Design of 3D volumetric display

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Abstract. Stereoscopic, or multi-view, display systems that can give significant visual clues for the human brain to understand three-dimensional (3D) objects, they are regarded as better alternatives to traditional two-dimensional (2D) displays. A device that can render 3D images for viewers without the use of specific headgear or glasses is known as an auto-stereoscopic display. Manipulation of light rays via Light engines is also used to create 3D images in 3D space. We introduce a new auto-stereoscopic swept-volume display (SVD) system based on light-emitting diode (LED) arrays in this research. A display device plus a graphics control sub-system makes up this system. The display device is a 2D revolving panel of LEDs that generates 3D images using “persistence of vision”.

1. Introduction
Displays are one of the most commonly found technology in our world. These are used for variety of purposes such as entertainment, advertisements etc. They conventionally display 2D images using technologies like Cathode Ray tube, LCD and LED technologies. Volumetric displays are displays that project 3D images/model onto a 3D space. These are categorized into two i.e., static-volume displays and swept-volume display (SVD) [1]. A 3D image is formed utilizing a static 3D space in static-volume displays [3]. The rotation of a 2D surface generates a 3D image in SVDs. The surface of emission within a volumetric display can be classified as either passive or active orthogonally [2]. Light beams are directed toward a passive surface of emission to activate it in a display with a passive surface of emission [4]. Within the three-dimensional image, a point or voxel is the key unit of a volumetric display is the voxel, which is equivalent to a pixel in 2D displays [1]. Light is emitted at the voxel position by the interaction between the passive surface and the beam(s), or sequences of cross-sectional 2D pictures can be reflected on such a surface. An image projection equipment, for example, can generate 3D images by projecting 2D pictures on a moving screen or mirror [4],[7],[9]. An active surface of emission, on the other hand, is made up of a 2D array of devices, such as LEDs, that actively produce light and form the voxels [2],[6],[8].

2. Design of 3D volumetric display
As most of the 3D display, we see or have interacted with use an external equipment for creating a 3D experience. These are stereoscopic display system. Here we propose a new and cheap way to create a
3D image by the rotation of a 2D LED array mounted on a DC motor using a frame where the LED array is controlled using a micro controller such as Arduino [13].

2.1. Selection of components

2.1.1. Microcontroller

The microprocessor is the fundamental component of the device. Its task is to run the Arduino program which identifies those LEDs that need to be illuminated. Here we use ESP32 WROOM32 Node MCU Module which is powerful tool used for various IoT purposes, with integrated Wi-Fi and Bluetooth which helps us to control the microprocessor wirelessly. It consists of 26 GPIO pins out of which 16 pins are connected to the LED array. The microprocessor can be controlled using a DC power source; therefore a 3.7 V Li-ion rechargeable battery is used. Its compact in size and weighs less than 50 grams, making it light and easy to incorporate on the rotating mechanism.

2.1.2. LED array

A Dot Matrix Common Anode Red LED Display is used here. The function of the LED display is to show the image and here it shows a 2D image after rotational slicing of the 3D image that need to be shown. The diameter of the LED is about 3mm with common anode configuration and it consist of total 64 LEDs with 8 LEDs in a row and it emits red color. It has a length and breadth of 32mm with a total weight of 400grams. This LED is placed with the frame so that it is properly fixed to the motor without any freedom of movement and it will rotate according to the speed of rotation of the motor.

2.1.3. Frame

This frame is actually used to fix the LED display to the motor. The plastics obtained from renewable materials such as Polylactic Acid (PLA) is using here. The 3D printed display frame is connected to the threaded shaft of the motor and the LED array is connected with the frame. The size of the display frame is about 100cm length. Display frame holds the LED array and hence the rotational sliced image will be properly rotated with the motor without any vibration and hence the persistence of vision is achieved.

2.1.4. Motor

For persistence of vision, the setup is required to rotate at an rpm of 1800 in order to achieve 30FPS. Speed above 1800 rpm is also applicable. Hence considering the weight of the rotating setup, a 24-volt DC brushed motor, capable of achieving a constant speed of 2400 rpm is used. It weighs around 850 grams which is around 5 times the weight of the rotating apparatus, as result of which, the motor need not be fastened to a bench, making it portable. The outer end of the shaft has threads, to which the rotating frame can be fastened.

2.1.5. Power supply

The power required for the microcontroller i.e., ESP32 WROOM32 Node MCU Module is satisfied using 3.7V Li-ion battery having a capacity of 2500mah. Whereas the power for the motor is given through AC/DC adapter.

3. Working

The above-mentioned components are categorized into base components and rotating components.

3.1. Base components

These include the mechanical frame and the 24V brushless motor. It is these components that realize the concept of a moving screen which is required to achieve the persistence of vision.
3.2. Rotating components

These include the microcontroller and 32×32 LED array. These are responsible for the image projection of a section of a predefined primitives onto the moving screen realized by the base components’ operation.

Both these components are to work in tandem with each other to produce an opaquer voxel in 3D structure. Here we employ a modular design approach to make this design easy to assemble and be cheaper to produce. A host PC is used for programming ESP32 WROOM32 NodeMCU Module with program which essentially provides the LED array with voxel coordinates for the 3D model to be created. For persistence of vision, the setup is required to rotate at an rpm of 1800 in order to achieve 30FPS [11]. Speed above 1800 rpm is also applicable. Hence considering the weight of the rotating setup, a 24-volt DC brushed motor, capable of achieving a constant speed of 2400 rpm is used. It weighs around 850 grams which is around 5 times the weight of the rotating apparatus, as result of which, the motor need not be fastened to a bench, making it portable. The outer end of the shaft has threads, to which the rotating frame can be fastened. Thus, when the LED array is activated for 1sec at the start of operation and is rotated at or above 1200rpm, persistence of vision occurs which allows us to create static image of the cross section in 3D space and when LED array is activated at all times while operation, we are able to stack these static images at different angles to create a 3D image. Primitives such as cylinder, cone, Di-cone, circle are achieved using this modular approach [15].

Since an ESP microprocessor is used, the programming is done using Arduino IDE software in C++ language. The basic function of the program is to take the values of the required image in a matrix form of which each element consists of a binary number, that is 1 or 0. The size of this matrix is same as that of the LED array matrix. Those elements having value 1 will result in the illumination of the corresponding LED in the LED array.

3.3. Multiplexing

The LED array used here is in the form of a matrix, containing 64 LEDs. They are arranged in the form of a grid of 8 rows and 8 columns comprising of 8 common positive terminals and 8 common negative terminals, summing up to give a total of 16 terminals as shown in figure.2. So, each row has a common positive terminal and each column has a common negative terminal. Therefore, to light up one or all LEDs in a row, the corresponding pin should be powered with 3.3V. Similarly, in order to ground any LED in any column, the respective common negative pin is grounded. PIN 1 and PIN 2 and ground the terminals PIN 9 and PIN 10. But doing this not only turn on LEDS D1 and D10 but also turn on LEDs D2 and D9, which is not desired as shown in figure.3.
So, if we wanted to turn on the LEDs along the matrix diagonal, it will instinctively turn on all the LEDs in the matrix [14]. In order to avoid this anomaly, a technique known as multiplexing is implemented. It is based on the human eye’s property of persistence of vision i.e., it cannot capture frequencies beyond 30Hz [11]. So, if an LED is turned ON and OFF continuously at a rate of 30Hz or greater, human eyes perceive it to be continuously ON. Now this method is used in the LED matrix where we first turn on LEDs of a single row for a very short period of time, then turns it OFF, then turns on the next row. This is repeated until the last row is turned on and the cycle is repeated. For example, if we wanted to turn on LEDs D1 and D10, we would power the PIN 1 and ground PIN 9 first, then wait for 1ms and then turn it OFF. Then we will power PIN 2 and ground PIN 10 which would light up LED D10, wait for 1ms and then turn it OFF. This cycle is repeated at high frequency.
so that although the LEDs are rapidly turned ON and OFF, our eyes would perceive both LEDs are continuously ON. This way we could light up LEDs D1 and D10 without turning on D2 and D9. So basically, LEDs are light up one row at a time [14].

3.4. Algorithm for 3D Image Generation
First of all, 16 GPIO (General Purpose Input Output) pins are setup in output mode, as they sent signals to the LED array. Since there are 16 terminals, each of these pins represent a particular pin of the LED array, that is 8 rows and 8 columns. Then we declare the matrices of size 8x8 for the required shapes in the binary form i.e., with 1s and 0s. Now in order to implement multiplexing, we declare 2 cascaded loops each of which undergoes 8 iterations. The outer loop is responsible for powering and turning off each of the eight rows one at a time. The inner loop is responsible for controlling the LEDs column wise for the corresponding rows. The data (the binary matrix) is taken into the inner loop. In the loop, a function checks for each element of the matrix in a particular row.

Consider the figure.4, where the binary matrix for the letter ‘I’ is shown. In this case, the program scans the 1st row and checks whether the first element is 1 or 0. If its 1, the corresponding LED (LED D1) of the matrix is illuminated. If its 0, that LED will remain dark. In this manner, the entire row is scanned and the required action is applied to the corresponding LED. Likewise, this process repeated on all of the 8 rows till the last LED i.e., D64. Thus, one cycle is completed. But in order to persist that image on the LED array for a particular time, this cycle is repeated for a period of time [2].

4. Conclusion
The proposed model of the 3D Volumetric Display is capable of generating simple primitives like Sphere, Cylinder, Cone, Di-Cone i.e., axisymmetric models can be generated with the right code programmed into the microcontroller. The 3D model generated using this setup gave images having a lower resolution and less structural integrity in the image. This is due to the de-sync that may happen between the host PC and the microcontroller and also the lighting conditions of the area where experiment was setup. This promotes formation of dark zones in the 3D model generated [2],[6],[8],[10]. This can be reduced with the use of a higher functioning microcontroller such as FPGAs (Field Programmable Gate Arrays) [2],[6],[8]. Thus, reducing the sync time between the Host PC, Microcontroller and LED array. The resolution of image can be increased by employing a higher degree of LED array i.e., 16x32 array [2],[6],[13]. The power supply can be made more integrated to the design by using a slip ring with a capacitor setup for smoother transmission of data [2]. Thus, allowing the design to be used anywhere where a 230V AC socket is present. The discharge of battery
for the current design is around 5 hours considering all the losses due to heat etc. [5]. The design can be modified to display larger 3D models by controlling multiple 3D Volumetric displays using a set of FPGAs to sync motor rotations and to display the 3D model by dividing the model into various sections using an algorithm [8].

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