

MAKER: Large Outdoor Display to Indicate 3D Printing Queue

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Nathan Delson's interests include mechatronics, biomedical devices, human-machine interfaces, and engineering education. He is Co-founder and Past President of Coactive Drive Corp., which develops novel actuators and control methods for use in force feedback human interfaces. Medical device projects include an instrumented mannequin and laryngoscope for expert skill acquisition and airway intubation training. He received his undergraduate degree in mechanical engineering from the University of California, San Diego, and then went on to get a doctorate in mechanical engineering from the Massachusetts Institute of Technology in 1994. He was a lecturer and Director of the Design Studio at Yale University for four years, and then returned to his alma mater, UC, San Diego, in 1999. He is now a tenured lecturer and Director of the Design Center in the Department of Mechanical and Aerospace Engineering. He teaches hands-on design courses, including an introductory design class, a mechatronics class, and a capstone design class. His interests in design education include increasing student motivation, teamwork, and integration of theory into design projects.

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DeWald is an engineer, educator and entrepreneur. As director of the EnVision Arts & Engineering Maker Studio at UC San Diego, he works directly with faculty and instructors, and empowers students to use the studio to the fullest extent possible. He is committed to the Experience Engineering initiative that strives to implement hands-activities beginning on day 1 of engineering programs.

Before joining UC San Diego in 2015, DeWald helped design and implement a fast-growing, NSF-funded engineering education program for high school students. DeWald has more than nine years of industry work experience in research and development, large-scale manufacturing and product design.

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Introduction

EnVision the Arts and Engineering Maker Studio¹ is an interdisciplinary design facility at the University of California at San Diego. EnVision contains resources like 3D printers, a laser cutter, and soldering kits are available for visual art and engineering students to collaborate, design and fabricate together. The space encourages hands-on prototyping for small scale, innovative projects. The space opened in January 2016 and is meant to support close to 7000 undergraduate engineering and visual art students.

As with many maker spaces, there can be a queue for the 3D printers since each job can run many hours. One objective of this project was to communicate to students how many 3D printers are in use without requiring them to come into the maker space. Also we wanted to create a “buzz” about activity going on in the space, and increase awareness of the maker space among the students. While we could have simply posted 3D printer activity to a webpage, we wanted to use a method of communication that highlighted making. Our approach was inspired by Natalie Jeremijenko’s art display Live Wire², where a spinning wire that would rotate based on the speed of the internet connection providing a visual and audible background signal indicating the bandwidth of the internet connection. We also were inspired the UCSD Stewart Collection³ of art projects that used moving text including Bruce Nauman's Vices and Virtues and Barbara Kruger’s moving text display. In a similar fashion wanted to use nontraditional ways of communicating information.

We chose to create a custom LED matrix display in the window of the Maker space facing the outside of the building. We put current sensors on each 3D printer to determine when they were in use, and created a wireless Arduino protocol to display the amount of 3D printing going on. The more 3D printers that were in use, the faster the animation of 3D printing. With this approach we accomplish both objectives of communicating the queue and creating a buzz on campus using maker technology.

LED Window Art Display

We wanted our space to highlight abilities to use technology in a wide range of uses. We also wanted to create a buzz on campus about the space. The makerspace is housed in a building with windows facing a walkway, so we repurposed the upper portion of the windows to build a LED display that would not impede light entering the room, but still be visible to people walking by the building. As with many makerspaces, the availability of 3D printers can become an issue. Accordingly, our display will provide information about the current percent usage of 3D printers. While we could have conveyed this information as simple text or a webpage with usage status,

we challenged our students to integrate art with engineering.



Fig. 1. LED Window Display of 3D Printer Animation



Fig. 2. Outside View of 3D Printer Animation

System Overview

The figure below illustrates the electronic hardware set up of the entire LED display system. It is important to note that XBee 1 and XBee 2 have a one way wireless communication over 20 feet. The function of each hardware component is explained throughout the paper.

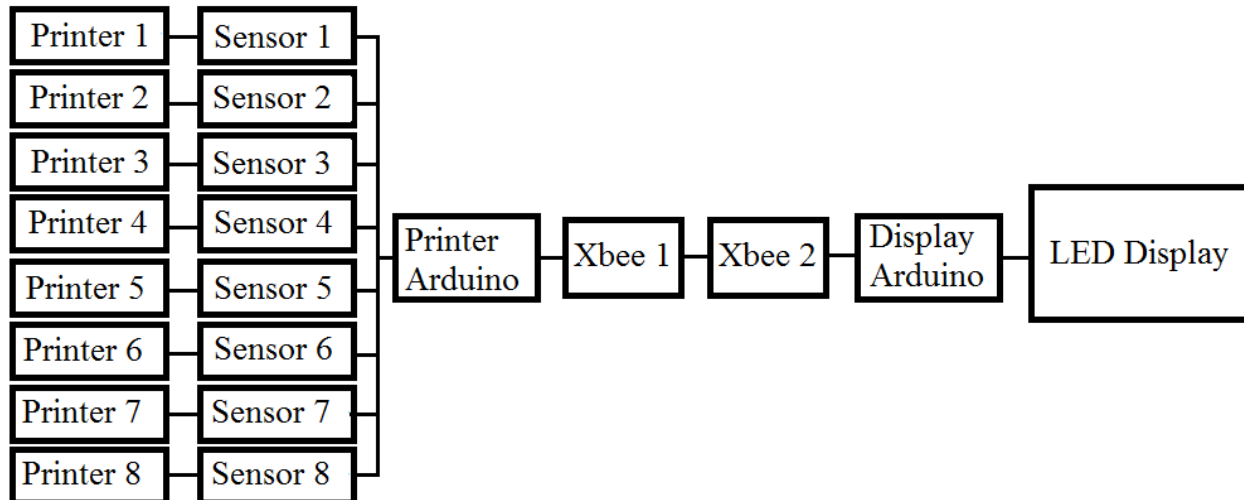


Fig. 3. Electronic Hardware and System Overview

Hardware design thoughts

The display was designed to be mounted in a window to advertise the Maker Studio on campus. Since we tried to avoid blocking sunlight, we made the display out of ¼” thick, transparent acrylic. Choosing clear acrylic doesn’t just have the advantage of being transparent, but it also makes the display bidirectional. The refractive property of the acrylic allows students inside the Maker Studio as well as people passing by, on the outside of the Maker Studio, to see the displayed images.

Components

The display is made from the following components: ¼” inch sheets of acrylic, individually addressable LED strips, aluminum extrusion profiles, a power supply and an Arduino as microcontroller as well a XBee for wireless communication. A control box—over 20 feet away from the LED display—encases stripped extension cords connected to 8 3D printers. Also made out of ¼” inch sheets of acrylic, the control box contains non-invasive current sensors, an Arduino, a XBee, and a breadboard.

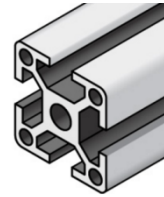
Getting Started with the LED Display

¼” thick acrylic is used to mount individually addressable LED strips which can be purchased online for roughly \$40 per 5 m. It is important to buy individually addressable RGB LED strips, since we want to be able to ‘speak’ to each LED light. Avoid getting LED strips that only light up in one color.

One starts off by dimensioning the size of the acrylic sheets. The size of the acrylic has to match the size of the window. Nonetheless we recommend leaving a small gap in between the acrylic and the window frame to account for the case that the window frame might not be fully squared. Leaving a 5 mm gap on either side of the acrylic sheets should be enough. The dimension of the acrylic would then be $(H_w - 10\text{mm}) * (L_w - 10\text{mm})$. The size of the acrylic sheet will be denoted as H_A (Height acrylic) and L_A (Length acrylic). One must keep manufacturing in mind. Since the acrylic sheets will be cut out using a laser cutter, one has to design for the capacity of the available

laser cutter. Sometimes the acrylic plate will have to be split up into multiple components depending on the desired size of the LED display and the capacity of the available laser cutter.

Next we have to look at the extrusion profiles that we will use as the frame to which we will mount the acrylic sheets to. We recommend squared anodized aluminum extrusion profiles of lengths 'a', as they will have a professional finish.



Calculating Pixel Matrix Dimension

In order to obtain the dimensions that will mark the boundaries of the area to which the LED strips will be mounted to, we will have to do the following calculation $L_1' = L_A - 2*a - 2 * S_s$ & $H_1' = H_A - 2*a$. S_s refers to the slot spacing which we recommend to be 25 mm or more.

Now we can figure out our pixel resolution and hence the dimension of our LED matrix. We take the obtained values L_1' and H_1' and use these to obtain our matrix size. The pixel matrix depends on the spacing of the individual LED lights on the strips as well as on the desired spacing between horizontally placed LED strips. The pixel densities on LED strips range from multiple centimeters between pixels to a few millimeters between pixels. We will denote the length of one Pixel as L_p and the vertical spacing between pixels as S_p .

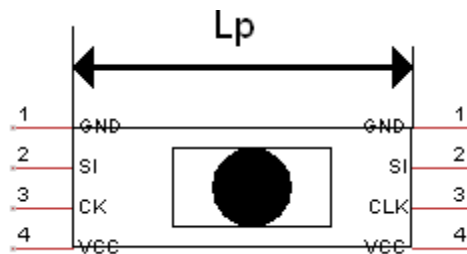


Fig. 4. Single Pixel

In order to obtain the matrix dimension of our LED strips we will do the following calculations: $L_1' / L_p = n'$. Now, we want to round n' down to the next lowest integer. Say if one obtained $n' = 25.69$ then we will use $n=25$. For the m value we will precede similarly. We will calculate the following $m' = W_1' / S_p$. Also here we will most likely not obtain an integer value when making this calculation. Hence we round m' down to the next lowest, even integer value. If $m' = 13.76$ we will take $m=12$. Why we choose m to be an even integer value will be explained later.

Referencing Where to Place LED Strips

Since we now know the matrix dimensions $m*n$ of our LED display we can continue with our design of the acrylic sheets to which the LED strips will be mounted to. Since we want to make our life easy, when mounting the LED strips to the acrylic sheet, we want to have reference points to glue the strips onto. We will obtain these reference points by scoring the acrylic with the laser cutter. The distance between the scoring lines will essentially be the length of the pixels. Since the pixel length might not be consistent throughout the LED strip, we recommend measuring the distance between at least 5 pixels and dividing this by 5 to get an average value for the pixel length. When scoring, it is sufficient to put a vertical scoring line between every 5th to 10th pixel.

Slots

When mounting the display onto the frame it is good to have slots instead of simple holes over the extrusion profiles to account for manufacturing errors. The high tolerance that one gets from using slots will make the final assembly more flexible and hence easier.

Choosing the Power Supply

Every pixel is usually rated around 0.25 Watts = P_p . This may vary though for your individual RGB LED strip. The minimum amount of power you will need is $P' = n*m*P_p$. We recommend using a Factor of Safety of 1.5. Getting a power supply that has at least 1.5 the amount of Power that you calculated should be enough for the display $P = 1.5 * P'$.

Wiring

We chose LED strips that have 4 input pins, which consist of a VCC, GND, Serial and Clock input. The Serial and Clock pins will all be wired in Series. VCC and GND will partially be wired in series and partially in parallel. The wiring of the display is shown in the next graphic.

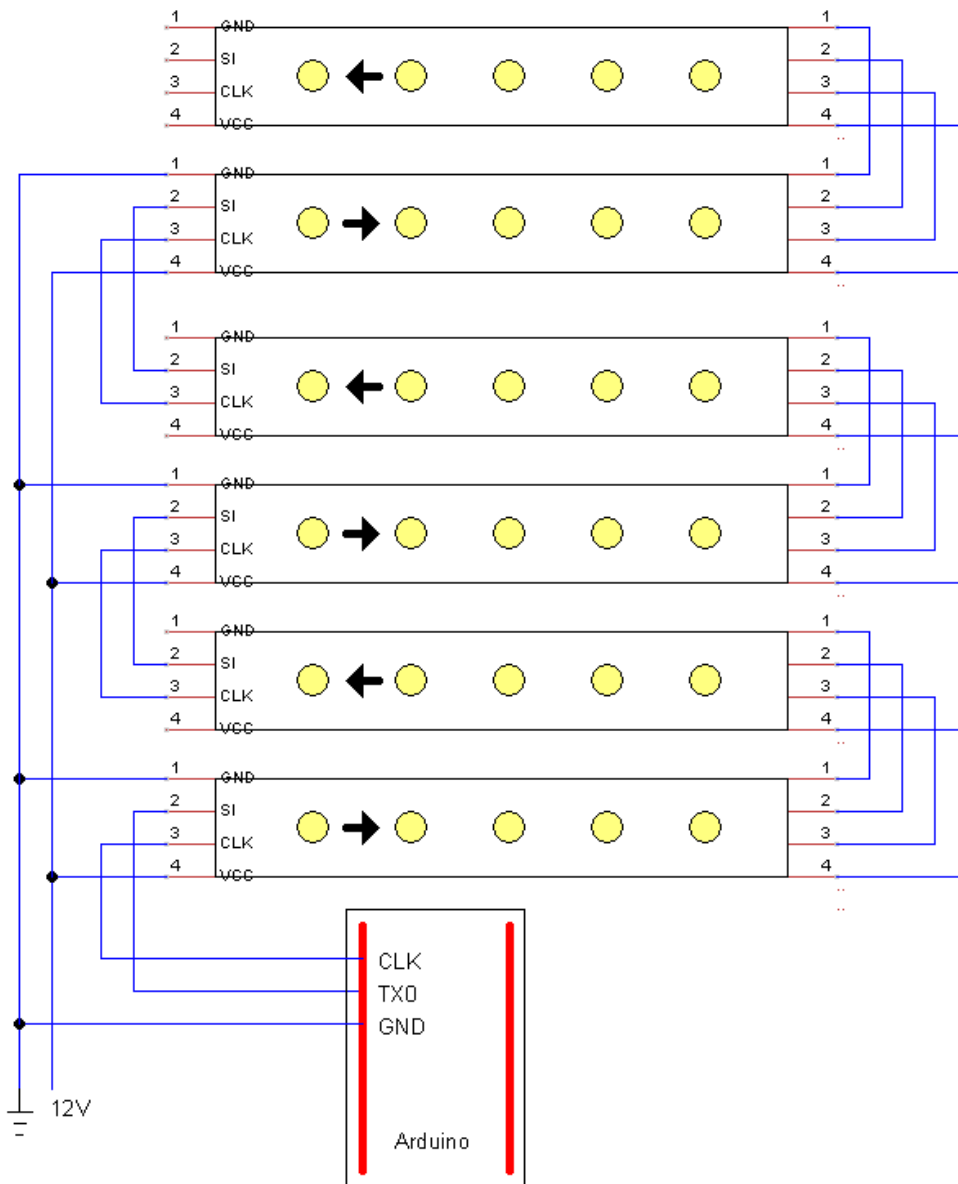


Fig. 5. Wiring of the LED Strip

Acrylic Design

After considering the pixel matrix dimension, wiring and the window frame size, the following CAD illustrates the acrylic design of the LED display.

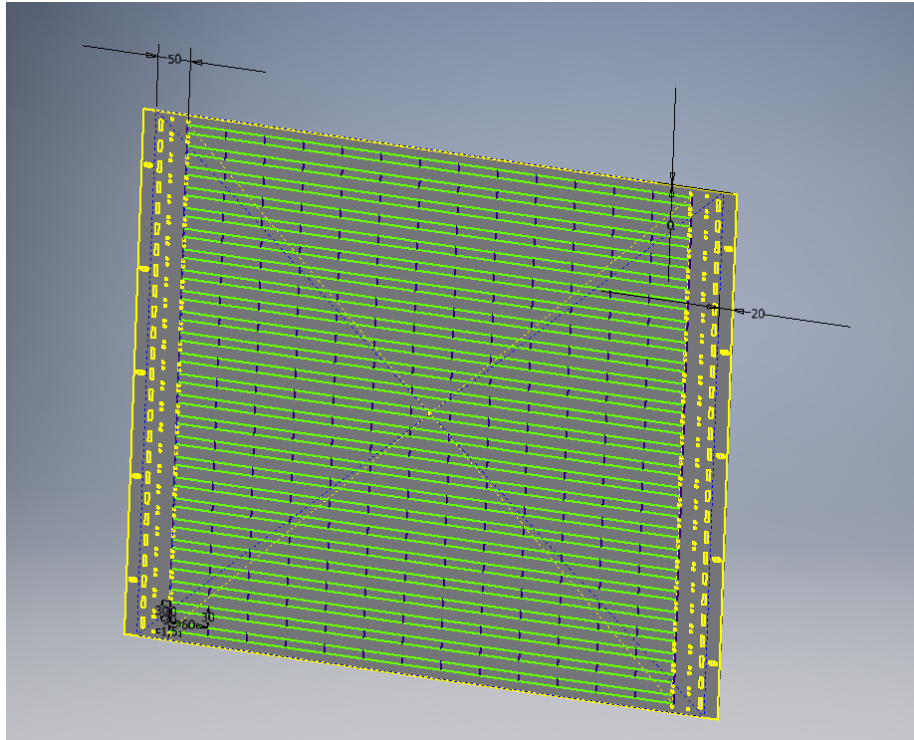


Fig. 6. CAD for Acrylic Design

The Control Box

The control box's objective is to neatly and securely enclose stripped extension cords that carry 120VAC. An Arduino is programmed to receive direct current that ranges from 0-5VDC. Non-invasive current sensors rated at 5Amps to 5VDC are attached to stripped extension cords that connect the 3D printer to a wall outlet of 120VAC. The current sensor converts the alternating current to direct current with varying magnitudes between 0 and 200mV, which are useable voltage inputs for Arduino applications. The completed control box configuration is shown below.

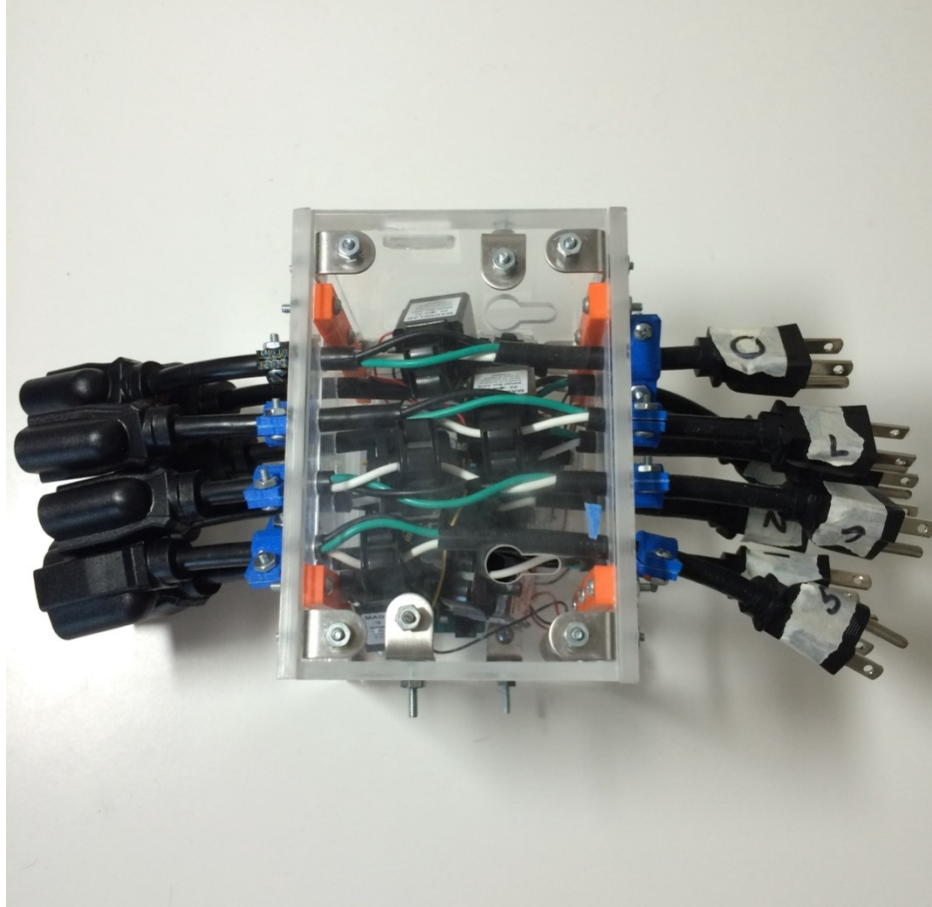


Fig. 7. Control Box

The control box is measured at 6.25''x5.5''x4.5'' with screw slots to join the walls with L-brackets and hook slots to mount to a wall near a row of 8 3D printers. Additionally, the bottom and top walls are segmented into 3 pieces of varying widths. The greatest width of the 3 segments is measured at 2.75'' which is the segment nearest to the Printer Arduino. This width is designed larger than the rest to manage wiring going into the Printer Arduino as shown in Fig. 8 and Fig. 9. The middle and last segment have measured widths at 1.5'' and 1.25'' respectively. As illustrated in the figures below, the wall segments are connected by 3D printed I-brackets (in orange). The purpose of implementing three segments is to account for 8 stripped extension cords to come in and out of the control box. Each female end is connected to a 3D printer while each male end is connected to a wall outlet. The holes were laser cut to fit the 1/3'' diameter of the insulated extension cord as shown in Fig. 8. The figures below are a top view and an isometric view of the open control box CAD with the extension cords and current sensors removed for visual clarity.

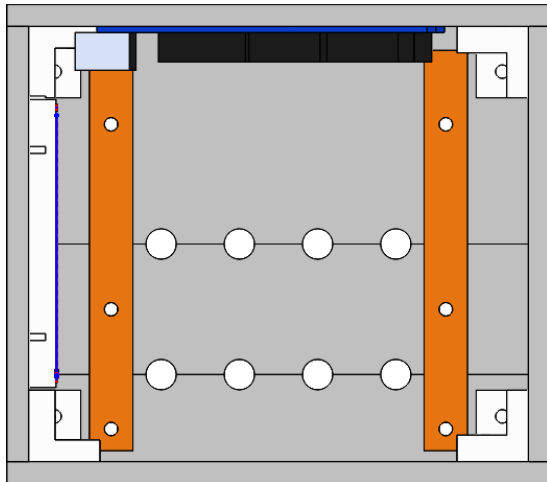


Fig. 8. Open Control Box Top View

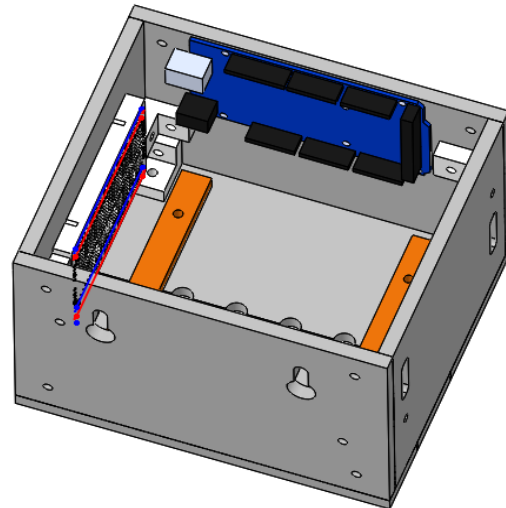


Fig. 9. Open Control Box Isometric View

A major design concern for the box is the movement the current sensors may experience because of tugging on the extension cord. Restricting current sensor movement is a priority to prevent a break in connection to the Printer Arduino. This is especially alarming during installation, where the current sensors move significantly. Stoppers are attached at the interface between the box surface and the extension cord to prevent movement. With the 3D printed stoppers, the current sensors securely measure voltage through the extension cords and directly deliver it to the Printer Arduino without breaking connection. Stoppers are composed of two symmetrical pieces sized to fit the 1/3" diameter of the extension cord. The stoppers are tightened on the extension and are fastened using nuts and bolts. The configuration for a single current sensor and extension cord is shown in the figures below.

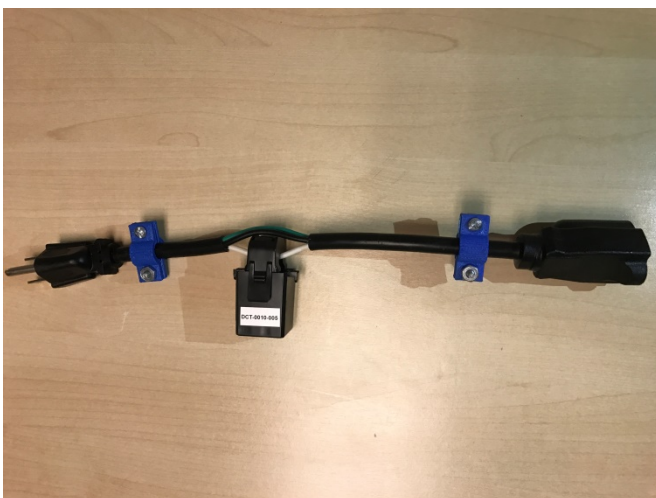


Fig. 10. Single Current Sensor Configuration

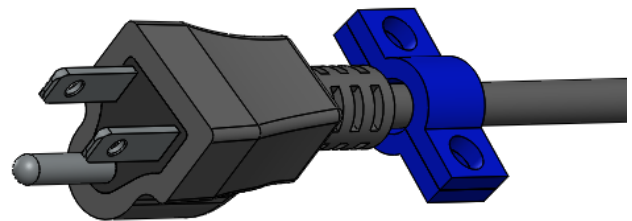


Fig. 11. 3D Printed Stopper

It is important to note that the current sensor is wrapped around the “live” wire (in white) which carries voltage through the extension cord. If the current sensor is attached to all three wires, or if

it is not stripped, then the current sensor outputs a net 0 voltage at all times. This result is related to a constant magnetic flux through the magnetic current sensor.

Implementation and Testing

The system has successfully tested on two TAZ 3D printers. As expected, the current sensors output varying voltages while the 3D printers are operating. Additionally, there are three distinct voltage states observed in the system. The first state is when the printer is completely shut off. The second state is when the printer is turned on, but the extruder is not heated (stand by). The last state is when the printer is working at full capacity and printing a respective CAD model. Given these three different states, the Printer Arduino is programmed to return integer values indicating how many 3D printers are on.

Printer status	Analog pin 1	Analog pin 2	Voltage Threshold	Return
Printers off	0	0	100mV	0
1 Printer Stand by	24mV	0	100mV	0
2 Printers Stand by	24mV	24mV	100mV	0
1 Printer on	200mV	0	100mV	1
2 Printers on	200mV	200mV	100mV	2

Table 1. Test on two Lulzbot TAZ 3D Printers

The table illustrates the most recent test of the LED display system. After many tests on a Lulzbot TAZ 3D printer, we discovered that the current sensor outputs an average value of 200mV when printing. Therefore, when programming the Arduino, we set a voltage threshold that is significantly higher than the standby output direct current voltage to account for possible noise disturbances. If the current sensor measures a voltage that is higher than the threshold voltage, then an integer value of 1 is returned in the serial monitor.

A one way XBee communication is set up to deliver the corresponding integer value of the number of 3D printers that are in use. The LED display is programmed with an Arduino that increases the programmed frame speed by five seconds when the number of printers in use increments. Making it more intuitive for passerby, the following frame appears on the display when an additional 3D printer is in use.

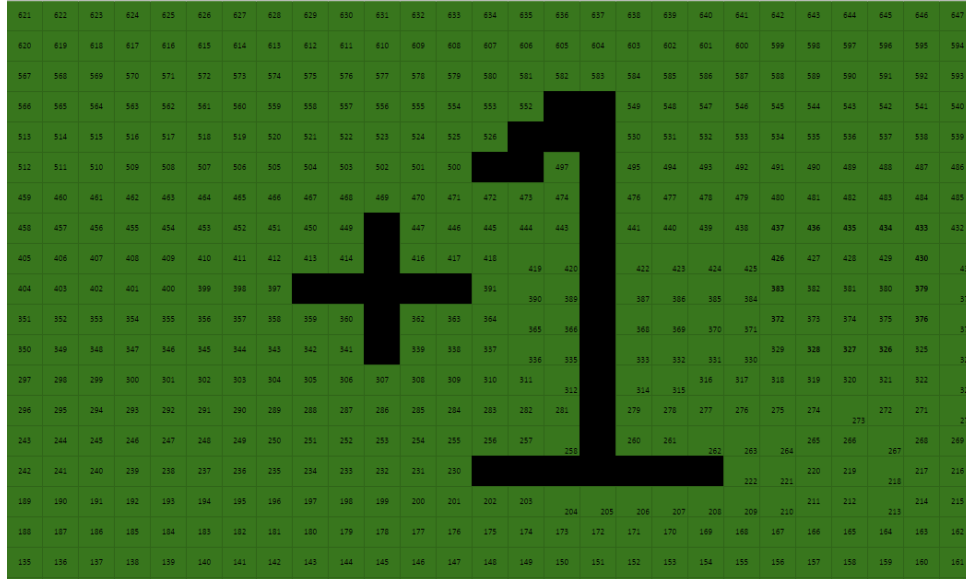


Fig. 12. Frame Signaling Printer Added to System

The frame above is an excel sheet composed 24 rows and 27 columns (note that all rows and columns are not shown in the figure). Here the color black represents LEDs off and the rest are green LEDs on. Each index is numbered from 0 to 647 that correspond to the 648 LEDs on the LED display. Centered in the frame is the value 1 which represents an additional 3D printer is added to the system. Furthermore, the frame below illustrates the frame displayed when a 3D printer is shut off or no longer in use

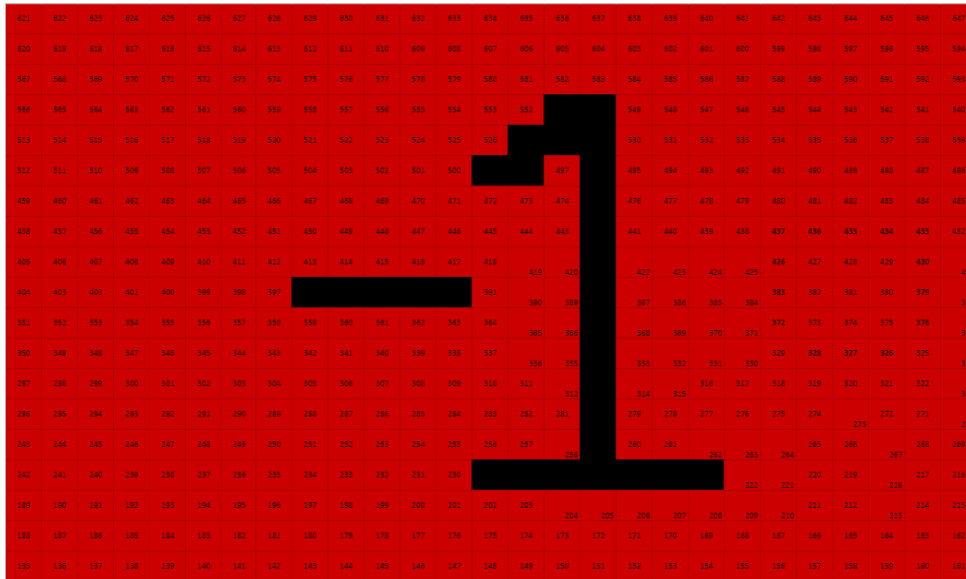


Fig. 13. Frame Signaling Printer Removed from System

Intuitively a passerby could discover that the figure above means that the number of 3D printers in the system is decremented. As mentioned previously, the animations do not display words to

garner passerby curiosity.

It is important to note that these frames do not appear at the exact moment that a 3D printer is added into or removed from the system. There is 10-120 second delay in the display of frames shown in Fig. 12 and Fig. 13. This delay is due to the processing speed from the programmed LED display Arduino. Since there is an additional and deliberately programmed delay between frames, the Arduino takes longer time to run its code. This means that the total processing time is increased between each iteration of code. For instance, when there are 0 printers in use, there is a 10 second delay between frames. When an additional printer is added the Arduino stores 64 bits of the previous integer value returned. In other words, the integer value 0 runs 16 times before switching the delay speed between each frame to 5 seconds. Delays are likely to accumulate when the system fully integrates 8 3D printers.

Printers in use	Programmed delay between frames	Delay due to processing speed
0	10 seconds	120 seconds
1	5 seconds	60-70 seconds
2	0 seconds	10 seconds

Table 2. Delay Between Frames in Animation

Future Applications

The project is still in development as we are still building the display and programming varying animations. However, one goal remains: attract passerby curiosity, so they invest their time in understanding the activity in the maker studio. Surely, one constant animation would become uninteresting after people become familiar with the display. As a result, people become less inclined to look at it, leaving it in their peripheral vision when they walk by. One way we hope to attract more attention is to have varying animations. This way, people will feel compelled to look at the animation; the LED display remains relevant. Additionally, we hope to have them build an attachment to the display by asking them to participate in our project directly. Our hope is that in building more displays, people will be able to incorporate their own animations. They can promote events on campus or communicate messages. In this process, the display becomes a part of campus culture.

Additionally, our focus is making the display real-time interactive. More displays will be made to accumulate over 2500 LED RGB lights. Increasing the number of LEDs by a factor of four allows for interactive experiences. For instance, using MATLAB we can record students' voices. The soundwaves can project onto the LED display as a low-resolution soundwave, so students can "see" their voices. Furthermore, students can choose to save recordings to leave messages, questions, and answers for the next student user in the studio.

Frame 1:

Table with 25 columns and 25 rows of numerical data. A vertical blue line is positioned at column 13.

Frame 2:

Table with 25 columns and 25 rows of numerical data. A vertical blue line is positioned at column 13.

Frame 3:

Table with 25 columns and 25 rows of numerical data. A vertical blue line is positioned at column 13.

Frame 4:

Table with 25 columns and 25 rows of numerical data. A vertical blue line is positioned at column 13.

Fig. 14. Soundwave Frames Projected onto LED display

The figure above shows a low-resolution soundwave that could project on the display as a result of user interaction. The blue vertical line is a reference point for a potential playback system. Since a recording will be stored and replayed, the blue line illustrates the data replayed in real time as the soundwave moves from left to right on the display.

Acknowledgments

We thank Alan Beas, Jeff Brodie, Wayne Li, and Tejas Shetty for their contribution in programming and mapping images on the display. Also, we thank Shawn Macasay and Jesus Sida for designing the control box to ensure safety in the makerspace. Lastly, we thank Arpie Shekoyan and Min-Chieh Chiu for their assistance in designing the 3D printer animation.

References

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2. Live Wire (Dangling String). Art Installation by Natalie Jeremijenko, Xerox PARC 1995 described by Weiser, Mark, and John S. Brown. "Designing Calm Technology. December 21, 1995." http://www.ubiq.com/weiser/calmtech/calmtech.htm
3. The Stuart Collection at the University of California, San Diego seeks to enrich the cultural, intellectual, and scholarly life of the UCSD campus. http://stuartcollection.ucsd.edu/