ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Digitally-controlled LED Rotating Display System

We update design during drafting design document to make it more feasible, so we rewrite the most content of proposal although we got nice scores in several sections before.
Since there is a big update, highlights are marked section by section.

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Contents

1 Introduction

Fix some grammar errors in this section.

1.1 Problem

By applying Persistence of Vision (POV), many spinning LED message systems are developed to display messages and images with few LEDs [1]. A higher frequency in displaying an image enhances the resolution of the image [2] and when the frequency is over 30 frames per seconds (FPS) [3], human can observe images with a great quality. With a high speed motor, many existing systems can display messages clearly.

However, there are some common limitations to be improved. First, many of them only support limited patterns of text messages [1] and the images or messages to be displayed are pre-defined and cannot be changed in a real-time manner during the display. Second, the wired connection between some components may limit the rotation of LED array, and reduce the quality of display. Some economical wireless communication technologies [4] and recent advances in component connections can be applied to achieve a better display and real-time image update.

1.2 Solution, Visual Aid

We aim at developing a digitally-controlled LED rotating display system. In this system, a FPGA board would be the core component which handles the data input and output, processes image data, and communicates with other components to work cooperatively. Compared with other popular micro-controller platforms, FPGA has more advantages in performing such functions. It easily handles complex calculations with more powerful computing resources and parallel computation among different computing units and it provides more flexibility for developers.

As shown in the figure 1 below, user can use input peripherals connected to the FPGA board such as keyboard and camera to transmit text or image data to FPGA board. Then the rotating LEDs are able to display the input text or image driving by motor. At the same time, the expected displayed pattern is also displayed on a VGA monitor for checking. Ideally, by connecting to a camera with video feature, the system can achieve real-time video stream display.

1.3 High-level Requirements

Make requirements more detailed and clearer

Compared to other existing LED spinning LED message systems, our system has three highlight components: fancy LED array, advanced image processing technology and high-speed wireless communication.

- The display system can present output with an sufficient luminance and high fidelity for both the color and shape despite the possible distortion from rotation in indoor environment. This is a subjective requirement.
- The wireless communication between FPGA board and microcontroller can transmit control signal for LEDs with the speed over 18 Mbps and low latency under 1 second

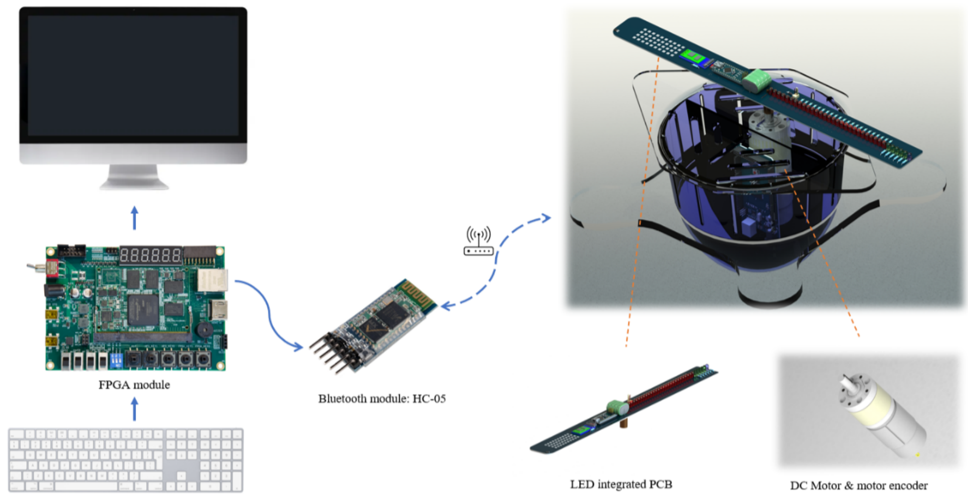

Figure 1: Visual Aid

continuously and stably.

- The image processing algorithm that transform the Cartesian coordination-based image data to polar coordination-based image data should guarantee the precision of angle calculation. Also, the overall process should have low latency smaller than 30ms to optimize the delay and guarantee real time video display.

2 Design

This sections contains diagrams and descriptions & requirements of our solution.

2.1 Diagrams

2.1.1 Physical diagram

small update due to new design

The figure 2 below refers to the basic structure design of CAD models. The upper left sub-figure shows the motor, which is powered by a 12V power supply. The upper right sub-figure shows the LED integrated PCB board. All these components will be fixed and covered by an outer shield, which is shown on the lower sub-figure.

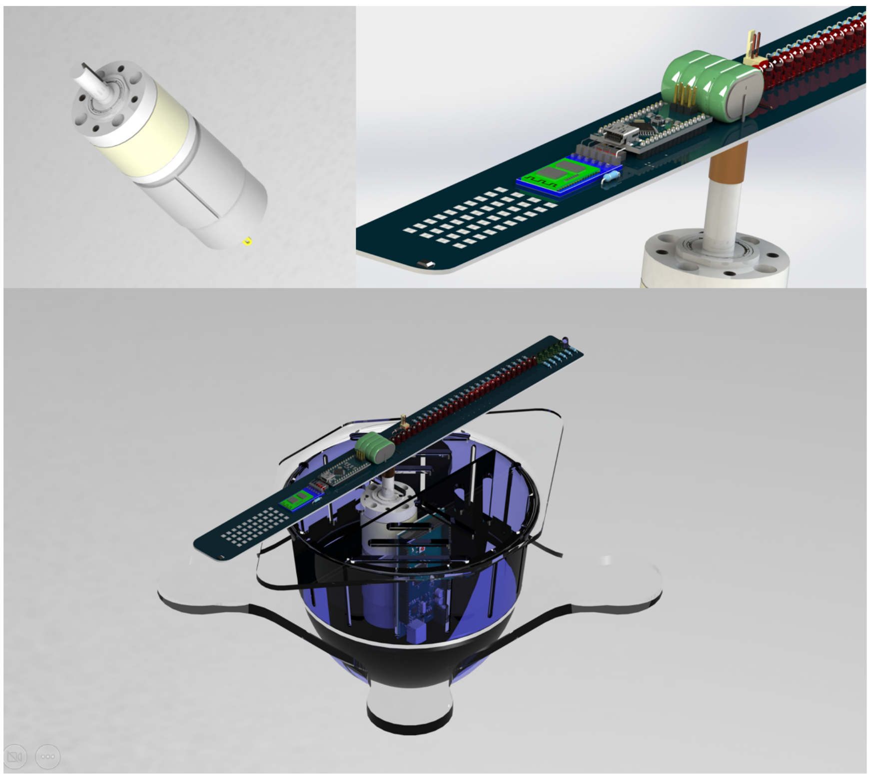

Figure 2: Design Overview

In our design, the goal is to build an integrated, compacted, and wireless LED display system, which is able to realize a real-time communication with FPGA board. Thus, we set a concept CAD model 3 with the total volume in 25,000 cm^3. The LED array is able to display a real-time image in the circle with a radius of 16 cm. The outer shield is assembled by 3D printed parts, which can give protection to motor. With a reasonable arrangement of the interior space of the shield, it will contain a 385 DC motor and a 12V power supplier.

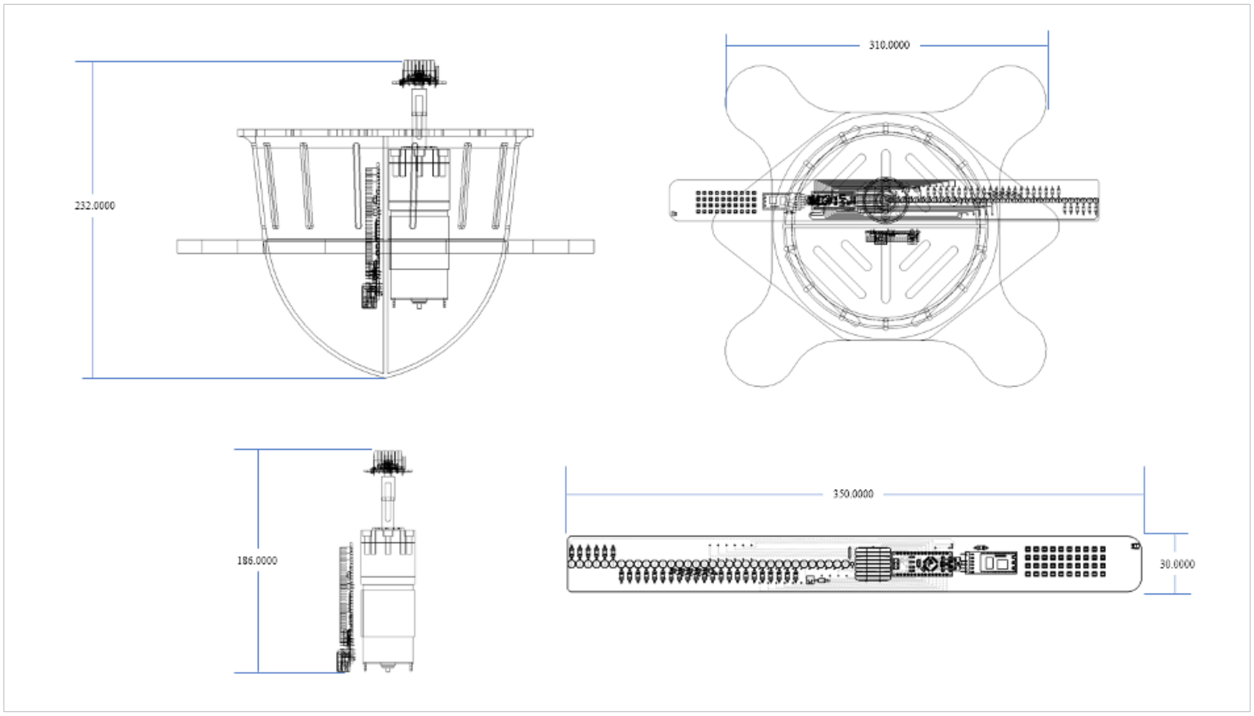

Figure 3: Design Dimensions

2.1.2 Block Diagram

improve visualization following the suggestions and update based on our new design

The block diagram of the system is shown in Figure 4. There are 3 subsystems with multiple components. We will introduce them and their connections in the next subsection.

2.2 Subsystem Descriptions

big update based on new design and improve expression of subsystem description and interaction following feedback

This subsection gives the description of all subsystem functions and interaction with other subsystems.

2.2.1 Display and Control Subsystem

The Display and Control Subsystem carries out the function of showing the image and video on the surface of rotating PCB board. The Display and Control Subsystem consists of a 385 motor, flanged joint with an integrated PCB. 160 LEDs distributed on the center line of PCB. With the rotation of motor, the LED array can show the image with 30 frame per second (FPS), forming a disk which has the diameter of 170 mm. All the LEDs are controlled by our main micro controller, ESP32-WROOM-32E, which attached at the center on the back of PCB. Powered by +3.3V voltage input through a voltage stabilizer from wireless charging module, ESP32-WROOM-32E can communicate with Logic and Interface Subsystem through Bluetooth, realizing the timely-control.

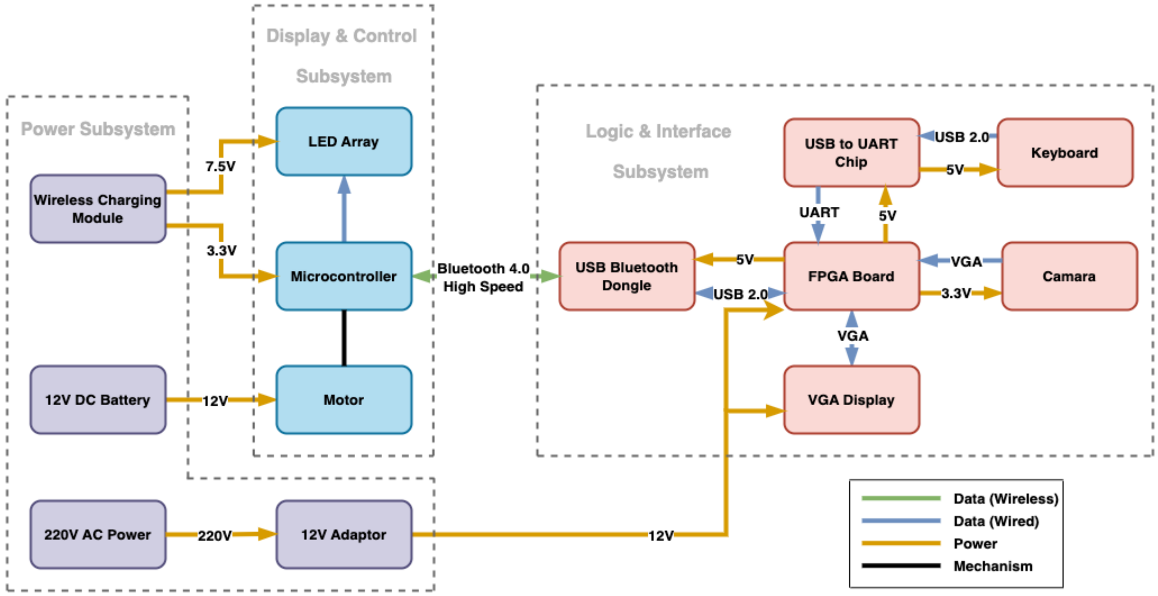

Figure 4: Block Diagram

2.2.2 Logic and Interface Subsystem

Logic and Interface Subsystem is the central subsystem to handel user's input, command Display and Control Subsystem and give user feedback. It contains input peripherals, DE2-115 FPGA board, standard VGA monitor. Specifically, the FPGA board receives user's input from input peripherals like keyboard and camera, process the input text, image and video with low latency with on-board hardware resource, send control signals of LEDs to Display and Control Subsystem with high speed Bluetooth communication, and offers VGA output to standard VGA monitor to offer Graphical User Interface for visualization. Since the communication with Display and Control Subsystem is wireless, it is physically independent with Display and Control Subsystem. Besides, it receive the power from the Power Subsystem with wired connection.

2.2.3 Power Subsystem

Power Subsystem supplies power to multiple components in other two subsystems. There is a wireless charging module which supply 7.5V power to LED Array and ESP32 micro-controller in Display and Control Subsystem with a pull-up resistor. The 12V DC Battery supplies power to the DC motor in Display and Control Subsystem. 220V AC power and 12V Adapter supply power to the FPGA board and VGA monitor in Logic and Interface Subsystem. In short, different power supplies are independent and form the power subsystem logically.

2.3 Subsystem Requirements

Got full points before but since we modify design, it is updated.

2.3.1 Display and Control Subsystem

- **LED Array** – The LEDs will be able to present full RGB colors and able to process the input signal timely.
- **DC motor** – The motor will output a rotation speed at least $1800RPM$ under a 12V power supply and torque of $480g * cm$.
- **ESP32 microcontroler** – SRAM need to large enough $520KB$ to contain all the instruction data for showing image.
- **Outer shield** – The outer shield should in a compact side, within the total volume of $50cm^3$. It needs to in a stable shape prevent the displacement (less than $5cm$) of the whole system and the resonance caused by rotation and motor vibration.

2.3.2 Logic and Interface Subsystem

- **Communication with peripherals** – The communication between FPGA board and input peripherals can handle continuous input with a low latency up to 0.5 s.
- **Bluetooth communication** – The FPGA board can handle high-speed Bluetooth communication with about 18 Mbps transfer speed to support great display. As a reference, the theoretical transfer speed of Bluetooth 4.0 is up to 24 Mbps which should be much larger than we need.
- **Image processing** – The image processing algorithm is designed using Verilog on FPGA to transform the Cartesian coordination-based image data to polar coordination-based image data such that the processed data could be easily used to display on rotating LEDs.
- **GUI and VGA** The Graphhical User Interface should be easy to understand and indicates the status of the system clearly with a low latency up to 0.5 s.

2.3.3 Power Subsystem

- **Wireless charging module** – The wireless charging module will transfer power of 7.5V +/- 0.5V, 2A +/- 1A from the base part to the upper PCB that carry voltage stabilizer, signal receiving module and the LED array.
- **12V DC Battery** – The 12V Battery needs to output a stable voltage 12V +/- 5% to control the DC motor. The power need to large enough (at least 1600 mAh) to support the whole system working 30 minutes for the demonstration.
- **Power to FPGA board and VGA** – It should be able to supply stable rated direct current to the FPGA board and VGA display at 12V +/- 5%.

2.4 Tolerance Analysis

Add a more mathematical analysis and simulation

Regarding to the subsystems we proposed, we consider the motor component poses a risk to successful completion of the project. Since it must handle the PCB board with microcontroller and multiple LEDs to do high-speed rotation. It is critical not only for high-quality display, but also for security. Here, we want to figure out the maximum load for the motor when we set the system vertically and horizontally and keeping a 30 FPS display of images.

The motor has a rotation rate of 5000 RPM when no load. And it will be stalled under a torque of 750 g·cm. Based on the relationship between rotation rate and torque, we will have an idealized function:

$$N = -\frac{20}{3}\tau + 5000$$

As we are aimed at forming a display with image refresh rate ¿ 30 fps, which means,

$$N_{aim} \geq 30\frac{circle}{second} = 1800RPM$$

Constrains has shown below in figure 5. By substitution, we will have a maximum torque

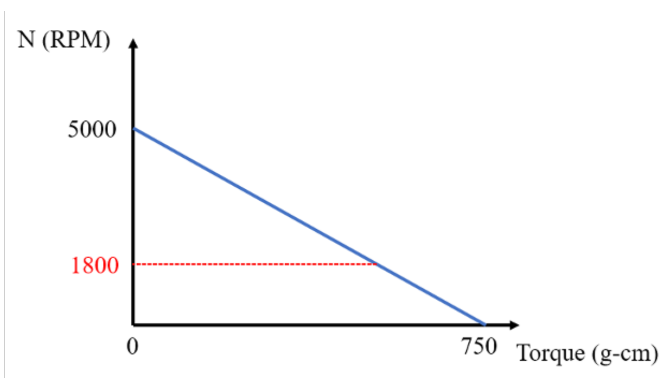

Figure 5: Motor N-Torque Constrains

shown below.

$$\tau_{aim} \leq 480g \cdot cm$$

When we place the system vertically, we can calculate the force on the output shaft of motor by the equation,

$$F_{shaft} - mg = F_{centripetal}$$

We have the equation for centripetal force,

$$F_{centripetal} = m \times w^2 \times r$$

where m is the equivalent weight for whole PCB, w is the angular velocity, and r is the mass offset on PCB.

The angular velocity w and rotation speed N have the relationship,

$$w = \frac{N \times \pi}{30}$$

With a minimum rotation speed 1800 RPM, we can calculate the relationship between mass offset on PCB and the PCB weight, shown below.

$$188.55^2[\frac{rad}{s}] \times r^2 + 9.81[\frac{N}{kg}] \times r - \frac{47[N \times m]}{m} \leq 0$$

Also shown on the figure 6 below, where m is PCB weight and r is mass offset on PCB. For

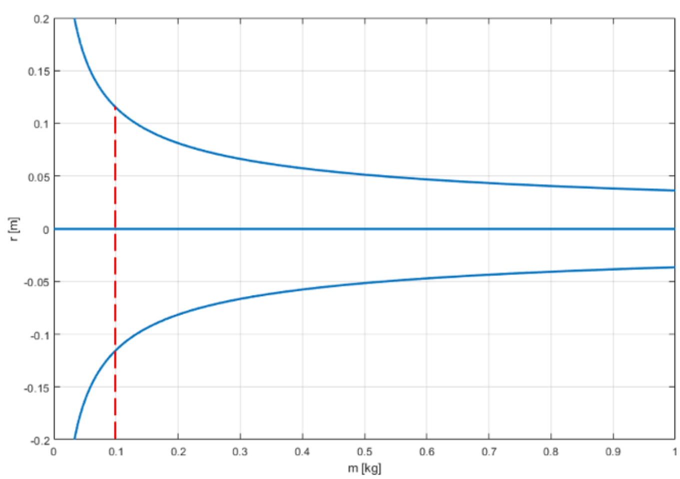

Figure 6: Relationship between mass offset and the PCB weight

example, we designed the overall PCB weight $m = 100g$, and by substitution, the mass offset on PCB can be calculated (Shown in red line on figure 6), which is,

$$-0.1151m \leq r_{offset} \leq 0.1148m$$

With a mechanical simulation, Finite Element Analysis is placed on our main PCB. During the rotation, the board will be bearing a torque of 480 g · cm for maximum, together with a pressure from all the components, which weight 30 g for maximum. The result is shown in figure 7 below. The maximum displacement at two edges of the PCB will within 1.5mm, which meets the requirement.

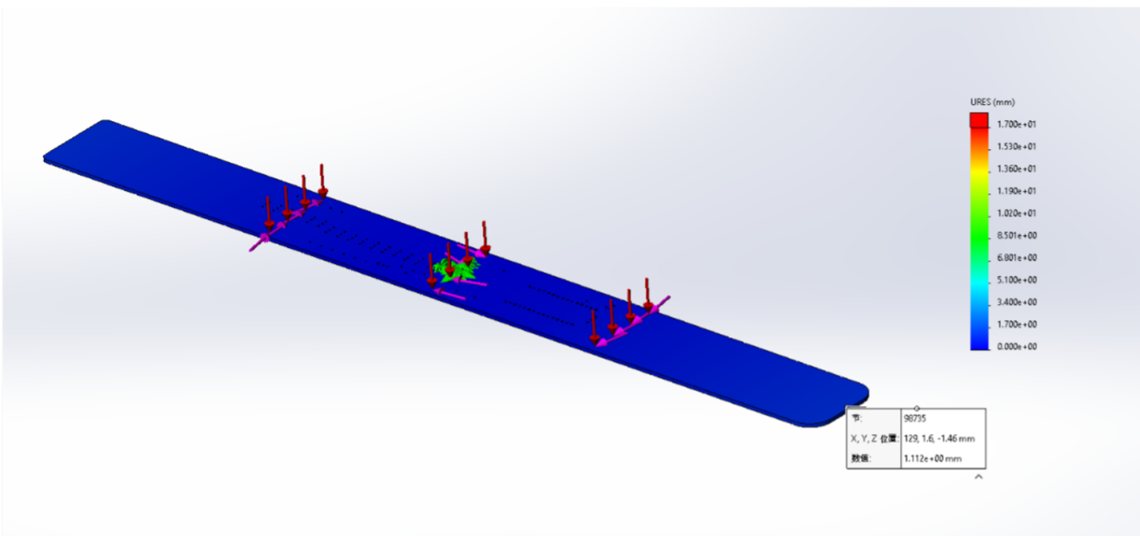

Figure 7: FEA Result for the main PCB

3 Ethics & Safety

Add missing referance

3.1 Ethics

Regarding to the IEEE [5] and ACM Codes [6] of Ethics, we summarize the following ethical concerns that apply to this project:

1. Consider the impact of our project on society: We should have a responsibility to consider the impact of our work on society as a whole, including the social, economic, and environmental consequences. This requires taking a holistic view and considering not only the immediate benefits, but also the potential long-term consequences.
2. Uphold the principles of fairness and justice: We should strive to ensure that our work is fair and just, and that it does not discriminate against individuals or groups based on factors such as race, gender, religion, or nationality. This requires being aware of potential biases and taking steps to mitigate them.
3. Be honest and transparent: We should be honest and transparent in the professional conduct, including the communication with team members, teaching assistant, instructors and the public. This requires being forthright about potential risks and uncertainties, and disclosing any conflicts of interest.

3.2 Safety

Regarding to the safety guidelines provided in course website and our project development flow, we summarize the following safety concerns that should be considered:

1. Electrical safety: The power system involved in our project could pose risks of electrocution or electrical fires if proper safety measures are not taken. This includes ensuring that all wiring is properly insulated and grounded, that circuits are appropriately sized and protected, and that appropriate safety equipment is available for handling and testing electrical components.
2. Mechanical safety: The rotating motor involved in our project could pose risks of injury or damage to equipment if not properly installed or operated. This includes ensuring that the motor is securely mounted and that all moving parts are properly guarded to prevent contact with users or other objects.
3. Lab safety: The design and testing of our LED display system involves working with various tools, equipment, and materials that can pose hazards to our members. This includes ensuring that all of us are trained in proper safety procedures, that appropriate safety equipment is available, and that all testing and assembly is performed in a designated and controlled laboratory environment.

References

[1] L. Yong, M. F. Zakaria, and H. Hashim, "Design and development of spinning led message display system," Mar. 2012.

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[3] T. Morris, P. Blenkhorn, and F. Zaidi, "Blink detection for real-time eye tracking," *Journal of Network and Computer Applications*, vol. 25, no. 2, pp. 129–143, 2002, ISSN: 1084-8045. DOI: https://doi.org/10.1006/jnca.2002.0130. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S108480450290130X.

[4] A. SARODE, D. SALUNKE, A. SHUKLA, and M. SONAWADEKAR, "Spinning led display using radio frequency," *International Journal of Computer Science and Informatics*, pp. 280–283, Apr. 2014. DOI: 10.47893/IJCSI.2014.1160.

[5] IEEE. ""IEEE Code of Ethics"." (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/08/2020).

[6] ACM. ""ACM Code of Ethics and Professional Conduct"." (), [Online]. Available: https://www.acm.org/about-acm/acm-code-of-ethics-and-professional-conduct (visited on 02/08/2020).