NIPES
Journal of Science and Technology Research
Journal homepage: www.nipesjournals.org.ng

Design and Construction of an $8 \times 8 \times 8$ RGB LED Cube

Bello N.[1*] and Muhammed A. A.[2]
[12]Department of Electrical/Electronic Engineering, University of Benin, PMB 1154, Benin City, Edo State, Nigeria.
Corresponding Author Email: nosabello@uniben.edu, abudu.muhammed@uniben.edu

Article Info

***Keywords*:** *3D, LED cube, 3D animations, $8 \times 8 \times 8$ RGB LED cube, RGB*

Received 4 September 2023
Revised 17 October 2023
Accepted 20 October 2023
Available online 29 April 2024

https://doi.org/10.5281/zenodo.11391936

ISSN-2682-5821/© 2024 NIPES Pub. All rights reserved.

Abstract

The study presents the design and construction of an $8 \times 8 \times 8$ RGB (Red-Green-Blue) LED (Light Emitting Diode) cube. The entire hardware structure uses 512 RGB LEDs connected three-dimensionally that displays the spectrogram animation of a music file. Each LED is controlled by a control circuit comprising a microcontroller for the lighting while the animated spectrogram is done with a second microcontroller. The circuit design and simulation were achieved with the Proteus software and constructed on a PCB (printed circuit board) whereas the PIC microcontroller used was programmed with a Mikro C compiler. The program applies the persistence of vision technique at a refresh rate of 250 Hz which lights a horizontal plane at a time. The plane is multiplexed to the driver circuits connected to the microcontroller. Finally, a 3D animation of the LED cube was achieved at a fast refresh rate showing different patterns and shapes.

1. Introduction

Humans perpetually use process information and the technology of information manipulation has concomitantly advanced with advancements in science and technology. Visual information is by far the most appealing to the human mind and many technologies make use of this to interface with its users [1], consumers and operators by way of output/display units. Conventionally, display units are usually flat 2D presentations of visual data or 3D presentations of visual data on flat 2D display screens. The 3D display is particularly appealing as we live in a three-dimensional world, and, consequently, attempts to simulate real-world 3-dimensional reality has been a major goal in display technologies. The entertainment and the commercial world, especially, are ever seeking ways to have a strong emotional appeal on the minds of viewers and consumers respectively. 3D RGB LED cube display is an evolution from the conventional 2-dimensional display, as it offers true 3-dimensional and volumetric rendering of imagery and character and thus has stronger appeal on the mind. Traditional flat 2D display of 3-dimensional data suffers some limitations, which include the fact that:

i. The observer cannot relate with the image intuitively (for instance, pointing out with one hand to a fellow observer a part of the image)
ii. The display may give wrong impressions of relative size and shape
iii. The display images usually have a limited viewing angle and (some display technologies) are only visible with special goggles.

All of these disadvantages are overcome by a true 3D volumetric display, that is, a display in which a volume in space is occupied (rendered in voxels). 3D cube LEDs are made into two main types: monochromatic and multicolour. They come in different sizes from $4 \times 4 \times 4$ to $64 \times 64 \times 64$ or larger. The complexity and mass of the LED and driver structure will rise for higher dimensions. As a result, designers will use larger electronic boards and faster algorithms to control the integrated LEDs [2].
[3] designed a 125 LEDs embedded acrylic tube 3D LED cube that was a starting point for a series of works by [4] in his first work in collaboration with other researchers used 100 LEDs per clear crystal plane in a 3D cube of a total of 10 planes resulting in a cube of 1000 voxels. His next work improved the versatility by enabling the 1000 LEDs to be individually controlled with a refresh rate of 60 frames per second and also displayed colours determined by the input picture (captured by a camera) or sound via a serial input. However, the design failed to meet the requirements of an unprotected outdoor environment. The Big Round Cubatron of dimensions of over 12 metres in diameter and 3 meters in height [5], is another work that has the LEDs controlled independently to display any colour and brightness at a refresh rate of 50 Hz. It had 6048 voxels in total each containing a red, green and blue LED. Also, [6] presented electrical engineering students' works at the Delft University of Technology in the Netherlands. They created a 3D display that consist of 8000 suspended ping pong balls that each contained a red light. The design played 3D snake, 3D pongs and 3D drunkhunt as well as a displayed SMS message and simple animations. [7] offered a DIY (Do-it-Yourself) $4 \times 4 \times 4$ and $8 \times 8 \times 8$ LED cube kit for sale. The kits consisted of PCBs, Atmel ($4 \times 4 \times 4$) or Arduino ($8 \times 8 \times 8$) microcontroller, single-coloured blue LED and other assorted parts with an instruction manual for coupling the contents of the kit and a link to the downloadable files to animate the lighting of the cubes. Also, [8] presented an $8 \times 8 \times 8$ blue LED cube designed using Arduino ATmega 32 microcontroller, a 3-to-8 decoder, eight 8-bit shift registers and a 5V computer power supply to maintain the high current demand. They also offered an open-source C code for animating the lighting of the cube. [9] shared a comprehensive guide on the design and construction of an $8 \times 8 \times 8$ RGB LED cube. The lighting of the LEDs is animated with an Arduino Uno microcontroller that lights up a horizontal plane at any time at a refresh rate of 125 Hz and the bit amplitude modulation (BAM) LED drive technique. In this paper, the design and construction of an RGB 3D LED cube is presented that uses 512 LEDs arranged into an $8 \times 8 \times 8$ lattice. The 3D RGB cube produces colourful animations like that of [9] but uses a PIC microcontroller, shift registers, MOSFETs and sink drivers at a higher refresh rate of 250Hz. PIC microcontrollers have more peripherals than Arduino, thus allowing future-proofing of prototypes. As strong and robust processors, they allow for multitasking and multiple simultaneous online component connections to accomplish tasks [10].

In this paper, we present the design and construct of an $8 \times 8 \times 8$ 3D RGB LED cube which displays a spectrogram animation of a music file. The proposed design adds to the existing works through the following: 3D Spectrum Analyzer, Date and Time Display, Public Address System, Memory Card Slot, Bluetooth Connection, WTV020-16p for storing music for hours AND 1GB Memory Storage
The added features bring uniqueness to this study and improvement to existing completed research. Also, to ensure a smooth transition of the proposed design to higher dimensions of the cube beyond the $8 \times 8 \times 8$ we implemented a control circuit that allows the extension of more driver units for the higher dimensions. Hence, development is simplified to just the design of the driver units and code optimization for a seamless display.

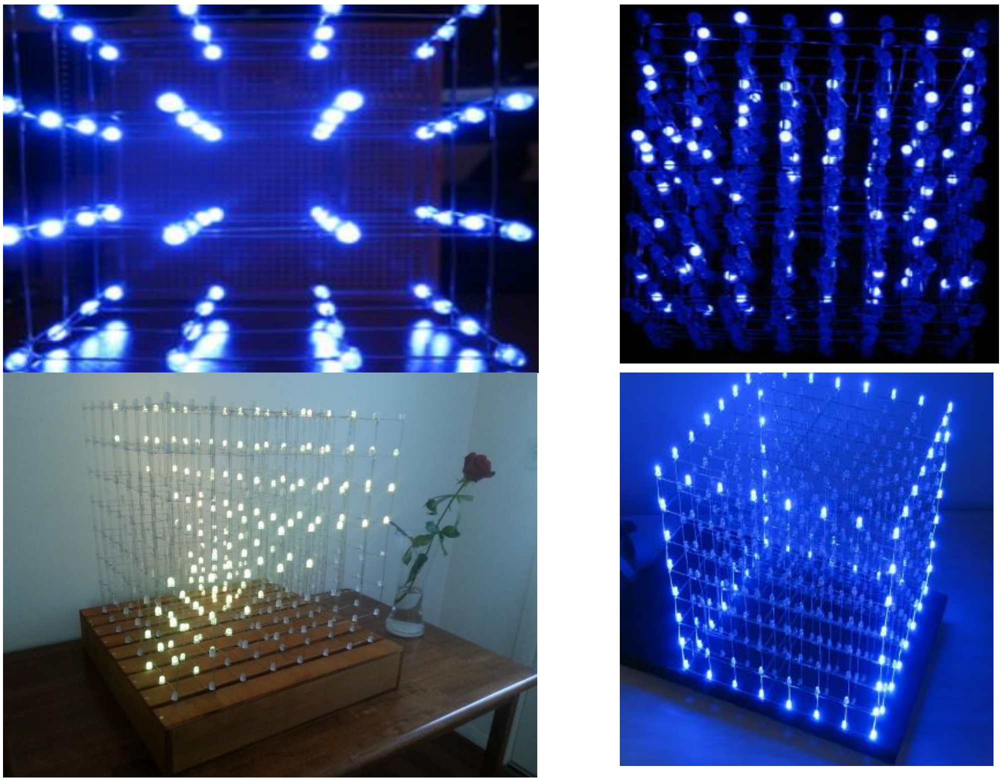

Figure 1 (a) 4 × 4 × 4 DIY Blue LED Cube [7] (b) 8 × 8 × 8 DIY Blue LED Cube [7] (c) 8 × 8 × 8 3D RGB LED Cube [9] (d) 8 × 8 × 8 3D Blue LED Cube [8]

2.0. Materials and Method

The design of the cube has been sectioned into hardware and software subparts which comprise the bulk of the work and effort. The design of the LED cube is divided into two major sections: Hardware section - LED cube array, circuit design and software section

2.1. Hardware Section

The hardware design consists of the LED cube array and the circuit design. The LED cube with 512 LEDs is constructed with each LED measuring a diameter of 10mm and consisting of four pins—red, green and blue anodes and a cathode. Each layer (horizontal plane) of the LED cube is made up of 64 LEDs. These 8 layers are then cascaded to form the cube. The LEDs are uniformly spaced as much as possible to achieve symmetric dimensions. The cube array was arranged and spaced within a 29cm by 29cm by 29cm dimension. The circuit design involves the design of the control unit, the power unit and other peripherals. The operation of the LED cube is highlighted by the block diagram in Figure 2. It shows the block diagram of the LED cube. It shows a detailed schematic of the entire system consisting mainly of the power unit, the control unit and the display unit. The control unit comprised two microcontrollers which are the main microcontroller (PIC18F4620) and the FFT microcontroller (PIC18F2620). The main microcontroller controls the multiplexer (4514) which in turn controls a sinking IC (ULN2803) that actuate an array of power MOSFETs that correspondingly actuate the individual anodes of each layer in the 8 × 8 × 8 LED cube. The main microcontroller also has a set of data pins and control pins meant to feed the cathode driver which is a different circuit through CONN-SIL connectors. The cathode driver comprises sets of shift registers, 74HC595 which is an 8-bit serial data in, a serial or parallel-out register with output latches. The shift registers actuate the sinking ICs (ULN2803) which sink the current from each pin of an RGB LED in the LED cube.

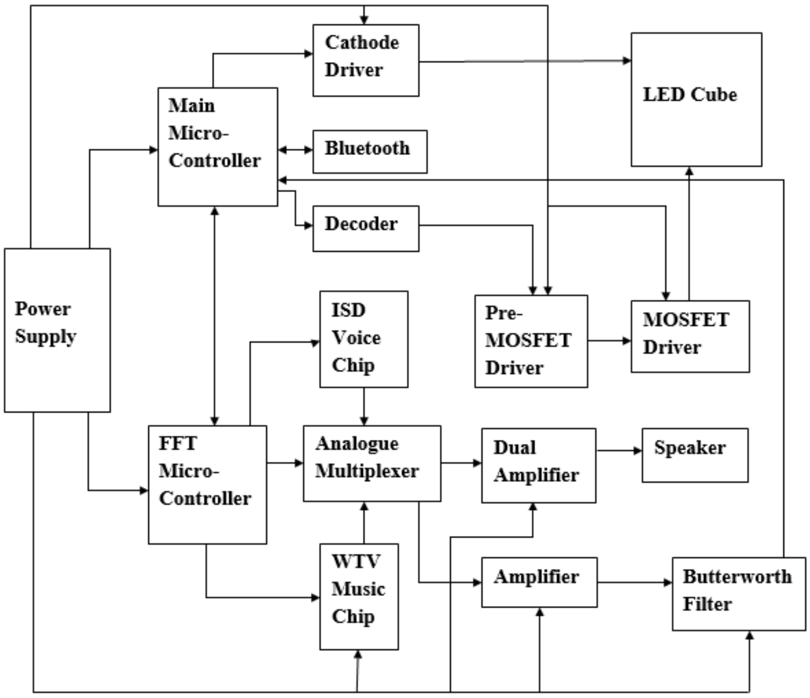

Figure 2 Block Diagram for the model $16 \times 16 \times 16$ LED Cube

The power unit has to supply the entire system's power requirement including the LED cube (display unit). For an $8 \times 8 \times 8$ RGB LED cube, the maximum current requirement is calculated as the current required to light up a layer of the cube. A layer contains 8×8 RGB LEDs and each monochrome LED has a different maximum current requirement. The voltage drop for the Red LED is about 2-volts and for the Green and Blue LEDs, 2-volts and 3-volts respectively. In the power design, a desirable current of 50mA, 25mA and 32mA to the red, green, and blue LEDs respectively were chosen to achieve even brightness. The plane of LEDs would consume a maximum current of 50mA per LED and a maximum of 64×3 LEDs (since each bulb contain 3 LEDs) being lit simultaneously. The maximum current required by the LED cube is calculated as:

Number of LEDs in a plane × maximum current per LED (1)

$$64 \times 3 \times 0.05 = 9.6A.$$

As a result, a power supply rated at 15A was chosen. For the other components consuming power like the ULN2803 Sink Drivers and 748HC595 shift registers including other peripherals, they consume close to a negligible value. Therefore, the power source should provide a rating of 5V, 10A power supply for the LED cube and the ICs in the controller circuit.
The cube has to take inputs from a limited number of microcontroller pins given a layer of the cube contains 64 columns and 8 rows of pins. The 64 columns and the 8-layer levels were controlled directly from the microcontroller through the driver unit. The controller circuit is a circuit that will supply (output) voltage to the LED cube so that the LED cube can display any animations that are programmed to them. The unit comprised the flip-flop integrated circuit (74HC595 IC) and PIC microcontroller which was used to control communication and sequencing and instruction control of the LED cube respectively. A source driver (UDN2981A) is used to drive the current to the LEDs on the cube and has a series of input resistors selected for operation directly with 5V TTL or CMOS. By way of multiplexing, all of the cathodes of a row are connected and the anodes of a column are connected. By applying power to only one row, and grounding only one column, an individual LED

can be turned on. By applying power to multiple rows, and grounding only one column, all of the LEDs in one column can be controlled. After this column has been controlled, the next column can be grounded, and its appropriate rows are powered. This cycle is repeated for each of the columns in the display, rapidly enough such that the persistence of human vision perceives that each of the LEDs that were turned on at one point is constantly on. The driver unit contained serial-in, parallel-out shift registers for minimizing the number of connections between the PIC and the circuit. The shift registers were cascaded to send information from the PIC Microcontroller to the anode and cathodes of the LED cube.

In a circuit that drives an LED cube made of $N \times N \times N$ LEDs, the number of shift registers needed is $N + 1$ (only if $N \leq 8$). With RGB LEDs, the LED cube is made up of $3 \times N \times N \times N$ LEDs and hence $3N + 1$ shift registers are needed. One is needed to switch on/off the cathode planes and the rest of the N shift registers are needed to switch the anode columns. In addition to the shift register, there are the MOSFETs for switching the anode layers. The MOSFETs are needed to interface the output control of the shift register to the high current demand of the cube. Each output of the first shift register (which handles the anode layers) is connected to an IR3808 MOSFET's gate through a 220 Ohm resistor. The source pin of the MOSFETs is connected to the power, from where it directs the current to the appropriate anode layer of the cube when the shift register switches it on.

Some resistors are needed between the cathode layers and ground and the anode columns and the negative voltage to help some currents go away after switching layers. Otherwise, these currents will go away through the LEDs and that will result in ghosting (i.e., when a layer is switched on, the previous layer is also dimly lit). So, to get rid of this ghosting, a 10K resistor was added between each cathode layer and the ground and a 1K resistor between each anode column and the negative voltage.

2.2. Making the jig

The construction of the LED cube took specific steps which have been discussed in the next three sections. It starts with the construction of the Jig. The Jig is used for putting into place 8 pieces of RGB LED on three strands of wire in the order of red, green, and blue to form a pillar of the LED cube. It is made from Medium Density Fibre (MDF) Board. It is made by making a base and square cutting of MDF (using chosen dimensions) placed on it. Each square cutting has a 10mm hole drilled on it to provide a grip for the 10mm LED while soldering. Two extra square cuttings are placed at both ends of the MDF base, each with three holes drilled through it to provide support for the three strips of wire.

Figure 3 Forming the jig

2.3. Making the pillars

Each pillar consists of three strands of stripped copper wire with eight LEDs equally spaced and soldered across them. Each LED has three anodes of red, green, and blue light which are soldered across each strip of wire.

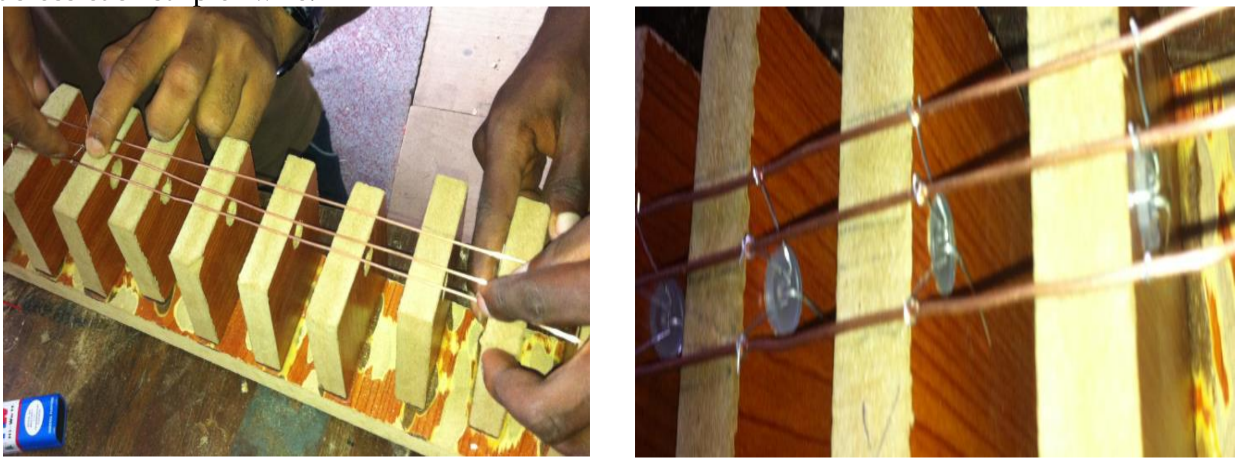

Figure 4 Inserting the LEDs into the jig

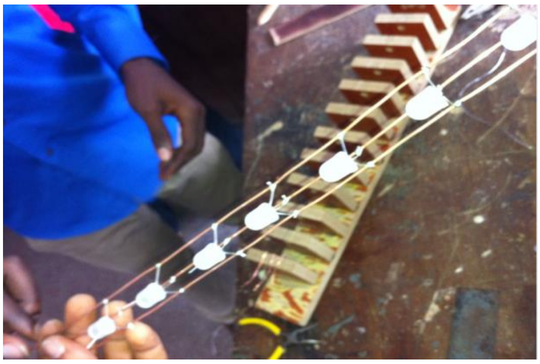

Figure 5 A completely formed pillar

2.4. Forming the slices

The following steps were taken to form the slices:

i. Eight pillars are placed side by side vertically with equal spacing and at the same time make sure the eight horizontal LEDs align.
ii. A wire strip is placed across the cathodes of the eight horizontally aligned LEDs and each cathode is soldered to the wire.
iii. Steps 1 and 2 are repeated across the eight rows to complete a slice.
iv. Steps 1, 2, and 3 are repeated to form the eight slices of the LED cube.

Figure 6 LED cube layer

2.5. Forming the 8 × 8 × 8 led cube array

The following steps were taken:

i. A cardboard sheet was cut with 1.5ft by 1.5ft dimension. Inside this sheet, the points of entry and alignment of the 192 wires from the slices were marked and drilled.
ii. The eight slices were placed on the cardboard to fit into the 192 drilled holes. This automatically aligns the 8 slices to form the cube.
iii. The single line of the cathodes of each row of a slice is soldered onto a wire strip passed across the rows of the slices. Each cathode line from all the slices is soldered together to form the cube.

2.6. Software design

The software section contains the programming, multiplexing technique, and signal processing algorithm applied to animate the cube. To ensure the lighting up of the LED cube, the persistence of vision (POV) technique is applied across the entire rows. The programming language used was the C programming language and the corresponding software was the MikroC compiler.

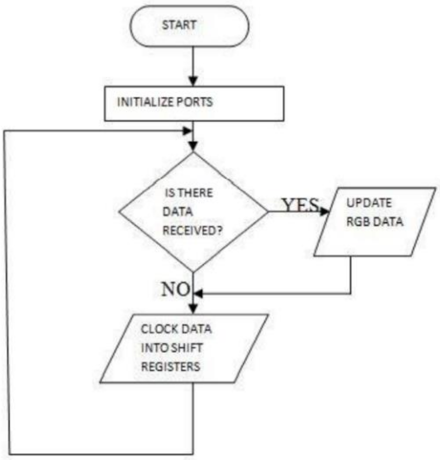

Figure 7 Flow chart for the display of the LED cube

The flowchart summarizes the main functions of the LED cube display, however, there are other functionalities. The FFT microcontroller communicates with the main microcontroller through a UART pin and also reads and writes to the Real-Time Clock, controls the ISD 17240 voice chip such as playing recorded sounds from the voice chip and increasing and reducing the intensity of sound. This sub-microcontroller also controls the music chip (WTV020) such as making the IC read music from a memory card which will be amplified by an amplifier and reproduced by a speaker. The music played by the music chip can also be displayed in form of a spectrum analyser.

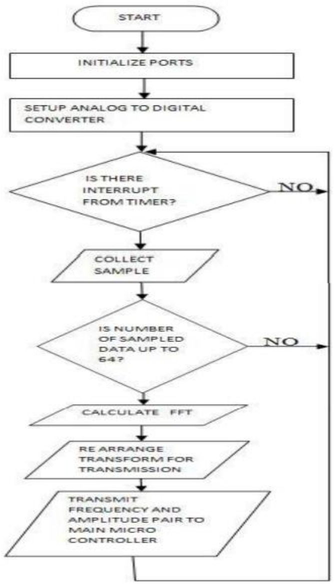

Figure 8 Flow Chart for FFT Code

The materials used in the development of this prototype is summarized in Table 1 which shows the quantity and cost of the research.

Table 1: Bill of engineering quantities and evaluation

S/No	Components	Description	Quantity	Unit Price (₦)	Total Price(₦)
1.	100n Capacitors	Ceramic capacitor	31	10	310
2.	22p Capacitors	Ceramic capacitor	3	10	30
3.	47uf Capacitors	Electrolytic capacitor	16	100	1600
4.	100uf Capacitors	Electrolytic capacitor	14	100	1400
5.	1000uf Capacitors	Electrolytic capacitor	1	100	100
6.	Resistors	10k, 1k,560R,470R	198	10	1980
7.	IRF3508	Transistors	8	250	2000
8.	Diodes	IN4148, Diode-sc	3	20	60
9.	PIC18F4620	Microcontroller	1	1500	1500
10.	MAX 232		1	400	400
11.	UDN2981A	Source driver	25	300	7500
12.	74HC595	Shift register	24	150	3600
13.	4514		1	400	400
14.	74HC541	Buffer	1	150	150
15.	Connectors		30	100	3000
16.	TBLOCK		5	300	15
17.	RN2, RN4	Resistor array	2	100	200
18.	Crystal oscillators	4Hz, 12Hz	2	50	100
19.	LM2576				
20	100uH	Inductor	1	300	300

21	MDF	Medium-density fibre is a form of plywood.	1ft by 1ft	1000	1000
22.	Copper wire	The wire used to connect the LEDs	3	3800	11400
23.	LEDs	Light-emitting diodes	550	50	27500
24.	9V HV Batteries	Used for testing	3	150	450
25.	Araldite	Glue	2	500	1000
26.	Soldering Iron	60w soldering iron	2	500	1000
27.	Soldering lead	Used to solder		1500	1500
28.	PCB	Column driver and the matrix circuits	2	3050	6100
29.	Perspex	1.5ft by 1.5ft		1500	1500
30.	Total				77,580

3.0. Results and Discussion

The construction of the LED cube was done in stages. Before the start of every stage, the tools needed for construction, the materials to be used as well as electrical components needed were made available. The materials used for the construction include: Araldite glue, Medium density fibre (MDF), 1m-3ft Measuring tape, Copper wire, Sandpaper, Soldering Iron, Soldering lead, Lead Sucker, Pliers, Wirecutter, Pencil, Digital Multi-meter, Knife, Scissors, PCB, Cardboard, Screw Driver, Nails, Perspex sheet, Drilling machine, 9v HV (high voltage) Batteries with clips
There is a lot of circuitries that had to be constructed to realize the final cube. Firstly, the LED cube had to be constructed following the steps discussed in section 2. This is the most difficult task considering the number of LEDs that have to be soldered together and the fact that some tend to get damaged if not properly handled. The LED cube is shown in Figure 9.

Figure 9 Completely formed 8 × 8 × 8 LED cube array

3.1. Circuit design and mounting

The circuit design schematics in Figures 10 – 16 were drawn using Labcenter Proteus circuit design and simulation software after which the PCB layout is designed using the same software tool.

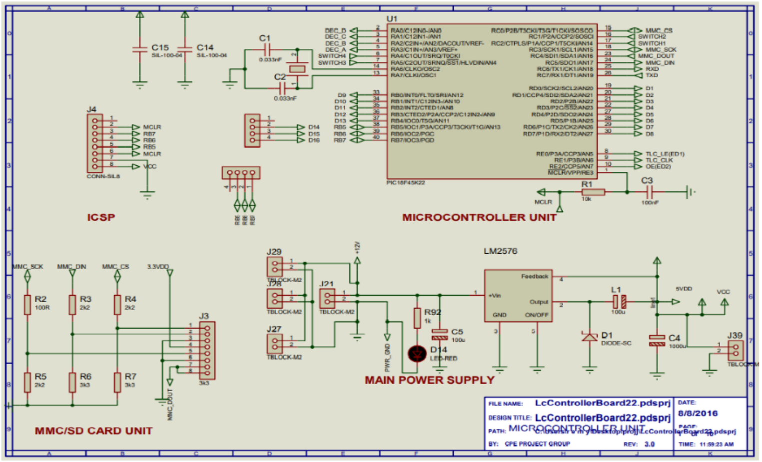

Figure 10 Schematics of the Microcontroller unit, MMC/SD card, and main power supply on Proteus v8.0

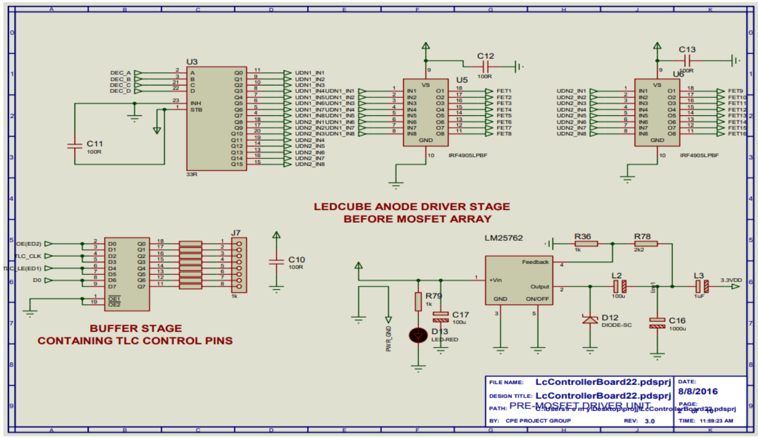

Figure 11 Schematics of the buffer stage and LED anode driver before the MOSFET array

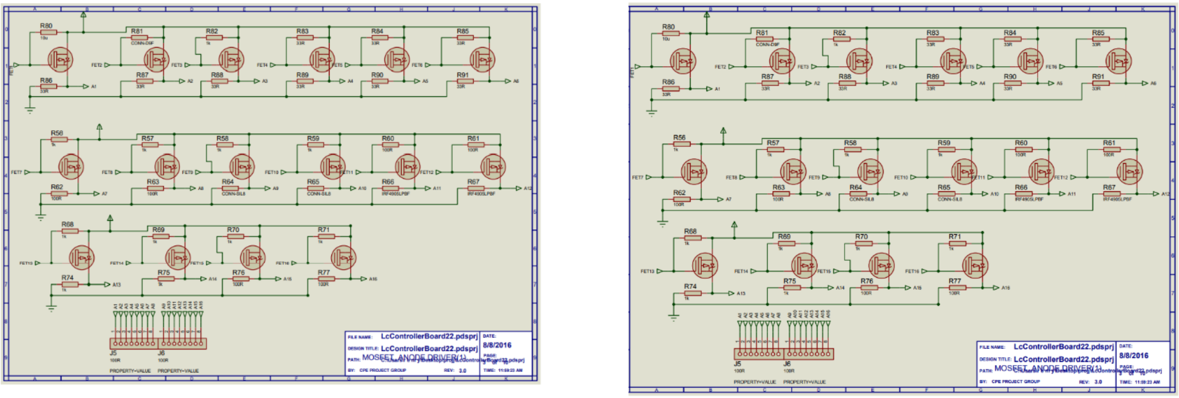

Figure 12(a) Complete schematics of the column driver (b) The complete PCB routing of the column driver

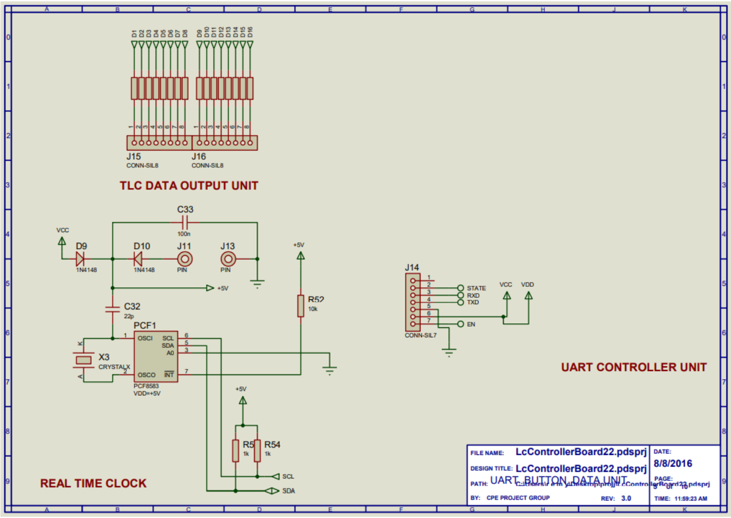

Figure 13 Real-time clock and the TLC data output unit

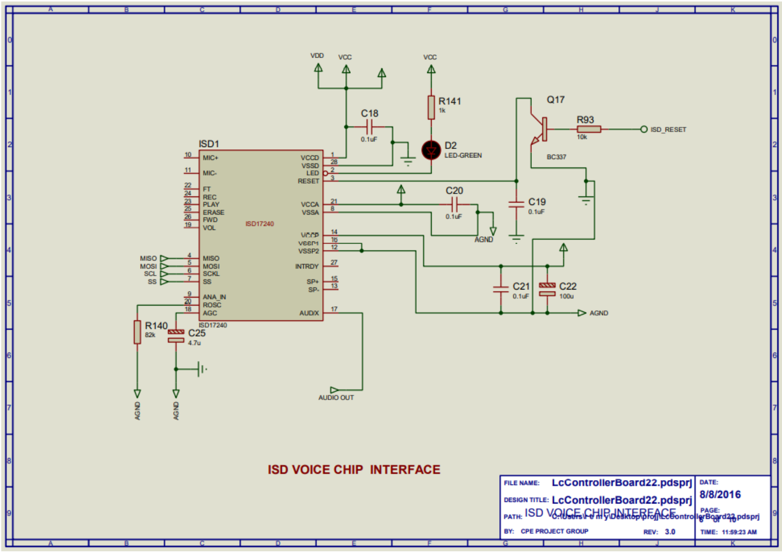

Figure 14 ISD voice chip interface

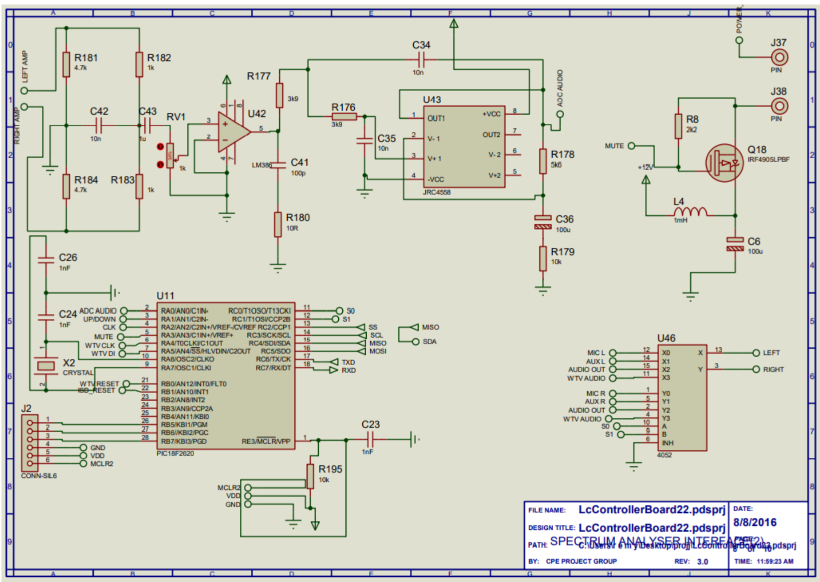

Figure 15: Spectrum Analyzer Interface

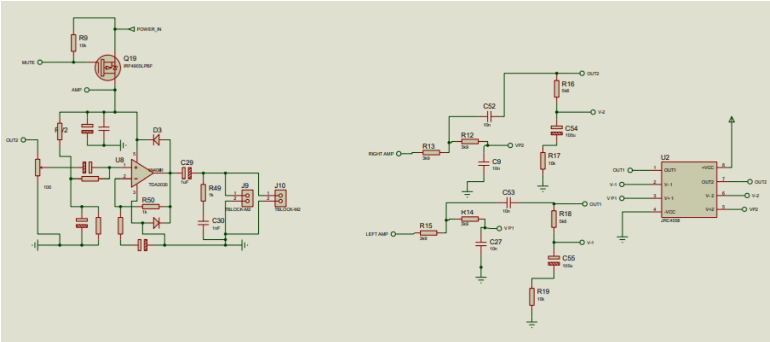

Figure 16 Dual high gain operational amplifier

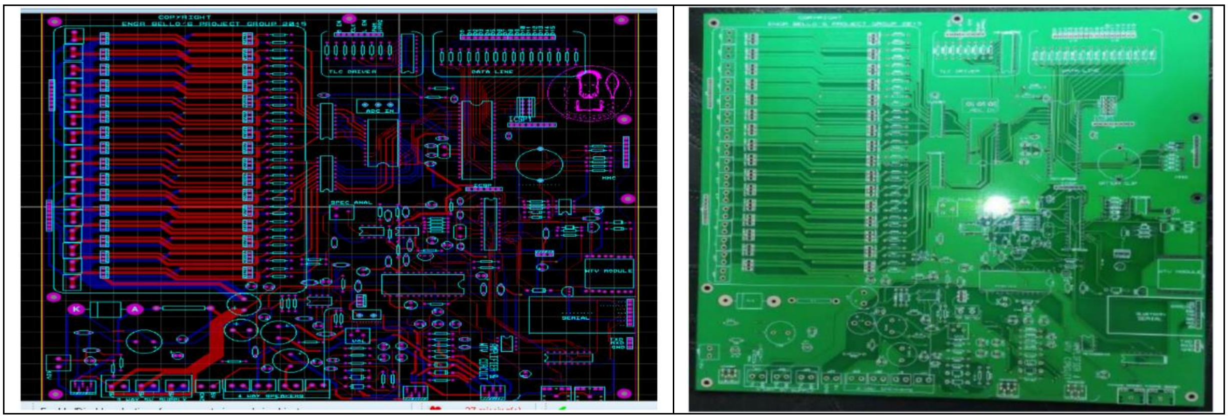

Figure 17 (a) Main Controller Board (designed in Labcenter ARES) (b) Main Controller Printed Circuit Board

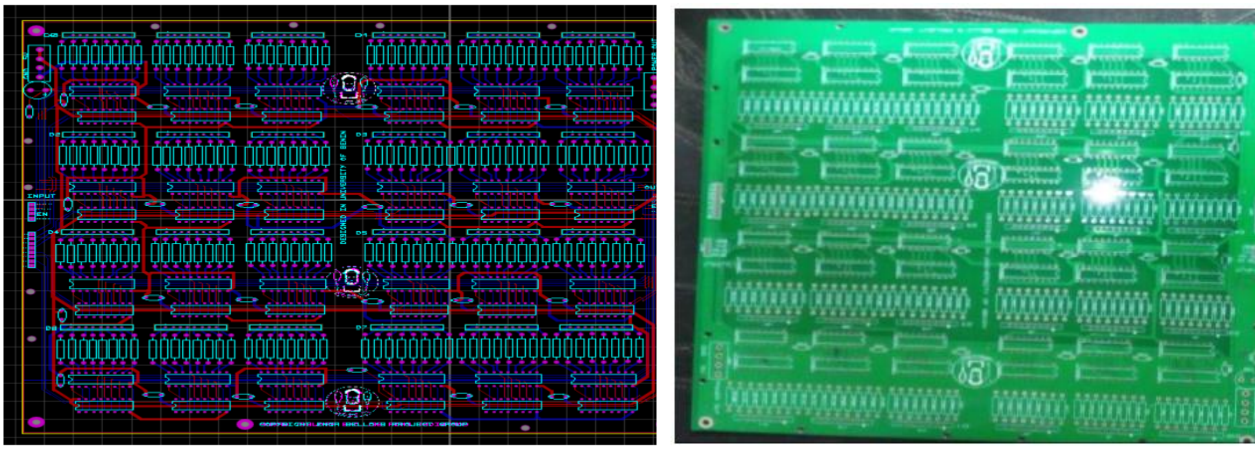

Figure 18 (a) Cathode Driver Board PCB Layout Designed IN ARES (b) Cathode Driver Board PCB Layout Designed in ARES

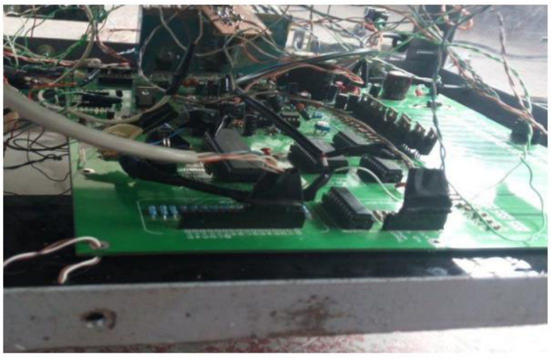

Figure 19 Main controller PCB with mounted ICs

Figure 20 Cathode driver with mounter ICs and wires connected to the LED cube

3.2. Casing

Figure 21 The glass casing

The last stage of the construction and mounting involved the wiring of the LED cube to the PCB circuits and the casing. Figure 22 is the results of completely wiring and casing the cube.

3.2. Testing

The electronic components on the PCB circuits after being soldered were tested using a digital multimeter to determine if the circuits worked satisfactorily and to check for continuity.

The tests were conducted both modularly and chronologically; each specific stage of the design will be tested individually throughout the build process. This allows cascading errors (an error early in the build process causing multiple errors later on) to be entirely avoided as well as provide the identification of any errors to a specific hardware or software functionality concern. The primary hardware components tested were LEDs. The LEDs were to be tested simply to confirm their functionality. Each LED test involved an "ON/OFF" check with each colour. Each LED was tested individually before being soldered to the cube, then also individually after soldering to the cube. This ensured that the LED is in operating condition, as well as identified any problems in the wiring of the LED cube. As the cube was soldered one plane at a time, each plane was tested before its addition to the cube structure. Finally, upon the addition of each plane to the cube, the entire cube existing then was tested.

4.0. Conclusion

In this paper, the 3D LED Cube display was implemented. The 3D LED Cubes from recent research presented in this study were non-modular and changing their resolution was difficult and needed redesign and programming. To solve the problem, we ensured the modularity of the design by separating the MCU from the driving units and the power unit. We implemented our method successfully and built the $8 \times 8 \times 8$ RGB LED display. Due to this modularity, our method can resize (changing resolution) 3D LED Cube simply and quickly. Successfully, the study completed the design and construction of an $8 \times 8 \times 8$ RGB LED cube of uniform brightness and compact design for outdoor proof to dust.

References

[1] West, D.M. and Allen, J.R., 2018. How artificial intelligence is transforming the world. *Report. April*, *24*, p.2018.

[2] Kolivand, H., Azar, M.R.S. and Aghamohamadi, R. (2019), Design and Implementation of Modular 3D LED Cube.

[3] Boyer, S.W., 2001. Light art structure. U.S. Patent Application 29/121,210.

[4] Clar, J. 2009 “3D display cube – white” [Online] Available at: http://www.jamesclar.com/portfolio_page/3d-display-cube-2002-2009/ (accessed 06-11-2015)

[5] Network Wizards, 2015 “The Cubatron Jr” [Online] Available at: http://www.3waylabs.com/projects/cubatron/ (accessed 06-11-2015)

[6] Ruairi Glynn, 2006. World’s largest 3D-display | Interactive Architecture Lab [Online] Available at: http://www.interactivearchitecture.org/worlds-largest-3d-display.html (accessed 20-06-2015)

[7] Jameco Electronics 2012 “4 × 4 × 4 Blue LED Cube Kit” [Online] Available at: https://www.jameco.com/z/KIT-4X4-Jameco-Kitpro-4x4x4-Blue-LED-Cube-Kit_2146329.html (accessed 06-11-2015)

[8] Instructables, 2001 “8 × 8 × 8 LED Cube [Online] Available at: https://www.instructables.com/Led-Cube-8x8x8/ (accessed 06-11-2015)

[9] HNTE, 2013. RGB LED Cube [Online] Available at: http://www.hownottoengineer.com/projects/rgb-led-cube.html (accessed 25-12-2015)

[10] EDUCBA, 2020. PIC vs Arduino | Amazing 6 Comparisons of Microcontrollers [Online] Available at: PIC vs Arduino | Amazing 6 Comparisons of Microcontrollers (educba.com) (accessed 32-10-2020)