Design Doc

Group 31: Modular Light Array

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1. Introduction

1.1 Objective

The holiday decoration industry is an incredibly lucrative field. At the end of 2018, the national retail federation reported that the average consumer spent about 1000$ on Christmas decorations, with retail sales of around $720 billion [1]. Among outside decorations, lights are the most common example, with some types including mini string lights, animated/color changing lights, LED rope lights, and LED projection spotlights. While these options provide a high degree of customization for home owners to optimally decorate their houses during the holiday season, these decorations are static, unable to be changed once set up. The inability to modify and innovate patterns on the fly for home light decoration displays is a problem that has very few if not any existing solutions.

Our proposed solution involves the creation of a modular 2D LED array, which would replicate drawn designs from a separate application. This application would let the user draw a grayscale design and translate that design onto the 2D LED array, sending this data through a Bluetooth module. This translation would relay the necessary brightness for each LED within the 2D array by transforming the gray scale design from the application. The 2D panel LED light display, hooked up in parallel, connected to a atmega328P which would interpret the gray scale image translation and update the lights to match the drawn image. Such a system would allow for easy updating of light-based simple images.

1.2 Background

An important facet of our design is the ability to update the LED display easily by simply redrawing a design within the phone application. Currently, similar products require reprogramming the display if you wish to change what is displayed. Some products require manual reprogramming every time you wish to change the design [2,3], while others do feature phone apps to create designs but rely upon manipulating strings of lights as opposed to an LED panel [4]. The modular design would also raise another benefit, namely the ability to quickly and efficiently update LED display panels with ease from the phone app assuming there were multiple. Another important distinction within our design is the use of differing levels of brightness to indicate grayscale values from the phone app.

1.3 High Level Requirements

1. The LED panel can replicate designs from the phone applications, using the LEDs to denote 4 visibly different levels of brightness. Darker portions of designs will be less lit as opposed to lighter portions of designs.
2. The LED panel can display any arbitrary combination of brightnesses of its 64 lights, allowing for deep customization of designs.
3. The image on the LED panel can be easily and quickly updated through the phone application via bluetooth in under 5 seconds.

2. Design

Our project consists of 4 major blocks, the power supply, the LED panel, the phone application, and the microcontroller. The power supply will deliver the 5V necessary for the microcontroller and the LED Panel to operate via a plug into an outlet. The phone will contain a front end interface that will allow the user to create and send an image to the microcontroller via bluetooth after the image has been processed by the phone app. Once the bluetooth module has received the image data the microcontroller will distribute the image data to the LED panel where the grayscale image is displayed. This process is illustrated in the block diagram below in figure 1 as well as in the physical design diagram in figure 2.

2.1 Block Diagram

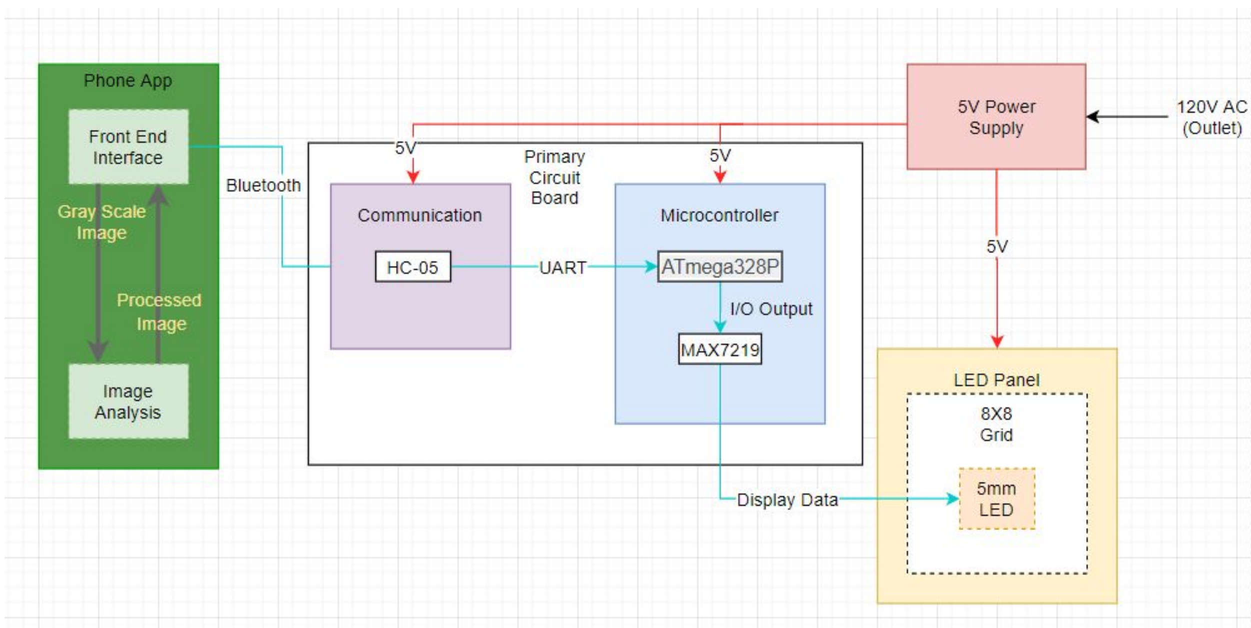


Figure 1. Block Diagram

2.2 Physical Design

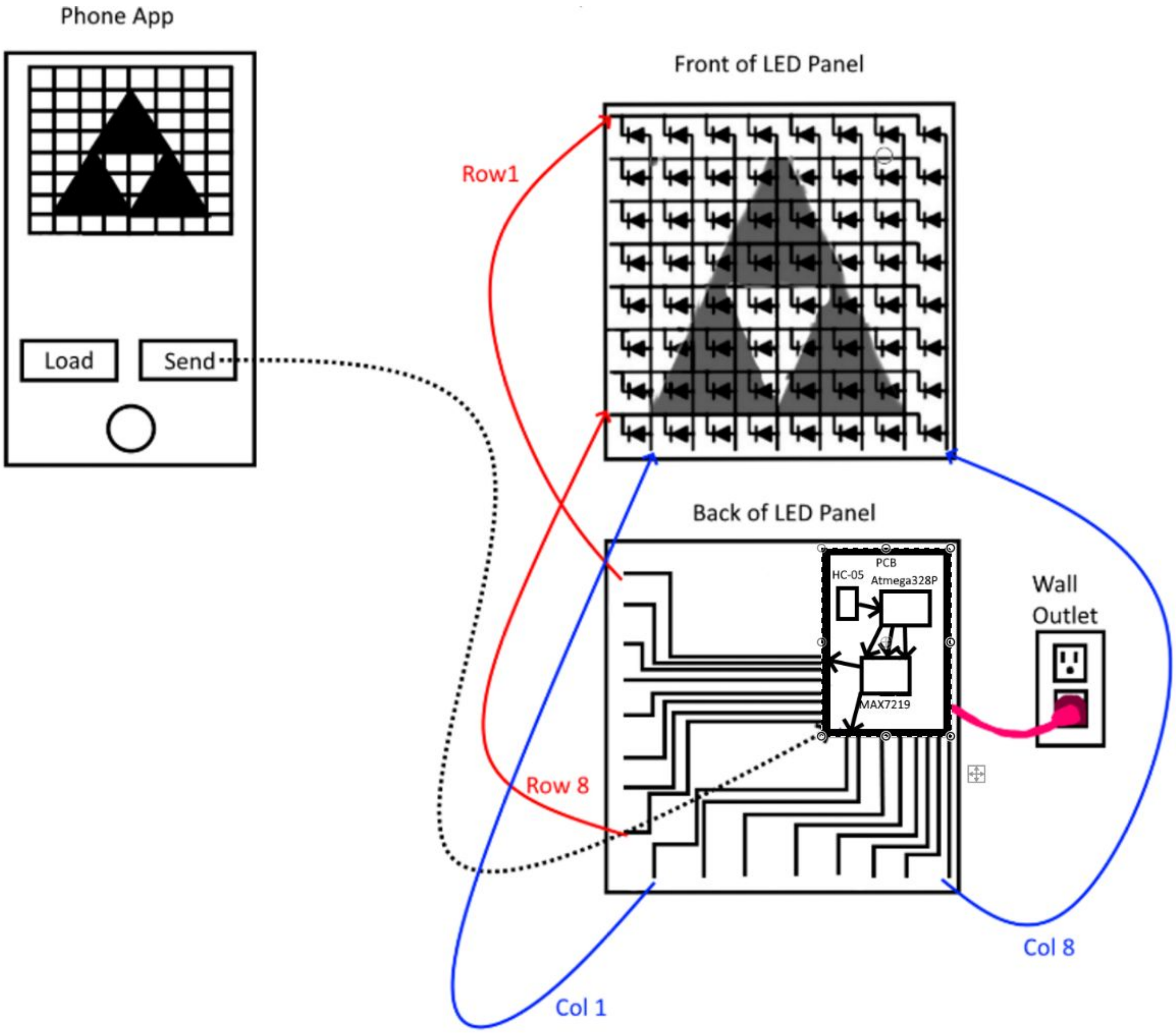


Figure 2. Physical Design Diagram

2.3 Function Overview

There are four major components to this project that interact with each other to make it work. To start off with, we have the phone application. This is the component that the user interacts with to make their design and choose to send it to the LED panel. After the user chooses to send their design to the panel, it is translated into a grayscale image, and sent to the bluetooth module connected to the microcontroller. The microcontroller receives signals from the phone app through bluetooth, and interprets those signals, sending them to the LED drivers on the LED panel. The LED panel is responsible for displaying the image in grayscale that the user sent from the phone app, and finally, the power supply component provides power to the LED panel and microcontroller. Figure 2 gives a visual representation of our design, including the major components discussed in this section.

2.4 Subsystems

- ### 2.4.1 Primary Circuit Board
    - This is the brain of our operations and is used for communication between the various components of our design. It will consist of our PCB that has our microcontroller chip (ATmega328P) on it, the HC-05 wireless chip, and the MAX7219 Chip. The PCB will contain the logic for relaying info from the ATmega328P to the LED driver chips (MAX7219). It will also contain the logic for the power system. The HC-05 wireless chip is connected to the ATmega328P chip and will provide communication between the microcontroller and the phone application. See table 1 for explicit requirements and verifications.

Table 1: Microcontroller Requirements/Verification

Microcontroller Requirement	**Microcontroller Verification**
The ATmega328p can receive a data packet (10 bits) from the phone app via bluetooth.	Write a sample program that sends one packet of information(10 bits) to the PCB. Using the arduino IDE, we can check for confirmation that the package is sent, as well as the accuracy of its contents.
Can communicate with phone app through bluetooth module chip via UART, sending a full grayscale input in under half a second	Write a sample program for controlling an LED through the phone app using HC-05 chip connected to the ATmega328P. Default Baud rate for the chip is 9600 [5], or around 960 bytes per second. We send ~80 bytes of data for a grayscale image, meaning the transfer should take around a tenth of a second.
Can send out signals to the LED drivers on LED panel to display grayscale image from phone app in under half a second	Wire up circuit with MAX7219 Chip along with ATmega328P and LEDs connected and program series of instructions for the MAX7219 chip. Through use of the arduino IDE, we can determine both the contents of the data the ATmega328p sends out as well as the time it takes to do so.

- ### 2.2.2 Phone application
    - This subsystem will involve the entirety of the phone application, including both the user interface as well as the image analysis component that will provide the needed data to the microcontroller via UART. The front end interface will allow the user to create and load designs onto the LED display board via the bluetooth chip located in the microcontroller. See table 2 for explicit requirements and verifications.

Table 2: Phone App Requirements/Verification

Phone Application Requirement	**Phone Application Verification**
Users can draw a design within a designated box in the phone app interface, and have the app save it.	Write a base version of the app with drawing capabilities. We satisfy the requirement if we can save and then later display the design we draw within the phone app.
The phone application can convert the user created design into a scaled down grayscale output for the LED panel with a 10% margin for error.	Passing sample images through the image analysis program, and then comparing the results with a scaled down version of the image and analyzing the difference in brightness from pixel to pixel in both images.

- ### 2.4.3 LED Board
    - This subsystem consists of the 64 LED display board. The board is responsible for displaying designs sent to the microcontroller via the phone application. See table 3 for explicit requirements and verifications.

Table 3: LED Board Requirements/Verification

LED Board Requirement	**LED Board Verification**
LEDs on the LED panel have 4 visibly distinguishable levels of brightness.	Create an LED circuit and determine resistance values, assuming a 5V power source, required for creating 4 distinct levels of brightness. Determining voltage levels for the 4 distinct levels would be as follows: wire up a breadboard circuit consisting of 4 evenly spaced LEDs in parallel with various test resistances. After powering on the circuit, observe by eye as to whether the 4 LEDs can be distinguished in brightness. If so, record the resistances required for these brightnesses.

LED panel can be configured such that any of the 64 LEDs on it can individually display any level of brightness.	After the LED panel has been created, write a program that individually turns on each LED, cycling through all 4 levels of brightness.
Clumps of LEDs can turn on, with some of the LEDs in the clump operating at different brightness levels.	Write a test program to turn on a cluster of 2x2, 4x4, and 8x8 cluster of LEDs to turn on. We would also set multiple LEDs within the cluster to operate at different brightness levels.
The LED board can display simple patterns.	Write a test program to display an “X”, a “+”, a “box”, and a “circle” on the LED board.

2.5 Overall Circuit Schematic and PCB

Our PCB will send data from the bluetooth module to the ATmega328p and then distribute the interpreted data from the ATmega328p to the LED array. The PCB is made of 3 MAX7219 circuits, which operate as the memory for which LEDs in the LED array are on, and a HC-05 bluetooth module. Each of the 3 MAX7219 circuits are unique inorder to allow each MAX7219 circuit to provide a unique voltage for the LED array. The voltage for each of the MAX7219 circuit is calculated using the table 4 values. The bluetooth module is connected directly to the ATmega328p so the signal is processed before it is sent to the MAX7219 circuit.

Figure 3 is a holistic view of the PCB, while figure 4 is a zoomed in MAX7219 circuit Figure 5 is a zoomed in version of the Bluetooth module, and figure 6 shows the connection between the ATmega328p inputs and the PCB. Figure 7 shows how the PCB connects to the circuit that is the LED array. In figure 3,4, 5,and 6 below the outputs from the ATmega328p to the PCB are labeled 5V, GND, CS(for chip select), CLK(for clock), CHIP_1, CHIP_2,CHIP_3., and TXD. The only output to the ATmega328p comes from the bluetooth module labeled RXD in figures 4, 5, and 6.. Lastly the outputs from the MAX7219 circuits to the LED array are COL_1, COL_2, COL_3, COL_4, COL_5, COL_6, COL_7, COL_8, ROW_1, ROW_2, ROW_3, ROW_4, ROW_5, ROW_6, ROW_7, and ROW_8 in figures 3, 4, and 7.

Table 4: MAX7219 Chip Resistor Guide[6]

I_{SEG} (mA)	V_{LED} (V)				
	1.5	2.0	2.5	3.0	3.5
40	12.2	11.8	11.0	10.6	9.69
30	17.8	17.1	15.8	15.0	14.0
20	29.8	28.0	25.9	24.5	22.6
10	66.7	63.7	59.3	55.4	51.2

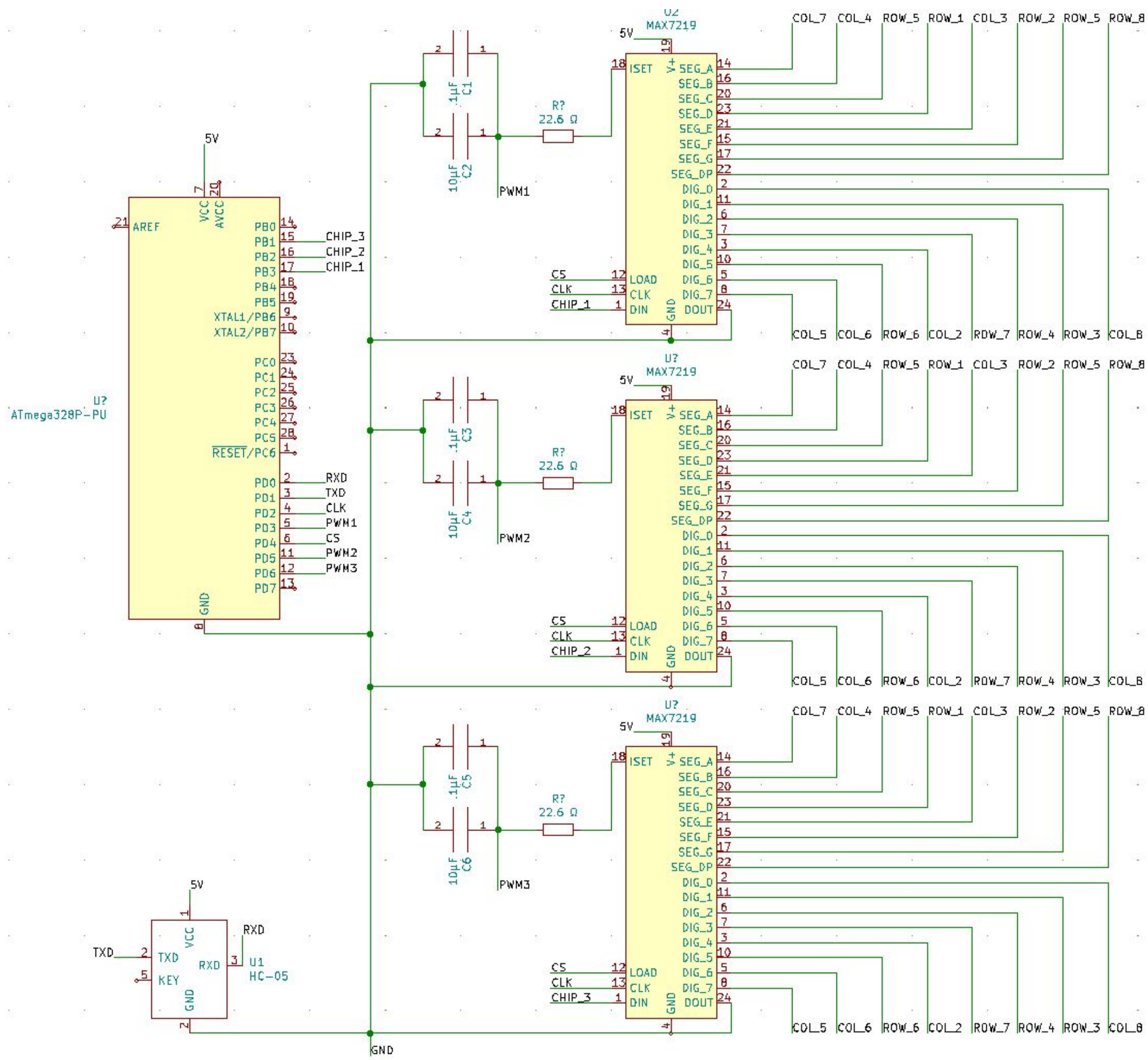


Figure 3. PCB Schematic

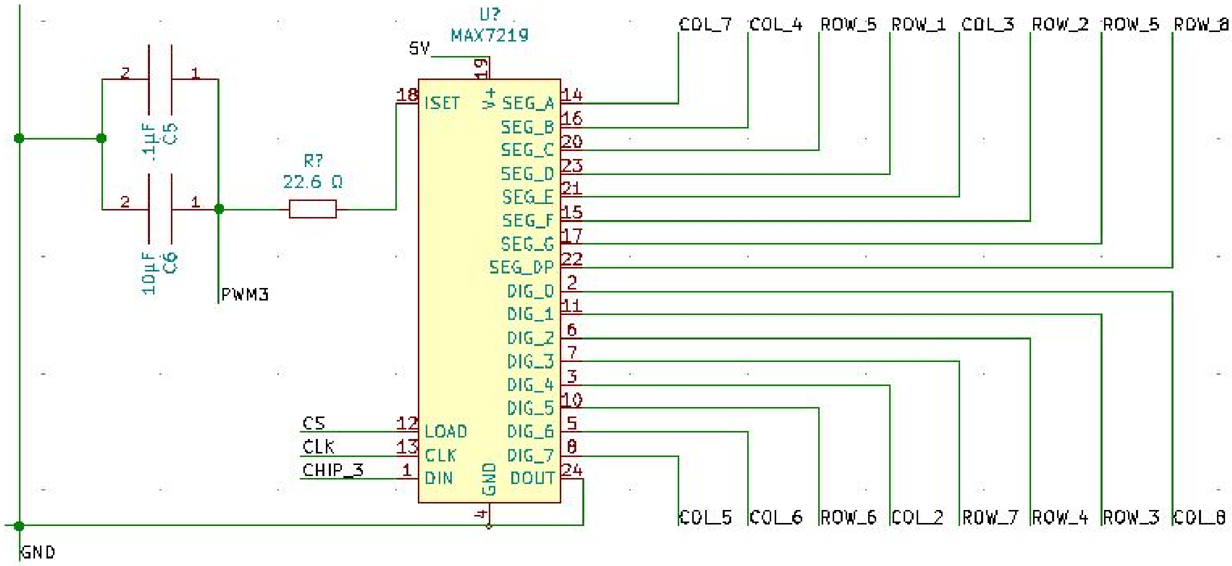


Figure 4. MAX7219 circuit from PCB

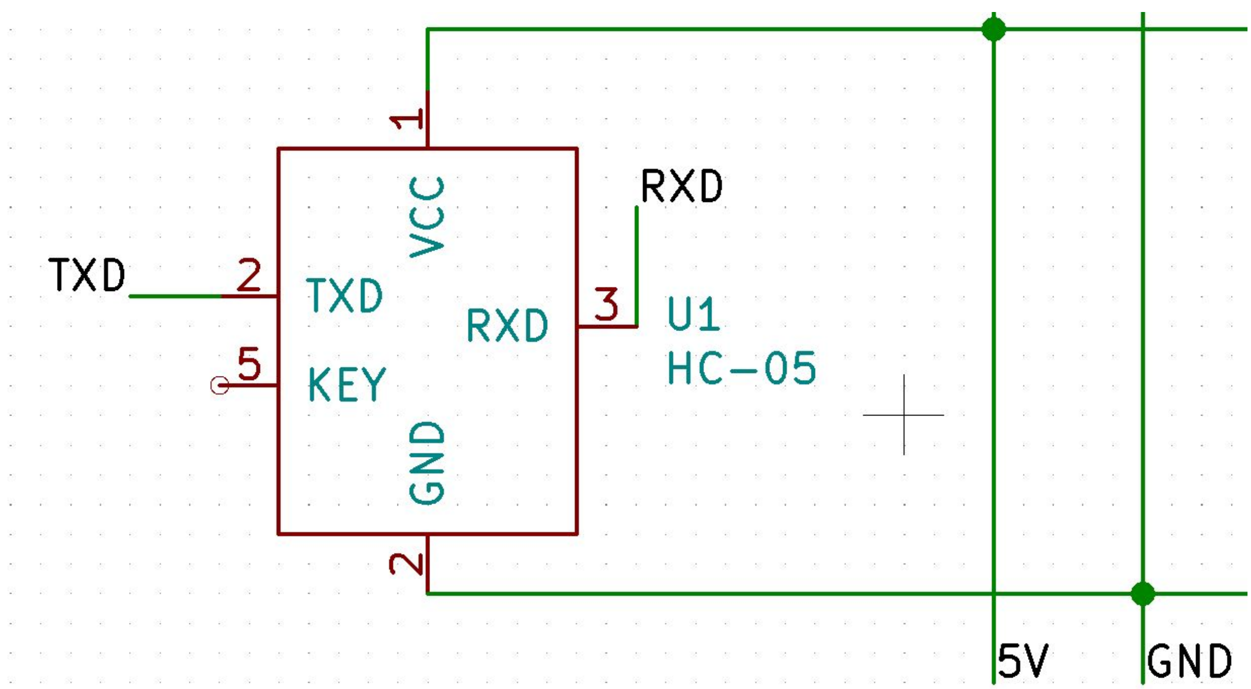


Figure 5. HC-05 circuit from PCB

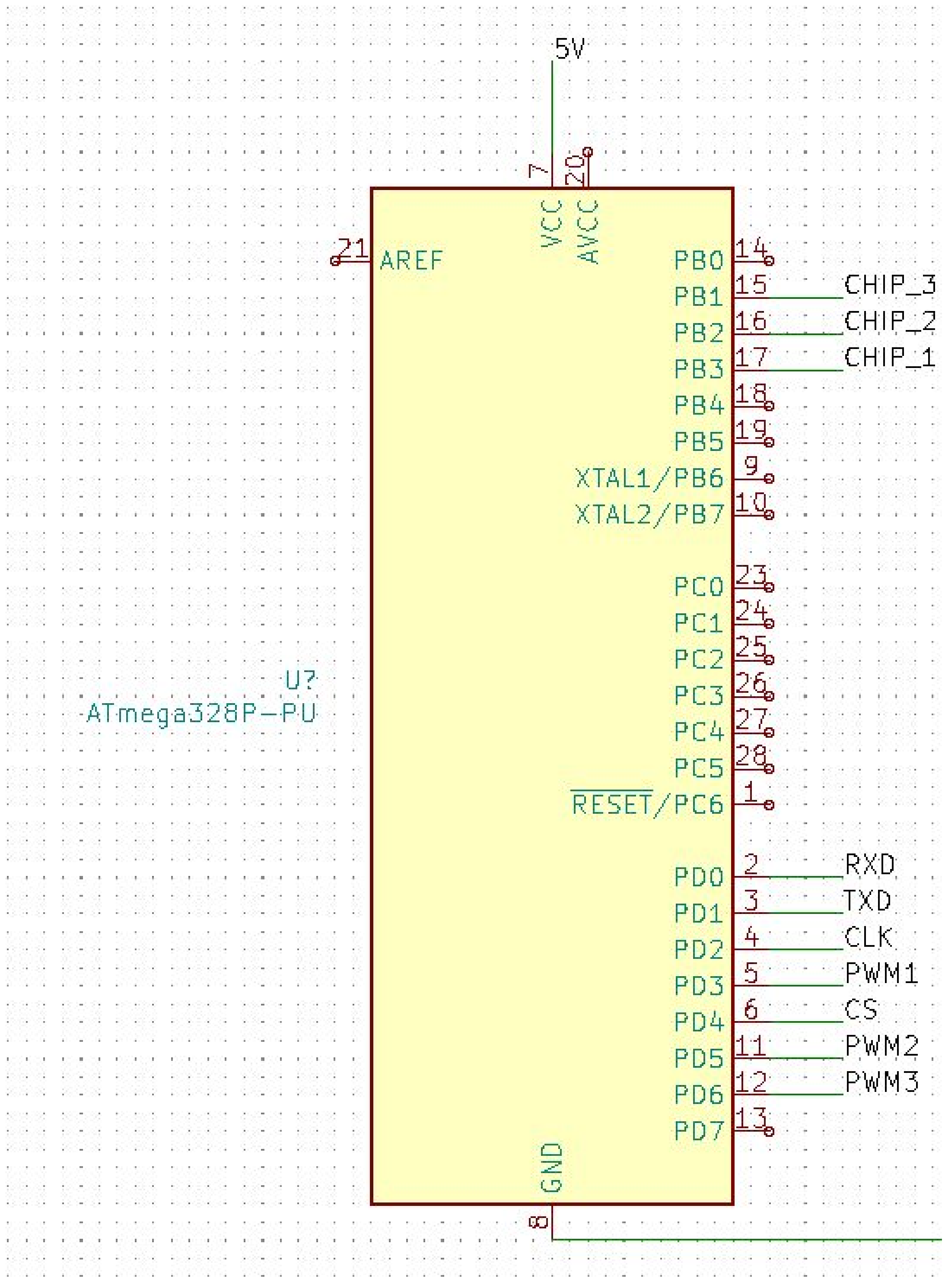


Figure 6. Atmega328P Pin Reference (specific to our project)

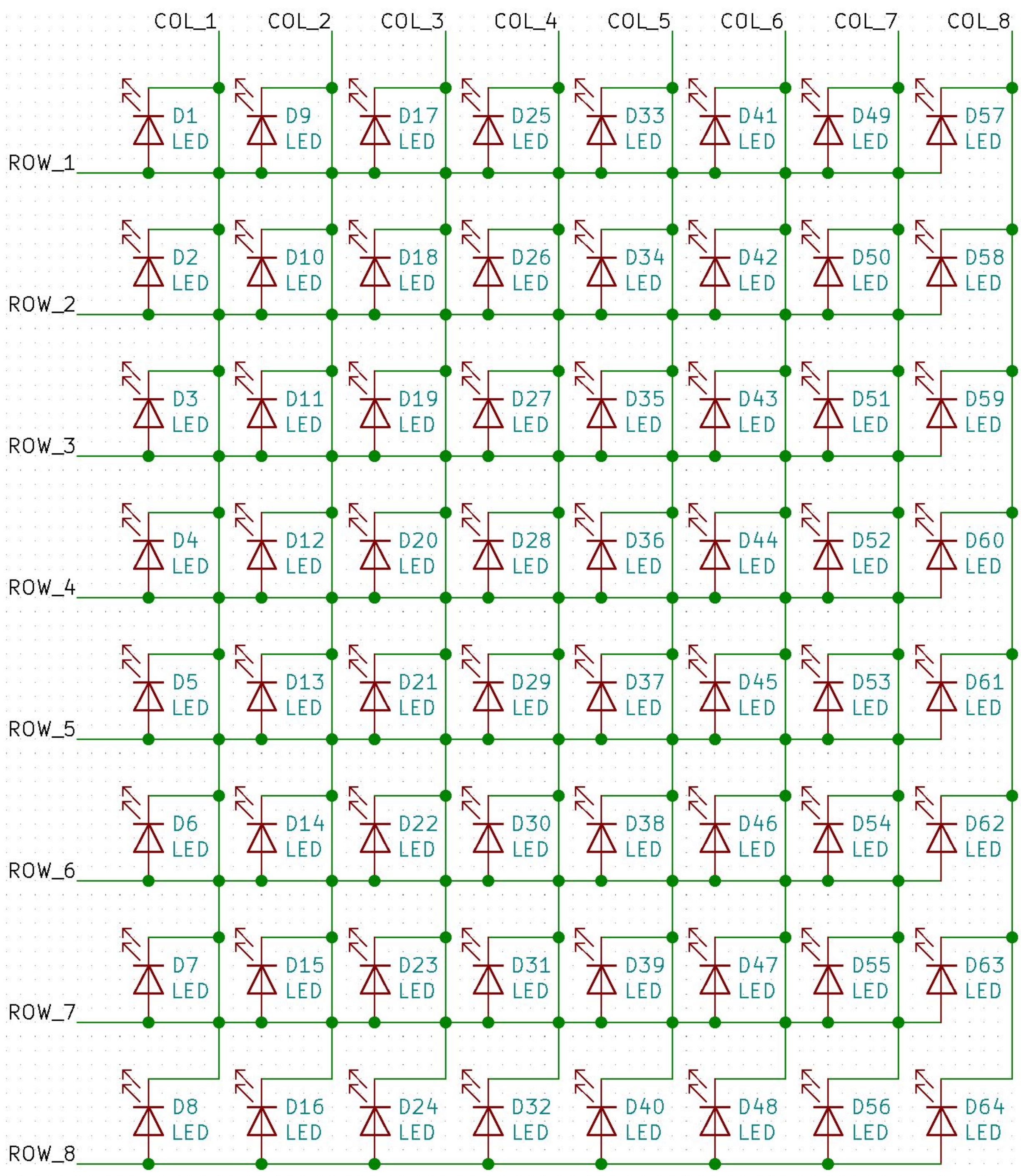


Figure 7. LED Array Schematic

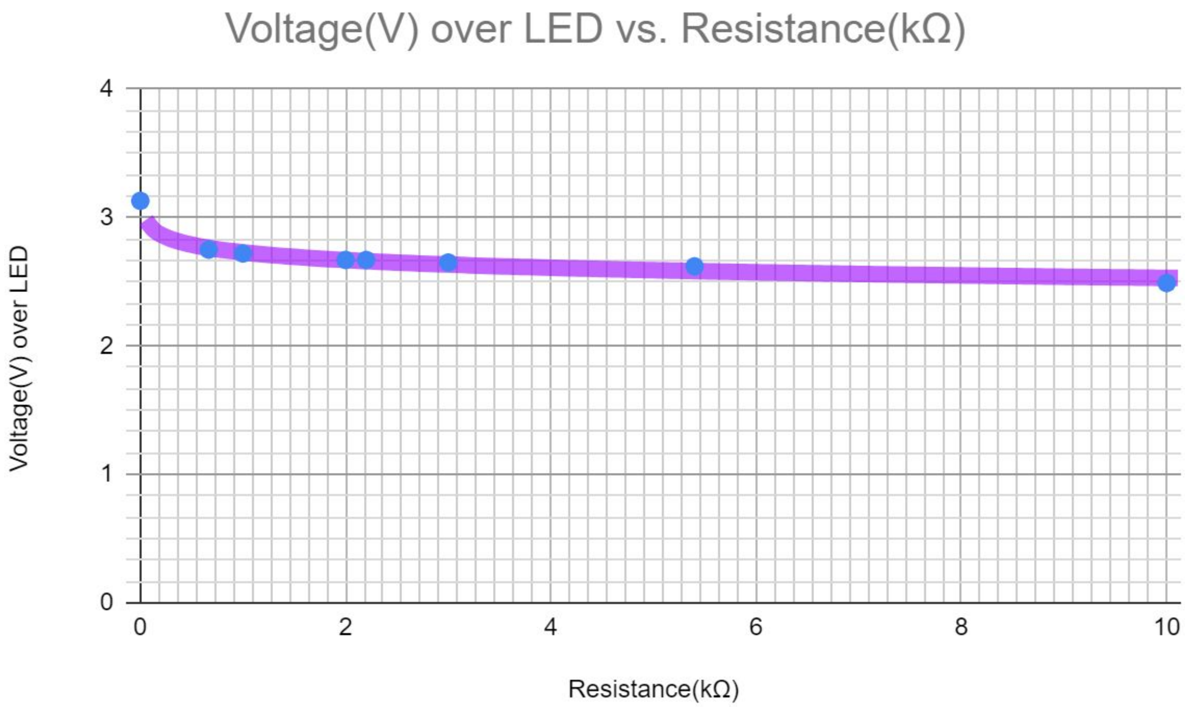
2.6 Tolerance Analysis

As part of our initial testing, we designed a small circuit to test our LEDs. Specifically, we wanted to determine the range of resistances, assuming a 5V power supply, required to have the LED shine at differing levels of brightness. The following table 5 denotes both the resistance of the resistors connected in series with the LED as well as the measured voltage over the diode while in operation.

Table 5: LED Testing Circuit Graph

Resistance	**Voltage**
0Ω	3.13V
1kΩ	2.72V
2kΩ	2.67V
2/3kΩ	2.75V
3kΩ	2.65V
10kΩ	2.49V
1MΩ	2.43V (off)
2.2kΩ	2.67V
5.4kΩ	2.62V

Below is a graph that shows the relationship between voltage and resistance from the point in which the LED turns on to the point at which the LED turns off. Graph 1 below shows that the relationship is logarithmic which is expected.



Graph 1: Voltage vs Resistance over LED

To control the voltage supplied to each of our MAX7219 chips, we will use pulse width modulation to control the 5V input voltage to the ATmega328 microcontroller. The ATmega already has PWM functionality implemented, allowing us to use pins 5,11,12,and 15-17 for PWM [7]. PWM works by modifying the duty cycle of the input signal, or how long the signal is turned on for. A duty cycle of 100% means the signal is always high, in this case meaning the voltage is always on. A duty cycle of 50% means the signal is high for half the time and low for the rest of the time. The exact calculation for duty cycle is as follows:

$$Duty\ Cycle\ =\ [ON\ time\ /\ (ON\ time\ +\ OFF\ time)\ ]\ *\ 100$$

To get from the duty cycle to the output voltage, which we are concerned with, we use the following equation:

$$Output\ Voltage\ =\ Duty\ Cycle\ *\ Input\ Voltage$$

In this case, our input voltage is 5V, so to get the voltages we need of 3.13, 2.81, and 2.49 Volts, we will need duty cycles of 62.6%, ,56.2%, and 49.8%.

To accomplish this we would use the fast PWM mode of the ATmega328's PWM timer, since it works well at high frequencies and is recommended for LED applications[7]. Basing our PWM off the systems frequency of 16 Mhz. To figure out the PWM frequency we need, we need to get our hands on an ATmega328 and set it up. This is because the PWM frequency we set will directly impact whether the LED will flicker/turn on. An arbitrarily high frequency will mean the LED will not turn on, while a low enough frequency will have the LED flashing on and off.

Lastly, regarding the verification of how well our image analysis algorithm works, we proposed a 10% margin of error. To clearly test this, we should clarify both the method to test our image analysis algorithm as well as the algorithm itself. The analysis algorithm works by averaging out clusters of the design the user draws, these clusters being 4x4 chunks of pixels. Averaging the grayscale values of all these pixels within a chunk will let us assign a grayscale value to what will be an LED on the LED board. To test this algorithm, we can compare the the pixels of the output of the image analysis algorithm to the pixels from the output of a downscaling algorithm performed on the original image. By comparing the difference in the RGB values between the two outputs, we can test for a 10% margin of error.

2.7 Risk Analysis

This riskiest part of this design is the possibility of improper use or installation of the LED components. If wires connecting LEDs to the microcontroller are not properly set up the correct brightness will not display throughout the LED panel. For example if wires are overlapping the LED light signals will not properly be sent to the correct LEDs as shorting throughout the circuit will turn off several LEDs. To avoid this, we will install all the LEDs in a way that will keep the LEDs isolated from the rest of the LEDs. We will also set up specific unit tests involving setting varying levels of brightness of the LEDs, and carefully examine and test wiring/soldering to ensure there is not a potential short in our project. There is also the possibility of LEDs burning out, but this is much easier to test for, since we can write a test program putting all 64 LEDs in the array through the various levels of brightness and eyeballing burnt out LEDs.

One other part of the design susceptible to problems is the interaction between the phone application and the bluetooth microcontroller module. Since the application is responsible for acquiring most of the data, the sending of that data is crucial for this project. If the connection between the module and the phone application is not processed correctly the LEDs might display incorrectly. To ensure that the connection between the phone and the microcontroller is stable we will create a connection stability test, monitoring inputs to the microcontroller, reverse engineering the sent image.

2.8 Extension Goal

Our extension goal for our project is to allow the grayscale image to display on multiple LED panels. This goal compliments the main objective of our project, to have a modular design, since distribution of a single image to multiple light panels allows for easy customization of each panel display.
The requirements for this extension goal include updating the phone app to allow communication with multiple panels, and the creation of a second LED panel. This means we would require doubling all components needed for the original.

3. Labor and Parts Cost

Table 6: Parts and Costs

Part	**Cost**	**Total**
HC-05 Bluetooth Chip	4.99	4.99
MAX7219 Chip	8.00	8.00 x 3 = 24.00
100 Ct 5mm Clear LEDs	6.00	6.00
Atmega328-PU Microchip	2.08	2.08
120-240V to DC 5V Power Supply Adapter	7.59	7.59

- TOTAL : $44.66

3.1 Labor:

- Assuming an hourly rate of 25$/hr and an average of 15 hours/week per member spent working on this project for 5 weeks, labor cost would come out to 25*15*5*2 = $3750

4. Schedule

Table 7: Schedule

Week	**Noah**	**Ashwin**
2/24	Design Review/ Incorporate Feedback	Design Review/ Incorporate Feedback
3/2	Begin to order parts and work on PCB for early order	Begin to order parts and incorporate feedback from design review
3/9	If needed finish work on PCB for early order	Work on phone application.
3/16	Spring Break Begin programming image analyzing programs.	Spring Break Work on phone application if needed.
3/23	Finish programming image analyzing programs.	Continue to work on phone application
3/30	Begin working on LED array. Also work on integration of Arduino into circuit.	If the phone application is not finished, continue to work on the phone application. Should have frontend done
4/6	Finish working on LED array Finish integration of Arduino into circuit.	Work on interface protocol between phone application and bluetooth module.
4/13	Design stress tests for LED and Arduino portions of the system.	Design stress tests for bluetooth modules and phone application portions of the system.
4/20	Mock Demo / Final Report / Final Demo / Final Presentation Preparation	Mock Demo / Final Report / Final Demo / Final Presentation Preparation
4/27	Mock Demo / Final Report / Final Demo / Final Presentation Preparation	Mock Demo / Final Report / Final Demo / Final Presentation Preparation

5/4	Mock Demo / Final Report / Final Demo / Final Presentation Preparation	Mock Demo / Final Report / Final Demo / Final Presentation Preparation

5. Ethics and Safety

Since this is a consumer product there is a certain level of safety we must ensure when creating the device. Immediately apparent is ensuring the safety of operating the LEDs on the panel display. Improper operation of LEDs leads to electrical hazards. Careful steps must be taken when designing the project to limit/entirely remove human contact from operating LEDs.

In the design of this project we must aim to adhere to the 3rd rule of the IEEE code of ethics: "to be honest and realistic in stating claims or estimates based on available data" [8]. In this design document and in the actual fabrication of the project, we should strive to clearly define the capabilities of this system. This includes the physical specifications, programming requirements, and accuracy of its operation. Also concerning design, we should also keep in mind the first rule of the IEEE code of ethics: "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment"[8]. Considering that we are working with electrical circuits, we must take proper care when constructing and testing these circuits to ensure that we are not potentially harming ourselves.

6. Citations

[1] *J. Greene, "Spending on Christmas decorations remains the same in 2018",* KCRG, November 2019. Available at: https://www.kcrg.com/content/news/Americans-spending-the-same-on-Christmas-decorations--501601652.html.[Accessed: 23-Feb-2020]

[2] *CXGuangDian 26"x 8" Programmable Scrolling Message LED Display Sign led Panel Indoor Board P5 Full Color Reviews*, Amazon, February 2020. Available at: https://www.amazon.com/CXGuangDian-Programmable-Scrolling-Message-P5/dp/B01GYJDZNY.[Accessed: 25-Feb-2020]

[3] *Super Bright Programmable Dot Matrix LED Remote Display | Score Board (Outdoor) Reviews,* Amazon, February 2020. Available at: https://www.amazon.com/Bright-Programmable-Matrix-Display-Outdoor/dp/B079NMX23Y?th=1. [Accessed: 25-Feb-2020]

[4] "*Animated RGB Lights,*" Christmas Designers. Available at: https://www.christmasdesigners.com/christmas-lights/animated-rgb-christmas-lights.html. [Accessed: 25-Feb-2020]

[5] "HC-05 Bluetooth Module Pinout, Specifications, Default Settings, Replacements & Datasheet," *HC-05 Bluetooth Module Pinout, Specifications, Default Settings, Replacements & Datasheet*. Available at: https://components101.com/wireless/hc-05-bluetooth-module. [Accessed: 27-Feb-2020]

[6] "MAX7219/MAX7221 Serially Interfaced, 8-Digit LED Display Drivers Datasheet," *MAX7219/MAX7221 Serially Interfaced, 8-Digit LED Display Drivers Datasheet.* Available at: https://datasheets.maximintegrated.com/en/ds/MAX7219-MAX7221.pdf. [Accessed: 29-Feb-2020]

[7] "PWM On The ATmega328 - QEEWiki," *Google Sites*. [Online]. Available at: https://sites.google.com/site/qeewiki/books/avr-guide/pwm-on-the-atmega328. [Accessed: 03-Mar-2020]

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