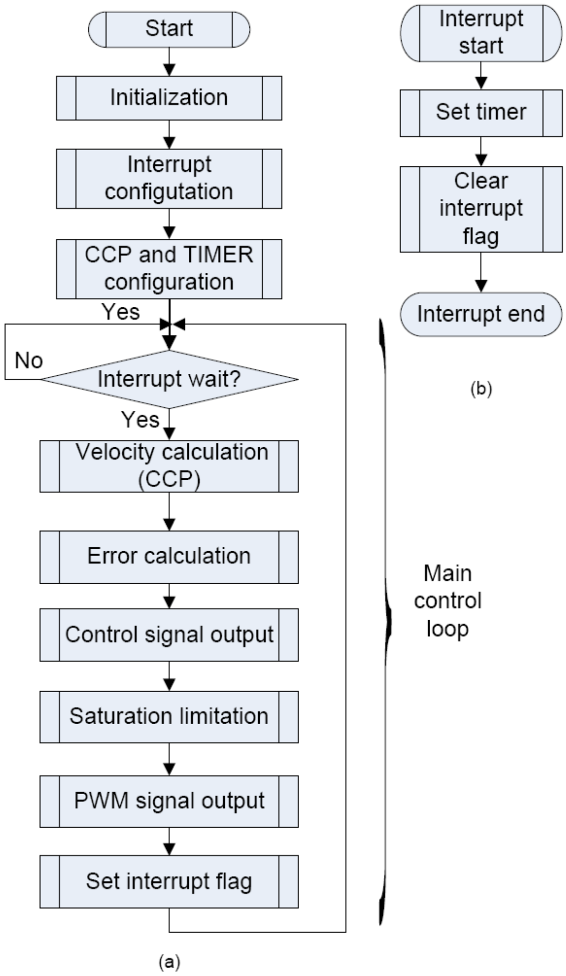

FIGURE 13. Motor speed control flowchart

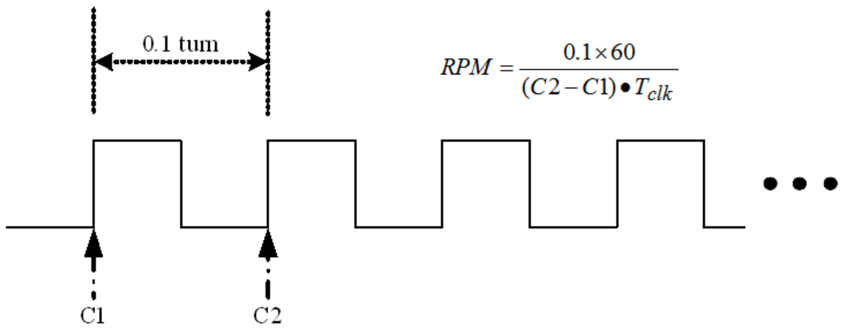

FIGURE 14. Schematic diagram of speed calculation

shows the closed-loop block diagram, where ω_d is the velocity command, ω is the output velocity, e is the velocity error, U is the voltage command, and $n(s)$ is the noise. The U is the PWM module output value of the microcontroller. The PWM set value is set to between 0 and 1023 for 10-bit PWM resolution.

As Figure 11 shows, the voltage command is sent to the DC servo system, and the time of response is recorded simultaneously. By observing the recorded data and using curve fitting scheme, the mathematical model is easily constructed. Figure 12 shows the step

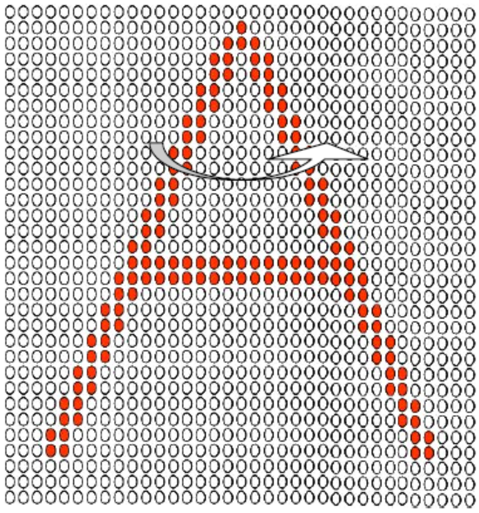

FIGURE 15. Schematic diagram of persistence of vision

time response curves, and the simplified mathematical model is

$$\frac{\omega(s)}{U(s)} = \frac{352 \pm 43}{s + 55 \pm 5} \tag{1}$$

Generally, the persistence of vision time is between 0.1s and 0.4s. In the case of 0.1s persistence of vision time, the time needed for the unit to rotate 180 degrees should be shorter than 0.1s, i.e., the rotation speed of the rotating unit must exceed 300 RPM. Here, the speed of the rotating unit is set to 1000 RPM. By using the PID controller, the control objective is easily obtained. Figure 13 shows the control flowchart.

In Figure 13, the default speed command is 1000 RPM. After one rotation of the rotating unit, the photo panel circuit produces 10 clock signals. The CCP pin captures the time difference between two adjacent clocks so that the speed can be calculated. Figure 14 is a schematic diagram of the speed calculation process where T_{clk} denotes the period of timer clock.

4.2. **Software program design of RGB LED string.** As Figure 1 shows, the RGB LED string appears as a cylindrical surface when the rotating unit is running. If the rotation speed is 1000RPM, then each half-circle takes 0.06 seconds. Setting the resolution to 200 per turn changes the display pattern to one time per 0.3ms. Figure 15 shows the schematic diagram for persistence of vision. After changing the display pattern when the LED string turns to the desired switching time, the rotation surface exhibits a relative pattern. A higher resolution produces a more detailed graph/text given sufficient transfer speed.

The RGB LED string design in this study had 45 RGB LED and used 9 DM632 chips. One pattern must transmit 9×16×16 bits to the LED string. Using dsPIC30F3010 [13] as the control kernel and the system clock is 24MHz the DCK clock is identical to the system clock. The transfer time for one DM632 is 10.66μs, and total transfer time for one RGB LED string is about 96μs which is faster than 0.3ms and therefore satisfies the design requirement.

To refresh the display pattern per 0.3ms, a main control loop and a timer interrupt subroutine were designed. The control flowchart in Figure 16 shows that the subroutine is interrupted every 0.3ms.

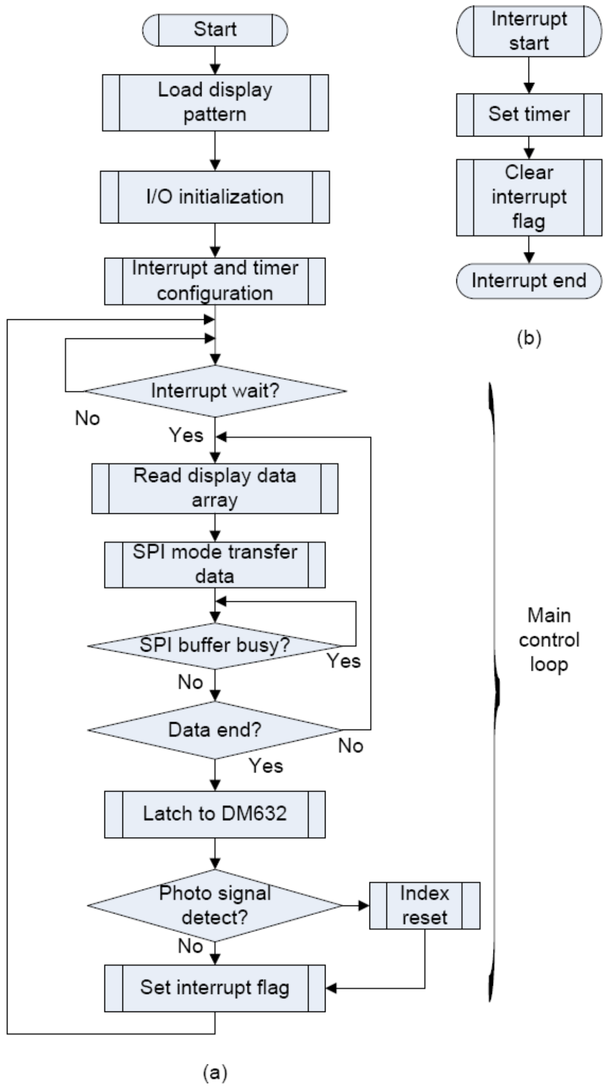

FIGURE 16. Software control of RGB LED string

4.3. **Display pattern transformation program design.** The proposed RGB LED displayer can display graph/text patterns. However, each original pattern has a different resolution. The original patterns must be transformed to suit the rotation resolution. In Figure 16, the first step is to load the pattern file. Pattern transformation is usually tedious and burdensome. A program is needed to finish the transformation work.

Assuming the RGB LED displayer is designed with 100×45 resolution per half-turn, after reading in the original graph, it would first be compressed as a 100×45 resolution image. Each pixel value can then be decomposed out of the R, G and B ratio. Depending on the driving circuit design of RGB LED string, the display graph can be transformed into pattern arrays.

In Figure 17, the left side shows the original image, and the right side shows that image resolution after compression is reduced to 100×45. Assuming the upper left corner pixel is green, it would be transformed as (0,65535,0) under 16-bit resolution of each color. Figure 18 is the operation interface for graph/text transformation. Pressing the **open file** button opens the file select menu, and the selected graph appears on the right side of the **Resolution** edit box. **Display options** can be used to change the background color to black or white. Otherwise, the default display mode can be selected. **Edge Sharpening**

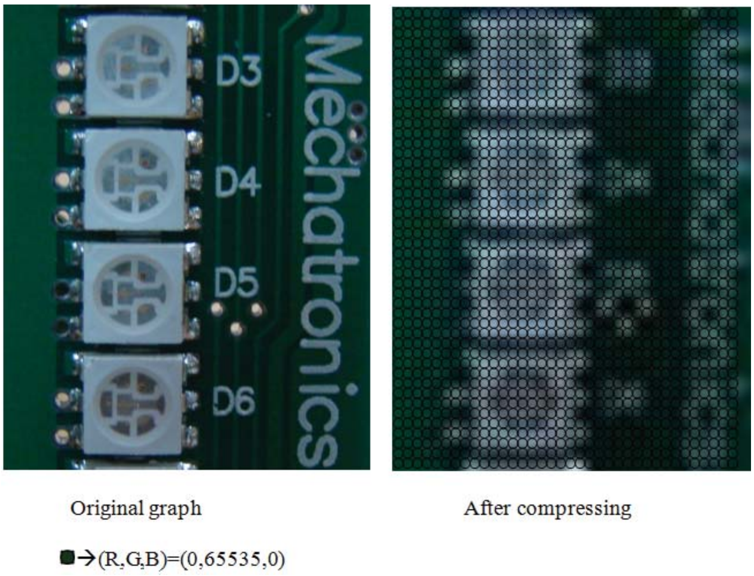

FIGURE 17. Schematic of pattern transformation

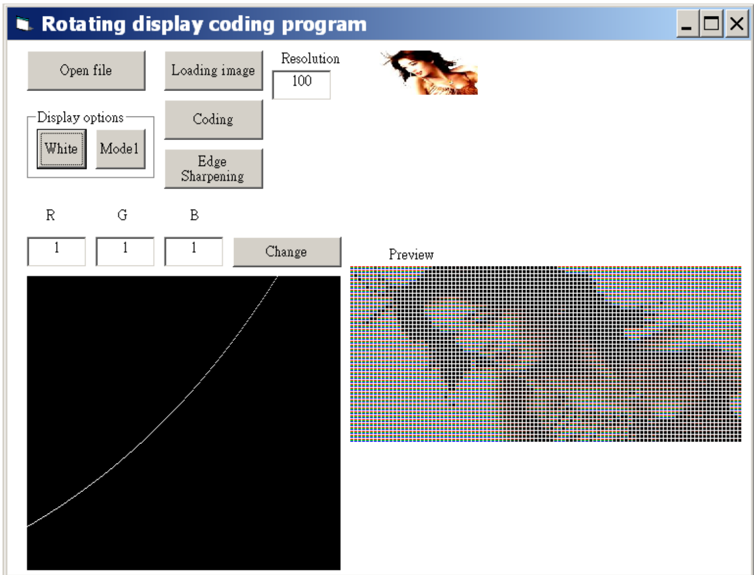

FIGURE 18. Pattern transformation operation interface

enhances the contrast ratio. The RGB edit box sets the ratio for red, green and blue. Pressing the **change** button displays the preview image. The user can adjust the image until the desired output is achieved. Finally, pushing the **coding** button outputs a pattern file to the work path. Figure 16 shows that the first step is loading the pattern file for display on the rotating unit, which displays the results for the preview image. Part of the pattern array is shown as follows.

```
const unsigned int image[ ]=
{0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,
0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0000,0x0C00,0x0C00,0x9C00,
0xB400,0xFC00,0xDC00,0xDC00,0xDE00,0xF6E0,0xFFF0,0xFF10,0xFF10,0xFF30,
0xEFE0,0xFF70,0xFF50,0xFF50,0xFD70,0xFF70,0xFF20,0xFF00,0xFF00,0xFF00,
0xFF00,0xFF00,0xFF00,0xFF00,0xF700,0xFF00,0xFF00,0xFF80,0xFF80,0xFF80,
0xFF80,0xFF80,0xFF00,0xFF00,0xFF00,...
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Figure 19. Prototype of RGB LED displayer

Figure 20. Graph display photos

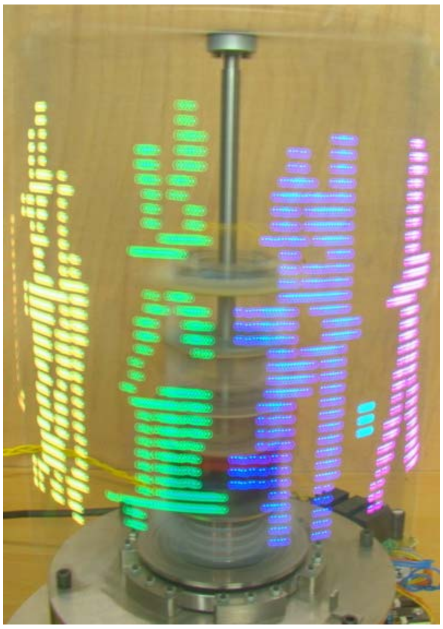

Figure 21. Text display photo

Figure 22. Digital clock display photo

5. Experimental Results and Discussion.

5.1. Display pattern transformation program design. Figure 19 is a photo of the prototype full-color RGB LED displayer. The RGB LED string can be designed in any shape to show the desired effect. Here, only the straight form is shown, and the cylindrical surface appears as a rotating unit.

5.2. Image clock display results. To demonstrate full color display capability, a cartoon image is tested first. In Figure 20, the left side is the original high resolution photo, and the right side shows the display result captured by the general digital camera. The live view is better than the captured photo. Capturing vivid colors requires advanced

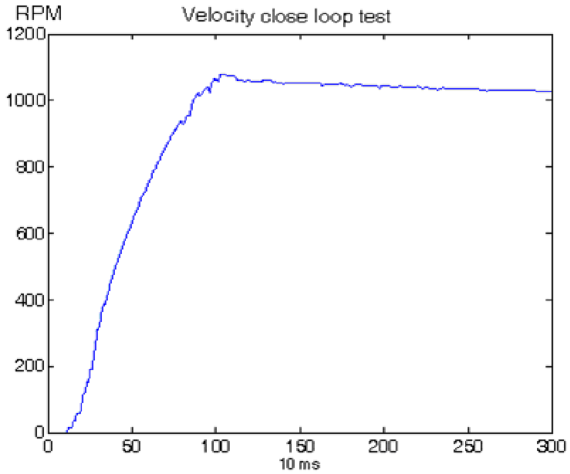

FIGURE 23. Time response of speed steady state output

FIGURE 24. Rotating displayer attracts everyone's attention

photography and a high quality camera. Figure 21 shows the test results for Chinese text. The high resolution results can be seen in the rotation direction. Generally, a static LED dot matrix array cannot achieve such a smooth effect.

5.3. **Clock display results.** A clock program is designed for the RGB LED string control board, and the time is displayed on the cylindrical surface, as shown in Figure 22. Again, a smooth curve and a circle are visible.

5.4. **Motor speed measurement.** Under PID control, the time response of steady state speed output approaches 1000RPM, as shown in Figure 23. To obtain more precision and robust velocity control, adaptive controller [14], sliding mode controller [15] are encouraged.

5.5. **Discussions.** It well known that commercial advertising affects the product's success is tremendous. Commercial advertising wants to become a bright spot must be innovative, novel and cool. On the application of commercial advertising, our design satisfies the characteristics of above. It always attracts everyone's attention as shown in Figure 24.

6. **Conclusion.** This study proposed a full color RGB LED rotating displayer design and control method. A novel rotation mechanism was developed to ensure stable rotation of the rotating unit, which was assembled with RGB LED strings. Also, a rotation contact component consisting of copper rings and carbon brushes was designed with a sufficiently small contact resistor to minimize the voltage drop between the copper ring and carbon brush. This ensured that the rotating unit had sufficient power for stable operation. The proposed rotation display scheme integrating microcontroller technology and the persistence of vision theorem performed well in all quality tests.

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