Senior Design 1: Divide and Conquer
3D Projection Grid
ECE Department

Group 27

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Chapter 2 - Project Description

2.1 Motivation and Background

In a data-driven world, 3D data visualization has become a problem in data analysis. In almost every field, there is a data analyst staring at graphs and interpreting all day. Trying to interpret data in three dimensions is difficult on a two-dimensional screen. We haven't had a consistent breakthrough of a system that can generate 3D data physically.

Inspiration for the project comes from netlogo that designs a 2D array of pixels to show, for example, cows and sheep grazing in a field of grass and dirt. We want to make that more immersive by using the pneumatic system to extend the LEDs view to make visualizing the data/picture in 3D. We also take inspiration from the children's toy lightsabers that extend out and shrink back in as our way to make the pneumatic system work.

With an addition of a rectangular prism shaped grid of LEDs, we would be able to not only see data in three dimensions but walk around and physically point, touch and explain the data to many people so everyone has a better understanding of said data. Everyone has their own way of learning and understanding new material and hands-on is a very popular one. Having this physical display of data could help these people who need hands on to understand what they're looking at.

Another application is in the school system. This system could help teachers better explain their content to the children, again, in a more physical hands-on way. With the addressable LEDs, the system can also be used not just for data visualization but in any way you can think of from light shows to decoration to complex data visualization. Especially with the common use of LEDs in households with kids asking for LED strips all the time, a new system or breakthrough to the third dimension would be a milestone in technological advancement that will be remembered forever.

While we do have static displays of data like blocks and styrofoam, it doesn't have the ability to be changed dynamically to accommodate different data sets and/or types of data displayed. With the projection grid, we can switch the display from a bar graph to a line chart to even just a random combination of lights. Also, with the pneumatic actuation system, we can visualize moving in real time so we can see the changes in data as they happen.

With the use of LEDs instead of physical objects as a diagram, we can see data change with the turning on and off of LEDs. An example could be showing a 3D pie chart or showing the topology of different areas in the world. Another example of the usefulness of this project in other areas of study.

2.2 Features and Functionality

The function of the 3D projection grid is to be able to display data in 3D. Using an 8x8x4 grid, data will be able to be displayed using red, green, blue, and white LEDs. The colors of the LEDs will not be fixed, meaning each LED will be able to display each of those colors when desired. Examples of data that could be displayed with this grid are mathematical functions, atoms and bonds in 3D, electric/magnetic fields, and more. With a 3D printed base housing the electronic components such as the battery, the microcontroller, and any other components needed to make it function, the LEDs will extend up from the base in

The static matrix aspect of the 3D grid will allow us to represent the 3D grid of the LEDs. Using an array, each LED will be able to be mapped to a specific coordinate in the LED grid. This type of mapping will allow each LED to be controlled independently from another in terms of brightness, color, or on/off state. Since the matrix is static, the size is fixed at compile time, meaning predictable memory usage and efficient indexing. Efficient indexing is important here to be able to access each LED with its coordinates without having the microcontroller search through. The static dataset playback target is 1 matrix/minute. With each matrix describing the on/off state, brightness, and color state of each LED, multiple matrices can be loaded into the grid to be cycled through to display a completely different data set every minute.

An intuitive feature that will be implemented into the 3D grid is module expansion. What this means is the user will be able to take an identical copy of the 3D grid and connect it to the first one. Given this connection, the user can decide to operate the second, connected grid as a separate grid to create a larger composite grid. Expansion is an important feature to be able to display larger data or display the same data to a larger group of people. When two grids are connected, the number of LEDs doubles, meaning the ability to display the same data as with one grid, in greater detail. The connection of two grids is designed to automatically recognize the connection and synchronize animations. Using a “plug and play” style of connectivity, these 3D grids could theoretically be connected infinitely to be able to make larger and larger grids to increase resolution, configure different layouts, and scale the display.

The 3D grid is intended for indoor use only. Its electronics, pneumatic actuation, and LEDs are designed for controlled environments. In outdoor lighting, the LED lights will likely not perform as they would indoors due to the lack of contrast, diminishing the effect of the grid. The grid will unlikely be waterproof meaning it would need to stay indoors at all times to avoid any rain damage.

Having a marketable product is crucial to be able to sell it. The 3D grid is designed with customer feedback in mind as well as taking into consideration other similar products on the market. A crucial part of this project that plays into the marketability role is the modular extension.

2.3 Related Work

One of the main drivers for this project was the website netlogoweb. When viewing different models on this site, certain datasets felt lacking in how they represented and displayed the data. For example datasets on animal activity in a region are represented by boxes, squares, and little icons representing different animals. This can vary significantly from how the region actually looks, however, and adding a height element to work alongside color would add to the understanding of how the region is laid out. Along with netlogo there exists other 2D data modeling services which all have the same goal as the 3D projection grid. These include Repast, MASON, and GAMA, with GAMA also being focused on geographic modeling.

Although there doesn't seem to be a retail product on the market for sale to consumers, there are other renditions of the 3D grid that can display data. When looking on YouTube, videos can be found of similar iterations of the 3D grid. Most of these grids are built using very small LED bulbs. There are examples of the LEDs hanging down from a console unit (the power, PCB, MCU housing, and more) hooked onto the ceiling, but also examples of the console unit being the base with the LEDs extending from the base up. Moreover, the grids online have the ability to change the display in real time. They show how the grids can display sine waves propagating in real time, they can show a sort of firework animation, and much more with very fast refresh rates. In other words, all of these renditions are very similar to each other with no significant innovation from one to the next.

The main notion that makes our proposed product different from those in the "market" already, is the pneumatic actuation aspect. In our proposed project, we will be using a telescoping effect with the pneumatic actuation. Similar to how a telescope can extend forward with tubes that nest inside one another, we will be using that to display data in 3D. The pneumatic feature will be how our 3D grid displays data of different heights. Instead of lighting up LEDs sequentially above one another, we will be raising the height of the grid physically.

Another aspect of our project that cannot be found elsewhere on the internet, is the inter-module connectivity. Each project seen online has a stand-alone project with a console unit and LEDs that extend from it. Nothing else. Our project is different because we will be able to take an identical 3D grid, and connect it to the original grid to display larger data. The two modules/grids will be able to communicate with each other to display data on a larger grid. The connection should be seamless and easy for anyone to connect and disconnect.

Lastly, we intend our grid to be very easy to use. The entire idea behind the grid is to be able to display different data. The user will input a dataset to be displayed (matrix) and output the result immediately. A goal of this grid is to be able to shuffle through different data sets, essentially the grid refreshes to show different data than what was previously shown, at least 1 dataset per minute, with a goal of 10 datasets per minute.

2.4 Overview of Project Goals

Basic Goals

- Create an 8×8 LED(64 LEDs) grid capable of displaying 2D matrices.
- Create a pneumatic system with the ability to represent data as different heights, to work in conjunction with the LED grid.
- Enable simultaneous visualization of datasets combining both color (LEDs) and height (pneumatics).
- Implement 4 discrete height levels per cylinder (resulting in an 8×8×4 matrix)
- Design and build opaque cylinders to diffuse light and represent height levels.
- Create a stable base that ensures proper LED spacing/mounting
- Be able to display 8x8x4 datasets with a refresh rate of at least 1 dataset per minute.
- Establish proper power distribution for all 64 LEDs
- Develop a microcontroller-based system to control and address LEDs.
- Design a PCB capable of routing power to the LED and pneumatic systems, along with aiding in communication with the MCU and data storage.
- Coordinate pumps and LEDs through a main microcontroller to synchronize color and height.
- Provide a human-computer interface (HCI) for uploading and interacting with data.
- Preset visualization modes(topographical, density, heat maps)
- Have a storage system able to store different static 3D datasets.
- Working communication interface between software and hardware
- Basic safety system

Advanced Goals

- Expand to include 4 additional pneumatic levels resulting in 8 discrete height levels per cylinder (8×8×8 matrix).
- Be able to display 8x8x4 datasets with a refresh rate of at least 5 datasets per minute.
- Develop advanced data visualization modes (e.g., real-time updates, animated transitions).
- Optimize for efficiency and responsiveness of pumps and LEDs.
- Allow pneumatics to work in both extension and retraction
- Allow for scalable expansion beyond 8×8 (e.g., larger grids).

Stretch Goals

- Be able to display 8x8x4 datasets with a refresh rate of at least 10 datasets per minute.
- Explore interactive controls (touch, gesture, or web-based interaction).
- Add dynamic dataset switching or streaming visualization.

Basic Objectives

- Create an 8x8 LED grid used for data visualization with the ability to display static datasets.
- Build an 8x8 pneumatic system on top of an LED grid with each having the ability to display up to 4 different heights.
- Have an MCU connected to an 8x8 LED grid with the ability to address each LED with RGBW+ colors.
- Have the ability for the MCU to store real time data on the different heights of each cylinder with the ability to control each height.
- Have connectors on top of LEDs to allow for more modules to be connected
- Use MCU to store state information, log events, and be able to reset from errors in operation.
- Have a memory storage device able to store multiple static datasets that the MCU can draw upon.
- Include the ability to upload data to the memory module via a connection to an external source.
- Include the ability for the MCU to detect when a new module is connected and adjust the LED grid to display the proper dimensions.
- With the pneumatic system, control the height of the z-axis to increase the height dimension by at least 4 levels.
- Have all components attached to a 3D printed housing.
- Store all power on housing and be able to sustain operation for more than 1.5 hours.

Advanced Objectives

- Expand pneumatic system to include 4 more height levels available by increasing cylinder height and pneumatic functionality, resulting in 8 discrete levels
- Be able to refresh the LED grid to display up to 5 different data sets a minute by increasing performance of system
- Live simulation of data, real-time interactive control, and reactive element to possibly incorporate game-like system by enhancing system complexity
- Store all power on housing and sustain operation for a minimum of 2 hours.
- 2-way pneumatic system to extend and retract levels without user assistance needed
- Achieve modular expansion, allowing grids of 8x16, 16x16, etc. with full capabilities

Stretch Objectives

- Be able to refresh the LED grid to display up to 10 different data sets a minute by increasing performance of system
- Implementation of interactive control methods, allowing for touch, gesturing, or web-based remote interaction
- Add dynamic switching, allowing for the potential of streaming visualization through cycling of datasets

Requirement Specifications

- The grid should contain LEDs that are *all* addressable. The LEDs will be addressed individually via an array in the software. This provides a design where there is no searching or lookup tables, just direct access to each LED.
- Base dimensions of the data visualization grid will be 8x8 LED grid centered around a base
- Base will be some 3d printed housing that is large enough to hold all hardware needed for the projection grid
- The entire grid and housing will be relatively light, with most of the weight coming from the pneumatic system
- Refresh rate 1 matrix/minute (goal 5/minute). Each matrix will correspond with a "design" or display of data. The goal is to be able to swap from one display to another at a rate of *at least* one display per minute with an optimal goal of 5 per minute.
- Pneumatic height control ≥4 levels (goal 8).
- Inter-module connectivity. The 8x8x4 grid should be connectable to another identical 8x8x4 grid. This connection should be synchronous across both grids so that data can be displayed across both, essentially both grids should be communicating with each other.
- The system should be able to display a 3D visualization of data depending on the user input from external feed.
- The LED system should support the full range of RGBW color space with the ability for numerous color combinations.
- Height controlled by air pressure.
- The system shall expect data input from the user through the form of USB/ external feed through the use of a web app or PC.
- For a system where so many moving parts are acting in combination, it is important to ensure the voltage levels are not too high as we do not want our power consumption to be too high to maintain safety.
- Maintaining low power consumption will be important, not only for safety, but for optimizing our system performance as a whole
- Low air pressure is also key to guaranteeing that the system does not get overworked as a result of the excess load on it.

Parameter	Specification	Engineering Requirement
System Specifications		
Dimensions	8x8x4	The grid will be designed in an 8x8x4 configuration as specified in the project overview
Weight	<10 lbs	The modules must be lightweight. Given the equipment that will be used to build it, less than 10 pounds is reasonable
Colors	Red, Green, Blue, White	Colored LEDs must be used to create contrast when displaying data
Component Specifications		
Housing	3D Printed	Using a 3D printer to construct the housing for the electric components will allow for a sleek look while keeping costs low
Power Consumption	≤60V, ≤24V System Bus, and No Mains	Low input voltage is required to ensure safe construction and operation
Operating Pressures	≤15 psi Working Pressure	Low pressure is required to ensure safe construction and operation
Matrix Display	Response Time	The grid must fully to display a new matrix in under 1 second
Demo Specifications		
Refresh Rate	≥ 1 Matrix/Minute	The grid must be able to refresh the matrix being displayed at least once every minute. The ultimate objective is to be able to refresh 10 matrices every minute
Pneumatic Height Control	≥ 4 Levels	The pneumatic height control must be able to alter the grid's topology of at least 4 levels on the z-axis.
Modular Expansion	≥ 1 Module Connection	At least one other module must be able to be connected to the initial module. They must be able to communicate with each other to create a synchronous grid that can display data on a larger composite grid.

Figure 2.1 *Requirements Table*

Hardware Block Diagram

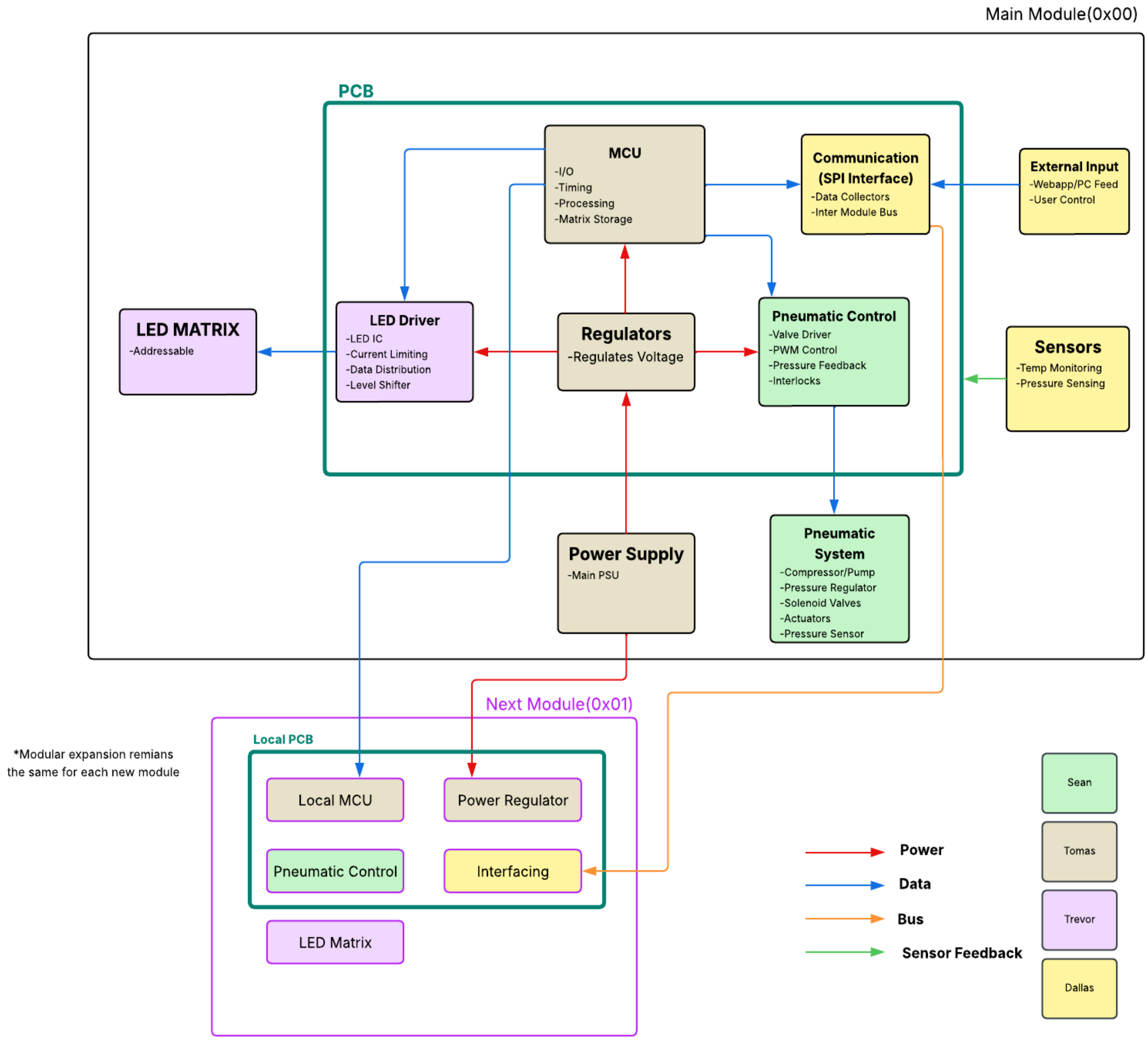

Figure 2.2 *Hardware Block Diagram*

Shown above is the hardware block diagram for the 3D projection grid. The block diagram outlines the fundamental aspects of the project. You can see the PCB section outlined in green, and availability for modular expansion outlined in purple.

Software Flow Chart

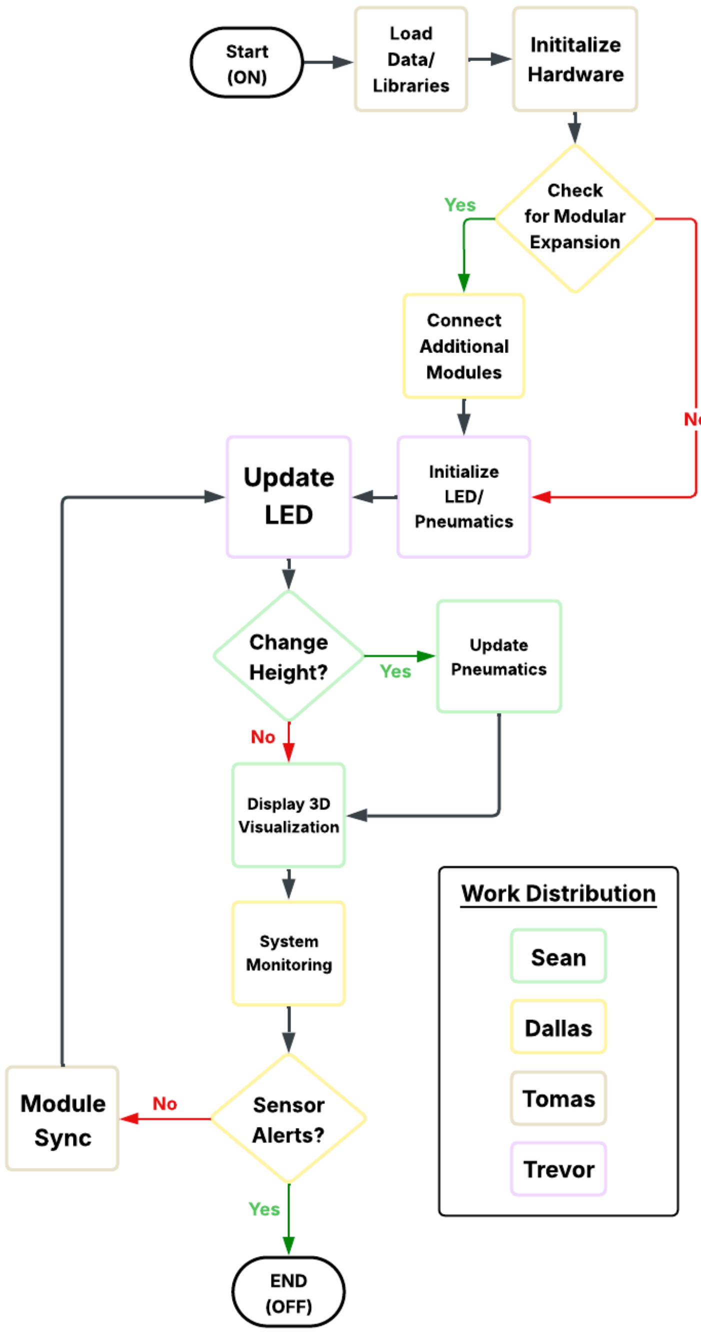

Figure 2.3 *Software Flow chart*

House of Quality

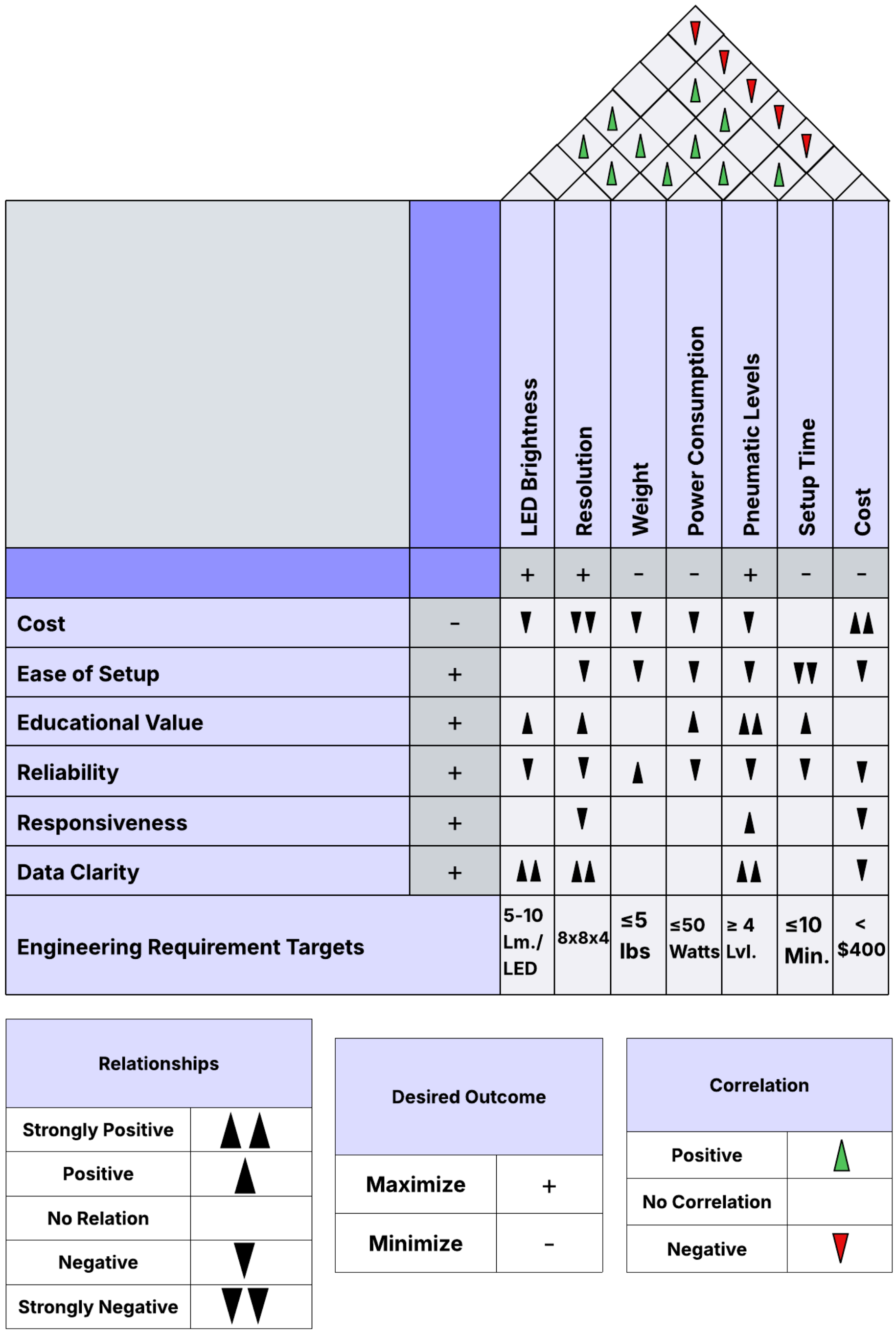

Figure 2.4 *House of Quality*

Chapter 10 - Administrative Content

10.1 Budgeting and Costs

An initial budget of $250 dollars is provided by DRACO labs. This will cover the LEDs, MCUs and power systems. Anything over this budget is covered by group members, giving additional incentive to keep the costs low. Given the cost constraints, 3D printing will be heavily used to provide cheap and customizable parts for the 3D grid. Another way this project keeps costs low is by focusing on low voltage/low pressure operation.

The two most expensive modules in the project will be the pneumatic system and the LEDs. One reason the pneumatics have a high cost is due to most prebuilt parts being used for high pressure systems. These parts have lots of expensive metal and seals that drive the costs upward. For the LEDs, one of the requirements for the project is to have each LED be addressable. This introduces complicated chips for each LED that also increase the costs.

For these reasons the project was given a budget of $500. A focus on low cost parts and solutions will help keep the project within this allotted amount.

Modules	Cost
LEDs and Connectors	$125
MCU/Controllers	$20
Power System	$30
3D Printed Parts	$40
PCBs and Shipping	$100
Pneumatic System/Height Control	$180
Total	$495

Figure 10.1 *Project Budget*

10.2 Project Milestones

Task	Start Date	End Date
Group Formation & Brainstorming	08/18/2025	08/26/2025
Divide and Conquer & Committee Formation	08/26/2025	09/05/2025
Meeting with Instructor	09/08/2025	09/08/2025
Selection of Materials	09/12/2025	09/19/2025
Schematic Design	10/03/2025	10/20/2025
Midterm Milestone	09/25/2025	10/31/2025
PCB Design	10/05/2025	11/01/2025
Prototyping	11/05/2025	11/12/2025
Final Report	11/18/2025	11/25/2025
Ordering Components	SD2 - TBD	SD2 - TBD
PCB Assembly	SD2 - TBD	SD2 - TBD
Testing	SD2 - TBD	SD2 - TBD
Revision of PCB Assembly	SD2 - TBD	SD2 - TBD
Retesting	SD2 - TBD	SD2 - TBD
Final Demo	SD2 - TBD	SD2 - TBD

Figure 10.2 *Table of Milestones*

Appendix A - References

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