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Design and Implementation of an RGB LED Matrix Display for Embedded Applications

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Abstract: *This project presents the design and implementation of an 8-bit microcontroller based RGB LED matrix display (4 rows × 8 columns). A driving algorithm for RGB LED matrix was also implemented to show colorful shapes, patterns and pictures. It is similar to the common LED matrix display but with the ability to show various colors. RGB LED is an element that emits the three primary colors (Red, Green and Blue) separately. Thus, we can obtain any color we want by mixing these primary colors together in particular ratios. Using such kind of LED allows to use a new technique in designing that the pixel in common colorful matrix display consists of three separate LEDs (Red, Green and Blue) but now by using RGB LED we reduce the number of LEDs which make the resolution much better and also make the design of matrix less complicated. The work is divided into two main parts; first part is to design a circuit to control a single RGB LED manually using 555 IC, second part which is the main part is to design an array of RGB LEDs with a control circuit using a microcontroller. Proposed design has many advantages like; simple and low cost. Besides, Duty cycle used in the driving algorithm is less than 10% and that reduces the power consumption which is considered as an extra advantage of the project.*

Keyword: *RGB LED, RGB LED Matrix Display, Microcontroller, primary colors.*

I. INTRODUCTION

Light Emitting Diodes LED matrix display is becoming popular in this digital world. Due to its clear bright light, way of displaying such as rolling left, right or fancy appearances, it has gained popularity around the world [1].These displays are used in shopping malls, theatres , public transportation, traffic signs, highways signs, etc.[2]. But these matrices are usually monochromatic. Unlike these matrices our project is full color which enables not only to show characters but even shapes, patterns and pictures. Employing RGB LED we could increase the resolution and make the size smaller than that using three separate LEDs [3].

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The novelty of the presented work lies in the simplicity and low cost compared with internationally manufactured RGB screens which are designed in complicated ways and using higher end microcontrollers in addition, to use complex and unknown algorithms, unlike these colorful matrices display, this project is designed simply and it implements a simple scanning algorithm by using microcontroller (ATmega8). It is a common microcontroller, low cost and easy to use that it can be programmed by C programming language.

II. DRIVING CIRCUIT FOR SINGLE RGB LED USING 555 TIMER

An RGB color space is all possible colors that can be made from three colorants for red, green and blue. Figure (1) illustrates the RGB color model [4]:

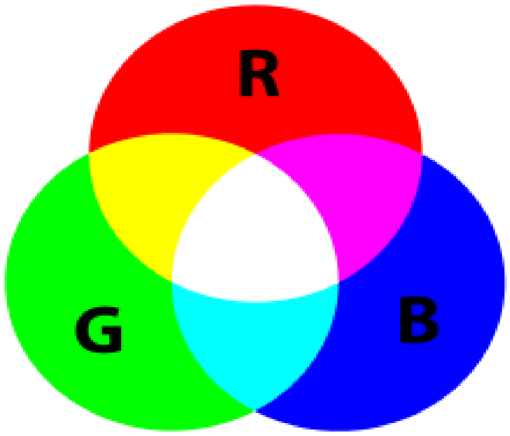

Fig.1: RGB color model

RGB LED as we mentioned previously is an element that emits the three primary colors (Red, Green and Blue) separately and it has four pins, pin for each primary color and a common pin that can be common anode or common cathode. Figure (2) shows a common anode RGB LED:

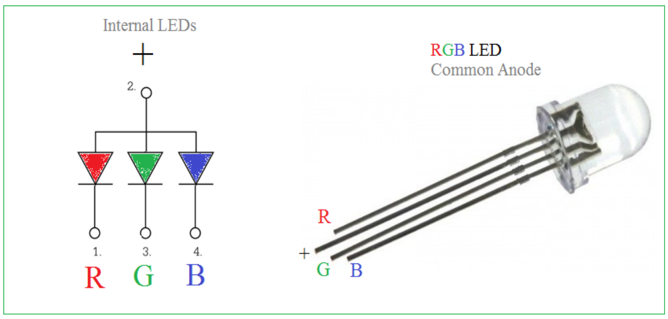

FIg.2: Common anode RGB LED

We can drive this LED by using electrical pulsed signals which are known as PWM (Pulsed Width Modulation) figure (3) illustrates the PWM signals used to control RGB LED. As we increase the duty cycle (time of switching on) the ratio of the primary color will increase. Equation (1) describe the duty cycle:

$$D = \frac{T_{on}}{T} \times 100 \quad (1)$$

Where,

T_{on}: Time of switching.

T: Total time.

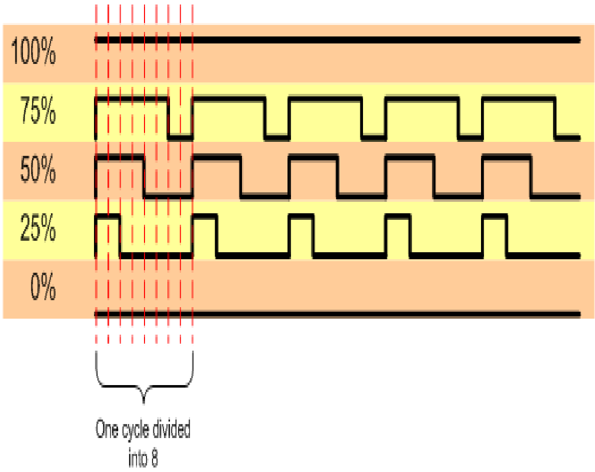

Fig.3: PWM signals used to control RGB LED

To understand the mechanism to control an RGB LED we designed a circuit to control a single RGB LED using 555 IC in A-Stable mode to generate PWM signals. Figure (4) shows the circuit diagram of A-Stable mode [5], [6]:

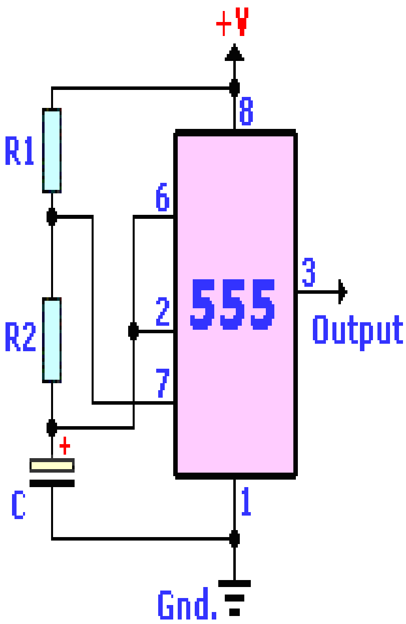

Fig.4: 555 timer in A-Stable mode

We used three 555 ICs in A-Stable mode that each IC output pin is connected to single pin of RGB LED which controls one primary color. Time-on and time-off are calculated from equations (2), (3). Equation (2) illustrates the time when output is in high level "H". Equation (3) illustrates the time when output is in low level "L" [5].

$$t_H = 0.7 \times (R_1 + R_2) \times C \quad (2)$$

$$t_L = 0.7 \times R_2 \times C \quad (3)$$

Then, total time and frequency are shown in equation (4) and (5) in respectively [5]:

$$T = t_H + t_L \quad (4)$$

$$f = \frac{1}{t_H + t_L} \quad (5)$$

In the circuit we used two diodes to separate time of charging from time of discharging and then, we can generate variable PWM signals. Time when output is in high level (t_H) becomes like in equation (6):

$$t_H = 0.7 \times R_1 \times C \quad (6)$$

Time when output is in low level t_L stays like in equation (3) without changing. We chose R_1 = 1KOHM, R_2 = 500KOHM, which it is variable to change duty cycle and C= 47nF then, the f = 60 Hz which it is appropriate for a good vision for the human eye. We chose different values of series resistors connected to RGB LED pins that the voltage thresholds of the three LEDs inside the RGB LED are different, the values are:

$R_R = 1000ohm$ ، $R_B = 500ohm$ ، $R_G = 820ohm$.

The times of charging and discharging are controlled by variable resistor (R_2) which changes the duty cycle and this changes the ratio of color. Figures (5) and (6) show the schematic and layout diagrams of the circuit in respectively:

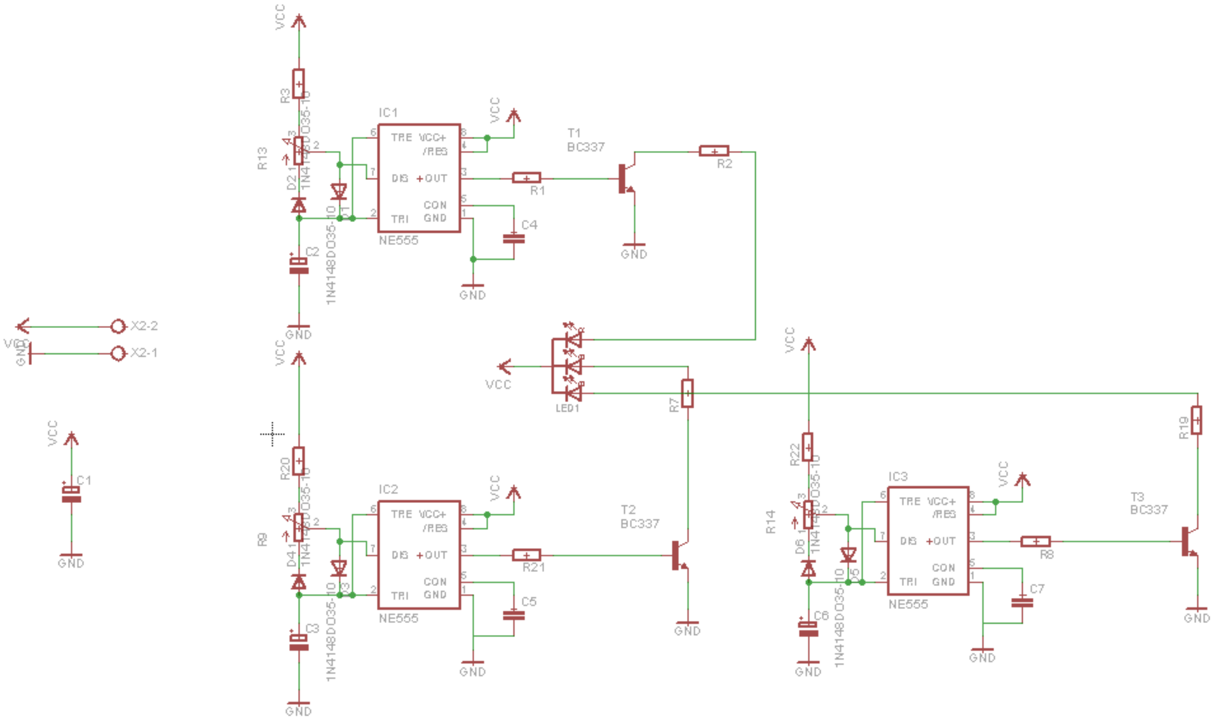

Fig.5: Schematic diagram of driving circuit for single RGB LED

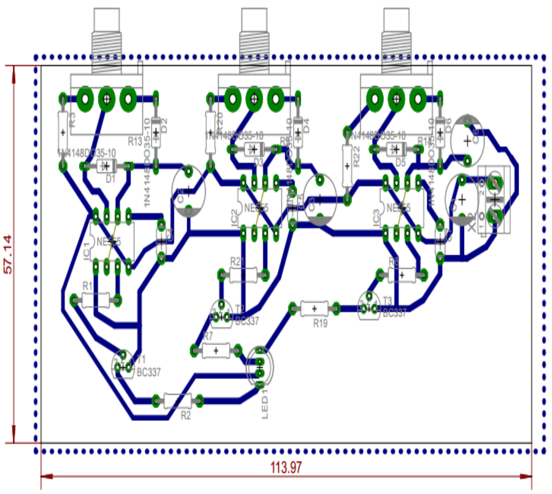

Fig.6: Layout diagram of driving circuit for single RGB LED

Figure (7) shows the proposed circuit after fabricating:

Fig.7: Fabricated driving circuit for single RGB LED

III. RGB MATRIX DISPLAY AND ITS CONTROLS CIRCUIT

A. RGB matrix display:

In LED matrix display we generally connect the cathodes of the same row together and anodes of the same column together and for showing on the matrix we scan periodically and synchronously the rows and columns by using microcontroller [2].

To illuminate one LED we have to apply (0) logic on its row and (1) logic on its column but the rest LEDs of its column we have to apply (1) logic on their cathodes. Figure (8) illustrates how we can illuminate one led in LEDs matrix display:

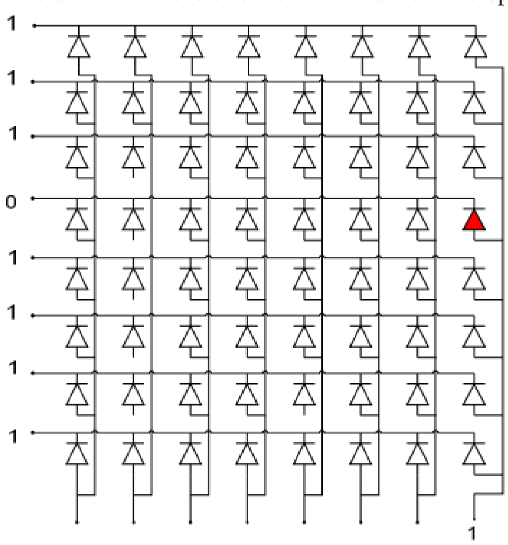

Fig.8: How to illuminate one led in LED matrix display

And for writing or showing on the matrix we have to set the LEDs which must illuminate in all the rows and columns then, write the code for each row and column.

In LED matrix display we usually use shift registers which are integrated circuits that convert data from serial form to parallel form and that will reduce the pins used of microcontroller.

In the past, one pixel in colorful screens was consisted of 3 separate LEDs (Red, Green and Blue) and sometimes two green but now and by replacing the three LEDs (or four) by RGB LED we reduce the number of LEDs which makes the resolution much better [3].

We used in this project common anode RGB LEDs and then we have for each LED three cathodes (each one for one color) so the pins of the same color in one row will be connected together (cathodes) and the common anodes for the LEDs in the same column will connect together. So then we will have 20 pins, 8 pins for columns and 12 pins for rows. Figures (9) and (10) show the schematic and layout diagrams of the RGB matrix in respectively:

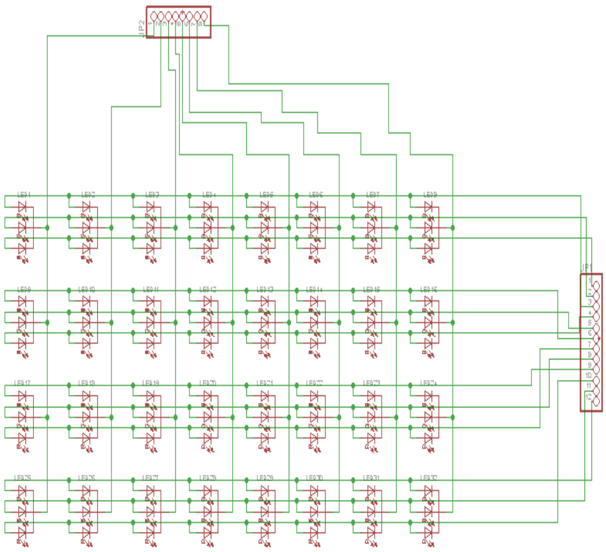

Fig.9: Schematic diagram of the RGB matrix display

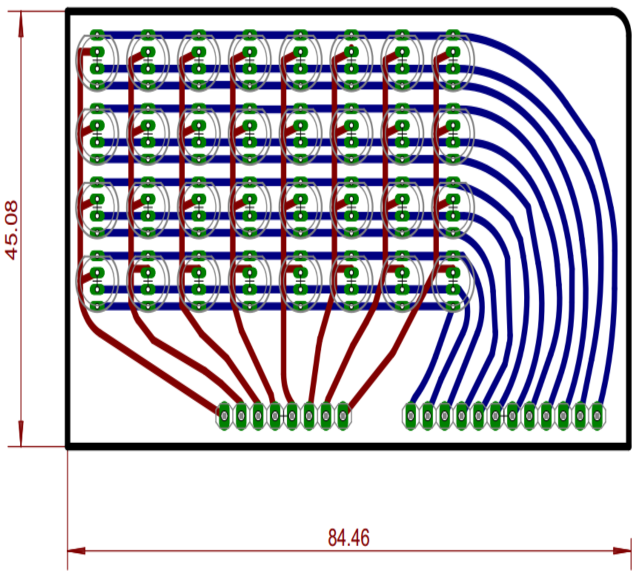

Fig.10: Layout diagram of the RGB matrix display

The footprint elements used in the previous figure is common cathode but that does not affect practically and that because no common anode footprint in Eagle CAD software.

Figure (11) shows the proposed RGB matrix after fabricating:

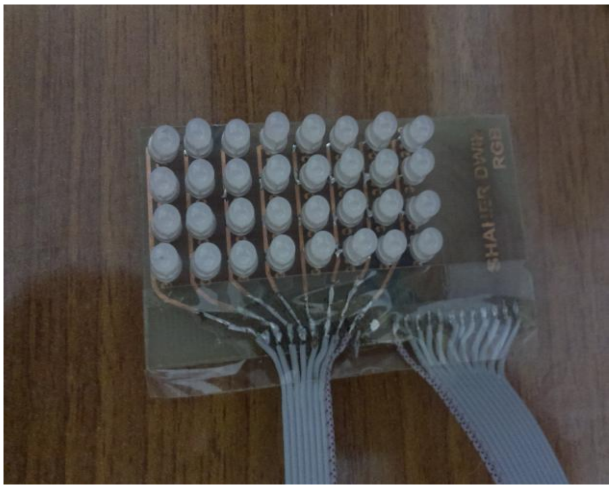

Fig.11: Fabricated RGB matrix display

B. Control circuit

Control circuit is mainly consisted of a microcontroller (AVR ATmega8) which is considered simple, cheap and easy to use. Microcontroller generates the PWM signals. Microcontroller also scans the rows and columns synchronously during constant time (t=20 sec) then frequency (F=50HZ) which is appropriate for a good vision for the human eye.

The output pins of microcontroller are connected to inverters and thus to control the rows. The function of these inverters is to isolate and protect the microcontroller. The output pins of microcontroller which drive the columns are connected to Transistors. Figure (12) illustrates the flow diagram of the control circuit:

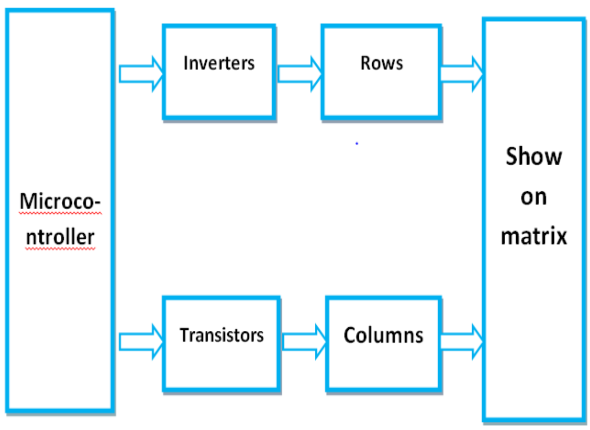

Fig.12: Flow diagram of the control circuit

Figures (13) and (14) show the schematic and layout diagrams of the control circuit in respectively:

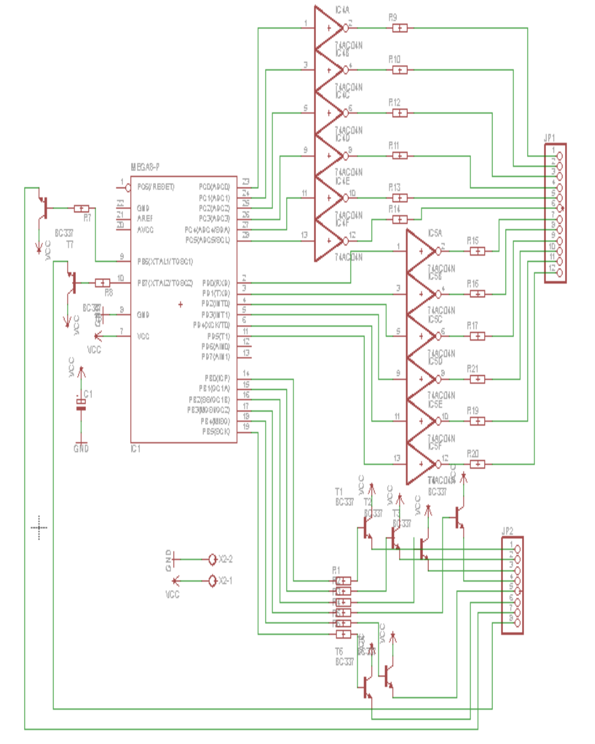

Fig.13: Schematic diagram of the control circuit

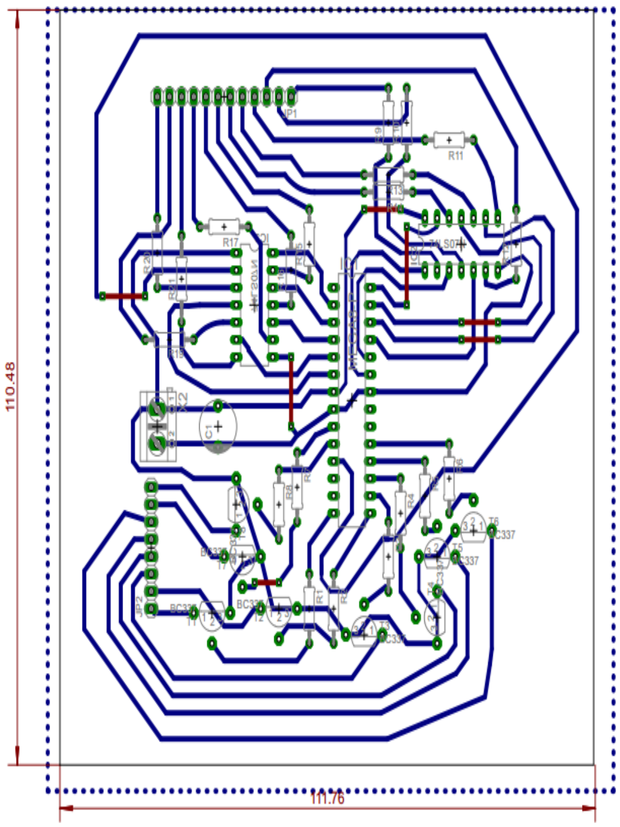

Fig.14: Layout diagram of the control circuit

Figure (15) shows the proposed control unit after fabricating:

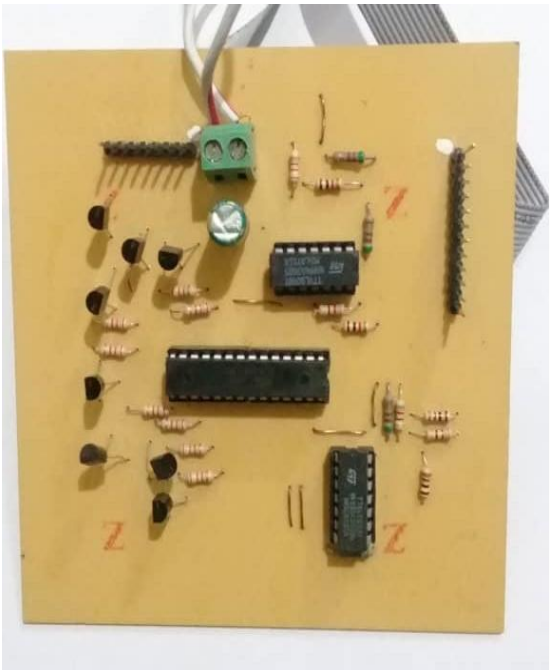

Fig.15: Fabricated control circuit

C. Algorithm

Our algorithm is very simple. First of all, we have to determine the shape we want to show with colors. Then, we need to determine which LEDs have to be illuminated and which not. After that we have to set the values of zeros and ones required to scan the rows and columns. Finally, we only need to program the microcontroller. In this algorithm we chose the scanning time is 20 ms which means the frequency is 50 Hz and that gives a good vision to human eye as we mentioned before. Used duty cycle is less than 10% and that reduces the power consumption. Figure (16) illustrates the flowchart of the control algorithm:

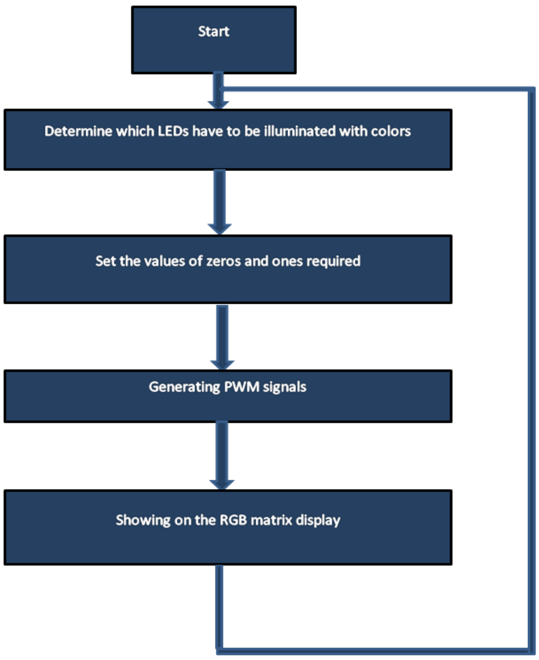

Fig.16: Flowchart of the control algorithm

IV. RESULTS

A. Driving circuit for single RGB LED using 555

After fabricating the circuit we did many experiments that we started by showing the primary colors then, we tried to mix colors. We fairly obtained all colors and even we could obtain different degrees of one color like brighter or darker which is considered very good results. Figure (17) shows some of colors we obtained:

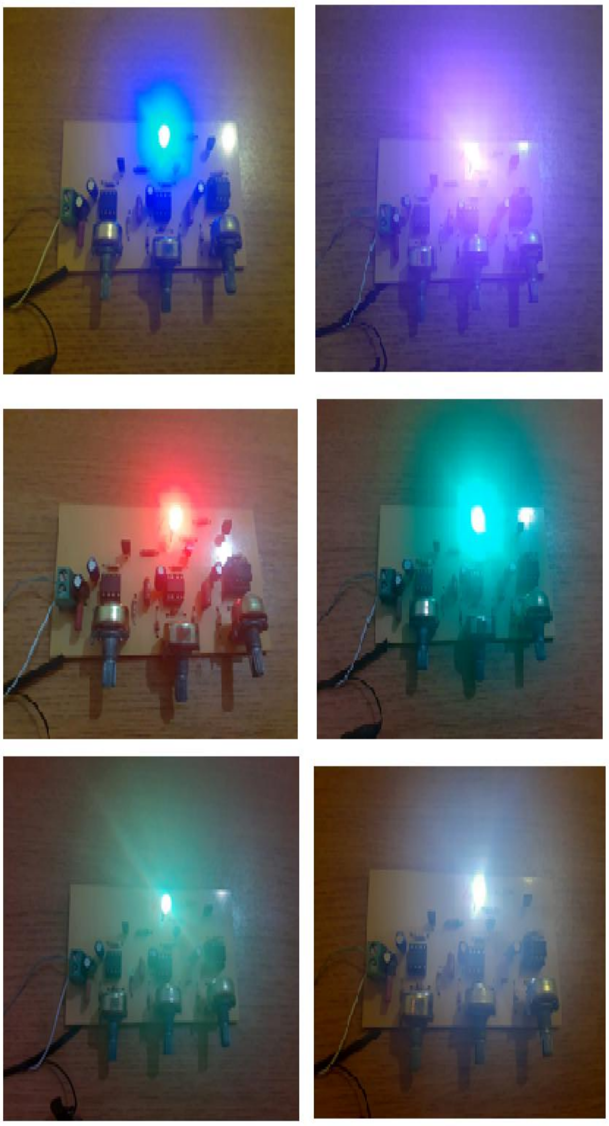

Fig.17: Implemented Driving circuit for single RGB LED using 555 Timer.

B. RGB matrix display and its control circuit

After fabricating the RGB matrix we tried to control it by showing first maximum numbers of colors with maximum degrees then we tried to show different statuses like separate LED, separate column, separate row, diagonal scanning and other status. The proposed project showed good results that we could show many statuses with different colors which is shown in figure (18):

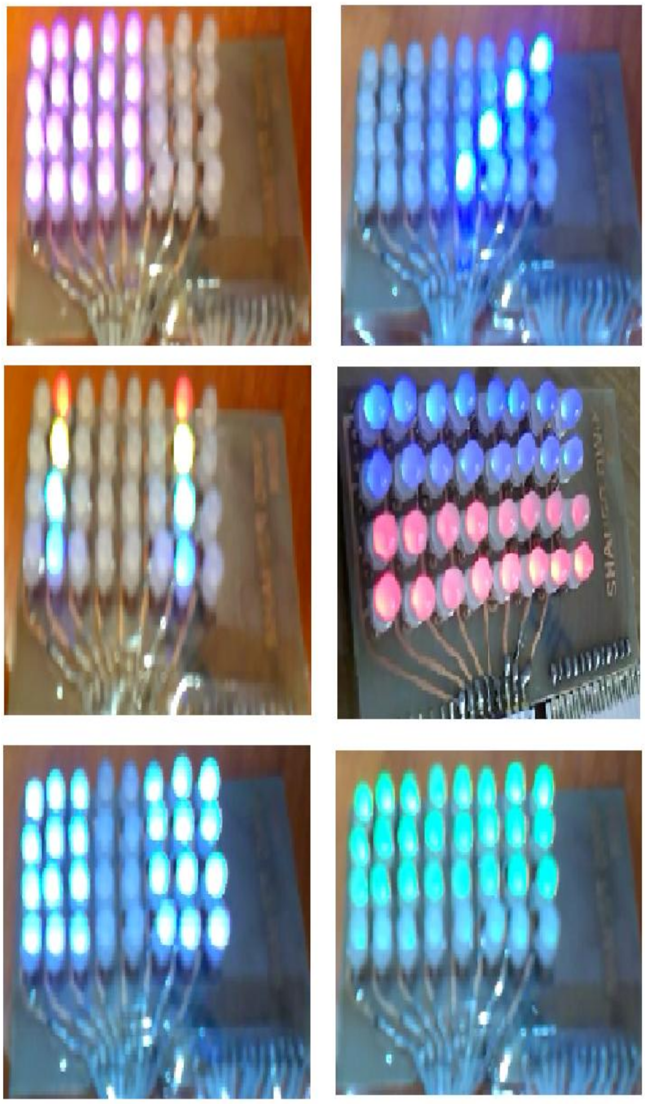

Fig.18: **Implemented RGB matrix display and its control circuit.**

V. CONCLUSION AND FUTURE WORKS

In this project we designed and implemented the simple RGB matrix display for embedded applications (4 rows × 8 columns) using simple tools like low level microcontroller and we obtained good results. We divided our work to two main parts; the first part was to design a circuit to control a single RGB LED manually, second part which was the main part was to design an array of RGB LEDs with a control circuit to.

There are many aspects can be enhanced in both parts hardware and software like:

1. Design bigger matrix with huge sizes for better showing.
2. Use high level controllers which achieve better controlling.
3. Enhance algorithms allow us to show more complicated shapes with less instruction like using arrays, functions or etc. which is considered the most important point.

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