The S.T.G Device
Smart Tabletop Gaming

Senior Design
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1.0 Executive Summary

The Smart Tabletop gaming (S.T.G.) device is a two-part device that can bridge players and their group when they can't meet up physically. There are a number of virtual tabletops (VTT)'s, but this version utilizes a physical board and a virtual board at the same time. They will be able to communicate their actions to their group without the overhead of correcting their actions, like with a VTT, but the group of people who are not using a VTT will able to see these actions take place on the main board. To help express the intent of the removed player's action, a LED array is employed to convey actions from the web app, while a sensor array on the board can pick up actions from a pointer tool.

Regular players utilizing the web app VTT will have their movement actions translated to the board, and a XY plotter physically navigating their game piece to the destination point. This XY plotter is situated beneath the board, with a magnetic piston setup on the actuating device. Each game piece will have a small magnet attached to their bottom, which the XY plotter will be able manipulate. To detect the game pieces on the main board and sync those pieces to the web VTT, the sensor array located under board tracks each grid square, reference the known piece locations, while any new signatures are transmitted to the database for the game piece position coordinates. The web app then picks up this update via a web socket event and then updates it's the VTT user interface. Other actions that can be transmitted are pointing out specific positions and performing special effects via the LED array, or adding/removing their game pieces from the board. Features on the web application will allow a player to track basic information on their game piece, such as health points and armor class.

This board is not just for the players of the group but also can be used by the Game Master. This role also goes by the title Dungeon Master (DM), and how that relates to the board is that the game that will be demonstrated on the board is Dungeon's and Dragons. The DM will be able to add or remove any game pieces on the board, designate locations in which a game piece cannot navigate, as well as see information on any game piece that is on the web app VTT.

The framework of the web app allows for scalability and improvements to the overall functionality of the S.T.G. device. With all changes happening server-side, multiple boards could by synced to a single game session, while more features can be added to the web app. For this project alone, they are sticking to a smaller feature set and building in the foundation that will allow for further development.

2.0 Project Description

In this section, the project will be generally described in terms of motivation, goals, objectives to follow and describing the main equipment essential to the project which includes XY plotter, controller, web application and server.

2.1 Project Motivation/Goal

When it comes to Tabletop games, one thing that keeps people from trying out this genre of gaming is they want to play with a group they are familiar with. Another would be that one or more people would like to join into an ongoing session, but they are in faraway locations. Also, most people would want to have a tangible feeling to their game and do not like to use a virtual tabletop. This project could provide a solution to a variety of people with different needs.

In this case, the game is featuring is Dungeons and Dragons, a fantasy role-playing game based on medieval myth. In a regular game, it will include game pieces, dice, paper, pencil and the people who are attending. The most important part for the game to proceed is the presence of people who want to play the game. This project will make that requirement an easier goal to accomplish and will allow people to attend the game session with a physical presence that you don't get through a virtual tabletop.

There have been various ways to include absent people onto a game session, such as using web cameras and having a mic to pick up the group's conversation. Most of these methods are effective up to a point but usually run into the difficulty of conveying the actions from the absent player to the gameboard. The Dungeon Master must interpret these displaced actions correctly and devote a certain amount of attention to perform these actions onto the tabletop. This slows down the session and can lead to some frustration. To fix this issue, the web application communicates to the tabletop all the various actions that a person will want to communicate to the group that is physically at the tabletop.

This implementation removes the middleman who must listen in and perform the actions while keeping the game session flowing smoothly. This middleman being the DM, who's time is best suited to guiding the campaign rather than micromanagement.

2.2 Project Objectives

The goal of this project is the following: to be able to move the game pieces using a magnetic XY plotter, to create a web application that will be synced to the physical tabletop, and for the player using the application, to be able to express their actions to that tabletop in various ways. These different actions can be spell effects, movement actions, and pointing out specific locations that player is interested in.

So far, the size of the board is one of the most critical steps for this project since it will lead a to an x number of magnetic sensors. The size will be reasonably big so that the game pieces can move freely and make the game interesting. Next, an XY plotter will be built and it will be used to move the game pieces around the board underneath the table. We will also implement programmable LED's to light up the board.

2.2.1 The Web application and Server

HTML and JavaScript will be utilized to create a web application that can communicate to the Device Controller. Various API's such as Node JS or a MVC framework will be used to access a server such as MySQL or MongoDB database. This application will allow the participant to click on the screen and it sends the data to the XY plotter controller to move a game piece physically on the board. It also continuously monitors all the game objects on the board by referencing their positional data on the server. On the application, it will display a login Username, Health points, Armor class, Speed, and a feature that can send an attack to the enemy. Also, the enemy will send the attack to the participant which can deplete the Health level. On the server, the information stored contain all the unique ID's of the game objects that are currently populating the tabletop device.

2.2.2 Controller

The controller communicates with the web server and receives information for any game object actions. It also communicates with the XY plotter for moving the game objects around the board. One feature that will be implemented is an edit mode combined with a magnetic pen that can be used to design structures of castles, trees, etc. to create an atmosphere to the game. These designs will be utilized to create obstacles in the grid. Let's say the participant would like to move his or her game piece across a wall in which the XY plotter will not move the game piece through that wall. However, the XY plotter can find another path to move the game piece around the wall. In other words, the XY plotter can find its nearest and most efficient path for the game piece to move to its designated location.

If there is no valid path to navigate the game piece to its destination or if the distance is greater than the speed value, then the board will notify to the application that the piece can't move and there will be a visible indication on the board that the game piece can't move. Manual movement of game pieces on the board will be monitored by the sensors and the controller picks up this action. When an object is removed, the controller references what object was in that position and when that object is placed on a new position on the board, the controller updates that object's positional data on the server. This game objects position is updated on the web application due to its monitoring capabilities.

2.2.3 XY Plotter

The functionality of the XY plotter is to execute physical moments in X and Y motion once it receives software commands from the controller. The assembly is using the main components such as step motors, micro servo, and belts in order to move the game pieces on a transparent surface. The step motors and the LEDs will be connected to ULN2003 chip since the chip contains multiple relays in order to receive multiple information and data from the controller and activation of LEDs during gameplay. Since the original functionality of the XY plotter is drawing, configuration is necessary in order to hold not just a pencil, but a magnetic sensor essential for the tabletop gaming. The game pieces are going to be glued with a magnetic material so that the magnetic holder can grab and move the piece to the designated location. The XY plotter will be located on the bottom of the surface to move the game piece.

2.2.4 Sensors

The sensors are needed to detect the user's movement and sense what's occupied on the board. They will have to be Hall effect sensors since the XY plotter will have a magnetic sensor, therefore the sensors must be magnetic, so they connect. Hall effect sensors are magnetic, they are also either latched or non-latched. The sensors need to be latched because the sensors need to turn on by a north magnetic pole and turned off by a south magnetic pole, which is what latched sensors do. The resistors are needed to be kOhm range (most likely 10 kOhm) to connect the sensors with the voltage supply, output, and ground. They will also need FET multiplexers/demultiplexers to differentiate between sensors and to input and output what the program sets. Since tabletop board will be a 16x16 matrix, they will need 256 sensors under each square.

2.2.5 LEDs

LEDs will be essential for the tabletop gaming and a feature to create a visual effect for D&D players especially for beginners. They will light up the designated location for the game piece to go to. When installing the LEDs, LED drivers will be used for power supply. However, it will be ineffective to use every LED driver to every LED. Instead, an electronic chip called LM3402 will be able to solve this problem. This chip direct and redirect individual LEDs to light up once the game pieces start to move. However, the connectivity will be complex and a tedious process to make every LED to work. If lighting up LEDs individually would be a problem, then using the LED strips would be the alternative. In this method, the LEDs will light up simultaneously and creating a path when moving the game piece.

2.3 Requirements, Standards, & Constraints

When building the project, there will be requirements for the team members to implement, constraints to mitigate, and standards to follow. Requirements are important because the requirements will tell the group what they need or is necessary for the project to work. Constraints are important because they let the group know their limits for any requirements found if something has to be a certain way. Standards are important to show what is compatible, reliable, and productive for any of the materials needed in the project.

2.3.1 Requirements

To accomplish this project, here are tables of main requirements and their purpose shown below:

Web applications are important for the project because this is part of how the software will work and how it will be programmed. The user interface is important because it will monitor what is going on in the game. The application is important because it will also monitor and update the game from the server. In Table 1 below, this shows the requirements for the web application for the project.

Table 1: Web Application Requirements

Name	Purpose
User Interface	– Display the current state of the board on the physical device. – When moving game object from one position to another, will update the server with object new coordinates. – If a move is successful, display board will update with new object's position
Application	– Maintain a constant feed from server for any update from device – Will read from the server if an attempted coordinate update is successful

The controller is important to the project because it is the microcontroller that will be used to program everything in the board. It is needed for the game board, the sensor matrix, XY plotter, monitoring for the game, and to program the lighting of each individual LED. Table 2 below shows everything that the controller will do and that is required for the project.

Table 2: Controller Requirements	
Name	**Purpose**
Monitors the Gameboard	– The Controller will monitor the gameboard for any input – The Controller will keep track of positions for game objects
Receive input from Sensor Array	– Will continuously receive input from the magnetic sensor array and keeps track of how
Output pathing to XY Plotter	– The Controller receives a move action from the database and creates a proper path for the game object to navigate to its destination
Checks updates from the Database	– The Controller will continuously check updates from the database for any changes within the game objects – Database changes on game object coordinates translates to game object movement
Outputs LED pattern to Sensor Array	– The Controller will take a pathing list of coordinates and turn on the destination coordinate LED with a specific color

For the project, having a database is important because it keeps track and organizes all of the different objects in the game. It will save the game object data and the user's data. The table below shows the requirements needed for the database requirements.

Table 3: Database Requirements	
Name	**Purpose**
Saves Game object data	– Each game object will have a database entry for specific fields such as a Unique ID, Name, Health Points, Armor Class, Speed number, and Position Coordinates
Saves User data	– Each user will have database entry containing basic information as the email, unique ID per user, and password.

The XY plotter is important for the project because with this device is how the games pieces will be physically moved around. The XY plotter requires an open-end timing belt, stepper motors, magnet holder, micro servo, and ULN2003A. The table below shows details of each requirement needed for the XY plotter.

Table 4: XY Plotter Requirements	
Name	**Purpose**
Open-end Timing Belt	– To move the magnetic holder X and Y direction
Stepper Motors	– To provide smooth rotation
Magnetic Holder	– Able to hold a magnetic sensor
Micro Servo	– To put the magnetic piece against the transparent surface underneath
ULN2003A	– Essential for Stepper motors' functionality using multiple arrays for movement and activation of LEDs

The sensors are important because they are responsible for detecting the XY plotter's magnet to move the game pieces around. A sensor matrix will be made to be placed under each square on the board. The group is still deciding whether to use hall-effect sensors or reed switches, so they are both included in the table below, but only one of them will be used. The table below shows the rest of the sensor requirements.

Table 5: Sensor Requirements	
Name	**Purpose**
Latching Hall effect sensors	– To detect the user's move and to sense what's occupied on the board
10 kOhm resistors	– To connect the sensors to each other with the voltage supply, output, and ground
FET Multiplexers/Demultiplexers	– To differentiate between sensors and to input and output what the program sets
Reed Switches	– To detect the user's move and to sense what's occupied on the board

The LED's are needed to light up the board, make it look nice, and to light up paths in the game. The LED's will used mostly for aesthetic purposes, but will light up the paths in the game or light up on a game piece when assigned. The table below shows what is required to make the LED matrix.

Table 6: LED Requirements	
Name	**Purpose**
LED Strips	– To light up the board
LED Driver	– To supply power to the LED's
MAX16802B	– To selectively power the LEDs to light up the designated location for the game piece to move

2.3.2 Standards

For this project, the group must abide by certain standards to make sure that there is compatibility, reliability, and productivity to the development pipeline. The following Table 7 to Table 9 define standards that pertain to the project.

Table 7: Electrical Standards	
Task	**Standard**
Connecting the Stepper Motors	– Must be less than 110 V
Connecting Arduino MEGA 2560 with MOSFET and Diode	– The circuitry must be clean and avoid overheating and overload
XY Plotter Configuration	– The weight should be safely distributed
LED Configuration	– Can only be powered up to 5V.

Table 8: Communication Protocol Standards	
Task	**Standard**
HTTP & HTTPS	– Safely transfer data over the web
	– Data encryption

Table 9: Coding Standards	
Task	**Standard**
Code Conventions	– Proper formatting. – Programming principles – Code quality

2.3.3 Constraints

In doing the project, they may be possible realistic constraints that will appear in doing specific tasks and procedure. These constraints need to be mentioned and accounted for before the beginning the project in order to mitigate risks and get the possible best outcome.

In the beginning of the software development, types of constraints are mentioned to be aware while doing the project. In the first stage, coding will take place and this process will develop few constraints. The lines of code must be in quality which then requires a long period of time and prototyping may inflict project's budget.

Table 10: Web Application Constraints	
Task	**Potential problem**
Coding	– It will take time to develop a fully functional code to test connectivity from application to device
Debugging	– Fixing any bugs that may come up while programming the web interface.
Time	– It may take a lengthy amount of time to program the application interface that is needed for the web application
Quality assurance	– May not detect bugs at an early stage which results in longer testing time
Prototype	– Costs extra money, excessive focus on one part of the product may result in other parts neglected

In assembling the XY plotter, the main components may create certain constraints that might sabotage the project. This information is explain on Table 11.

Table 11: XY Plotter Constraints	
Task	**Potential problem**
Open-end Timing Belt	– It may not calibrate well when moving the game piece
Stepper Motors	– It may not receive coding commands from the software and not able to execute the lines of code well. `
Magnet Holder	– It may not hold the magnetic sensor very well.
Micro Servo	– It may not touch the transparent surface with the magnetic piece in order to move the game piece.
LD	– It may lead to complex connectivity for the step motors and LEDs

When building the sensor, few constraints must be considered including the components such as the resistors to have a magnitude of 10Kohms and the type

of sensors must be connected to the XY plotter with a magnet. This information can be mentioned on Table 12.

Table 12: Sensor Constraints	
Name	Purpose
Sensors	– They must be latched Hall effect sensors because they need to be able to connect with the XY plotter which has a magnet
Resistors	– They must be kOhm resistors

When it comes to the LED's the constraints that come with it are for them to be able to be individually programmed. Also, because they are LED's they need to be powered by LED drivers. The Table 13 below shows the minimal constraints for the LED's.

Table 13: LED Constraints	
Name	**Potential problem**
LED Strips	– LED strips must be individually addressable, so it can be programmed by the controller.
LED Power Supply	– Will need to be powered by LED drivers and MAX16802B

Social constraints are important to consider in the project because it is important to know how the project will influence society. The Table 14 below shows any social constraints that can come from this project.

Table 14: Social Constraints	
Name	**Potential problem**
Game Violence	– Parents may not like the setting or premise behind playing D&D

Political constraints that can be considered in the project are not too many because it's just based off of a simple game on Table 15

Table 15: Political Constraints	
Name	**Potential problem**
Dungeons and Dragon Age Rating	– The game may not be suitable for younger

Assembling the project may create harmful effects for the environment. This information appears to be on Table 16.

Table 16: Environmental Constraints	
Name	**Potential problem**
Game Piece Materials	– The game pieces are made of plastic
Server Environmental Impact	– Server uptime helps contribute to extra electrical usage – Increased electrical usage indirectly contributes to extra greenhouse emissions

Setting up the project can results in more increased expenditure than previously anticipated. This is information is explained on Table 17.

Table 17: Economic Constraints	
Name	**Potential problem**
Pricing for Materials	– Various materials have to be bought premade in order to save time.

The XY plotter's components are manufactured by different companies which can cause adversaries. This information is explained on Table 18.

Table 18: Sustainability Constraints	
Name	**Potential problem**
XY Plotter maintenance	– Plotter's parts are made of various materials that would require the tabletop disassembly

Safety is the main concern when building this project. It is imperative to be aware and apply these safety practices to mitigate risks. This is information is explained on Table 19.

Table 19: Health & Safety Constraints	
Name	**Potential problem**
Moving Parts hazard	– Lots of moving parts within the assembly could catch loose objects

2.4 Project Budget and Financing

After researching a few materials for each type of device, budget expectations are listed below within Table 20 below. The biggest expense is expected to be the XY Plotter, since creating a plotter from base materials is a huge undertaking by itself.

Design and testing of a custom XY plotter would consume a significant amount of development time, and as such, the group have chosen to buy that section of the device.

Table 20: Budget Expectations		
Unit	Quantity	Cost
XY Plotter	1	$150-$400
Sensors	256	$150
LEDs	256 (16x16)	$50-$70
Controller	1	$40-$70
Server	1	$100
Power Source	1	$80
Magnet	Variable	$2-$20
Total		$820

2.5 Milestones for project

The project's milestones is set to motivate and keep track of the current progress of the Senior Design Project. This represents documentation, software and hardware tasks, research, and possible goals that the group can achieve by a certain timeline.

2.5.1 Senior Design 1 Milestone

Senior Design 1 milestone consists the documentation process. Here is Table 21 that consists main dates to complete the report:

Table 21: Senior Design 1 Milestones		
Week	Date	Activity
2	May 21st	Project for senior design chosen
3	May 28th	Begin of research, analyze all components and task required to accomplish project
5	June 15th	Begin writing design document
8	July 2th	Check-up, at least 50% of paper complete
11	July 25th	Complete final design document
12	August 1st	Submit final design paper, order parts to begin assembling project

2.5.2 Senior Design 2 Milestone

After the documentation process is completed, using the information from the report would be a helpful guide to fulfill project's parameters.

Here is Table 22, which consisting all the main dates along with each specific task:

Table 22: Senior Design 2 Milestones		
Week	Date	Activity
1	August 27th	Start assembling project
3	September 10th	Begin testing components in project, start prototype
6	October 1st	Finish prototype; have at least one function fully running
9	October 22nd	Finish project; test all functions
13	November 18th	Prepare project for presentation, multiple tryouts
14	November 28th	Showcase final project presentation

2.6 House of qualities

For this section, relationships of the customer needs and engineering requirements were made within a combined matrix called the House of qualities. The team evaluate the interactions with a positive or negative correlation to achieve a well thought out design. This Figure 1 can be seen below.

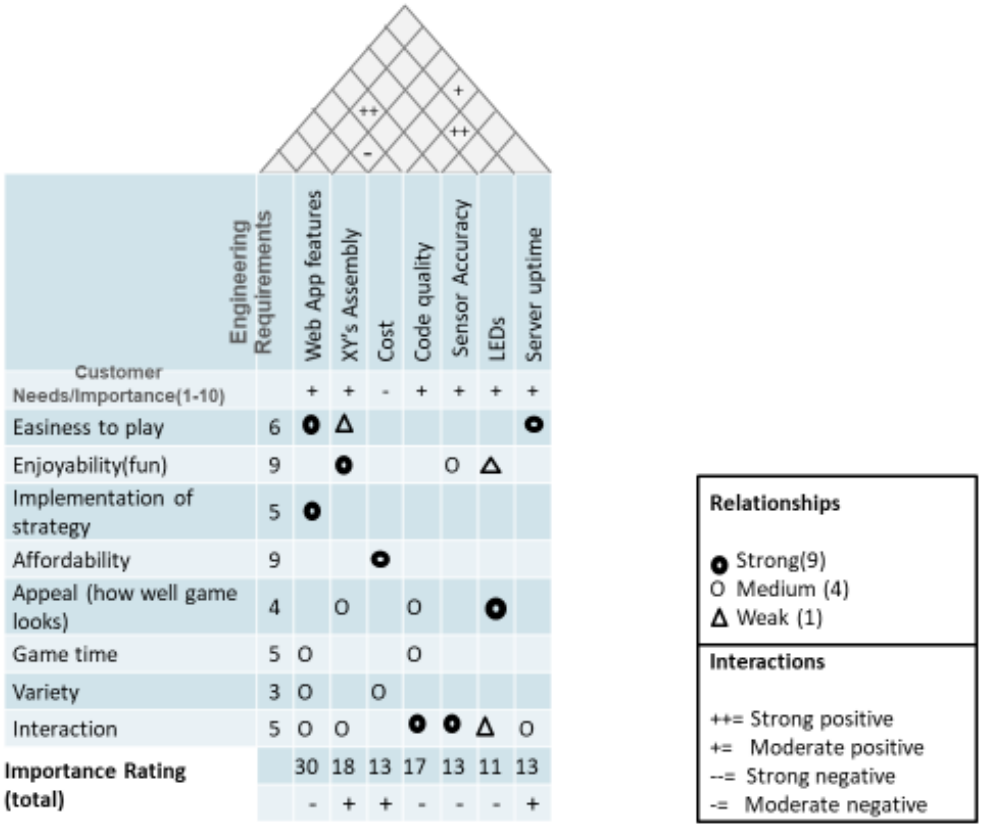

Figure 1: House of Qualities Diagram

The center grid containing symbols displays how strong a relationship each customer needs has in respect to engineering requirements. The roof (top part) displays potential connections and conflicts between engineering requirements. The importance number at the bottom is the overall importance after evaluating customer importance and engineering relationship.

2.7 Block Diagram

The Project Block diagram as shown in Figure 2 below, represents a high-level understanding of the various systems that will be integrated within the project. It is a two-part application, in which a web app and a tabletop application will interact with each other. Responsibilities are assigned to each person towards specific blocks of the project and the current status is kept track with weekly updates.

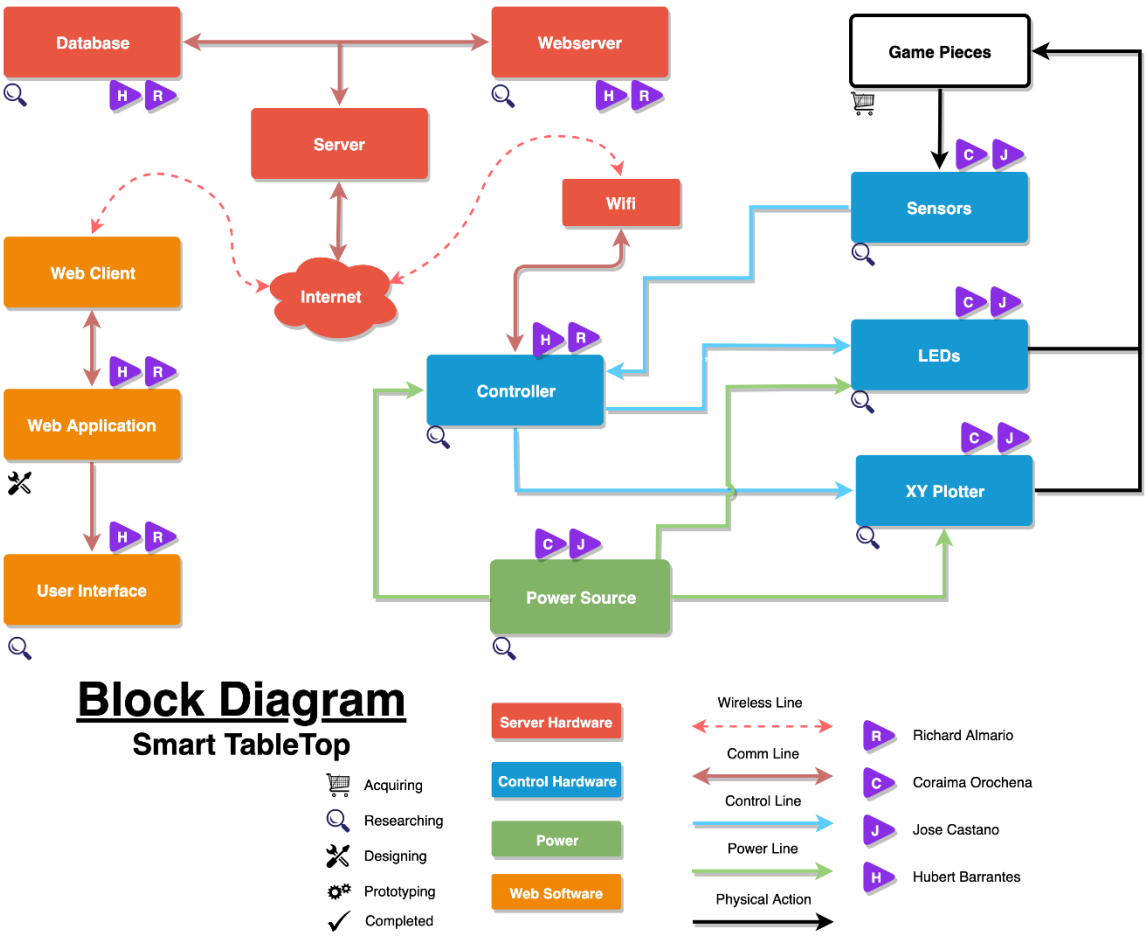

Figure 2: Project Block Diagram

2.8 Project Prototype

The project prototype is a 3D model representation of what the team believe the tabletop application will look like. This contains the different layers of the device that will be developed and integrated into the device shown in Figure 3 below.

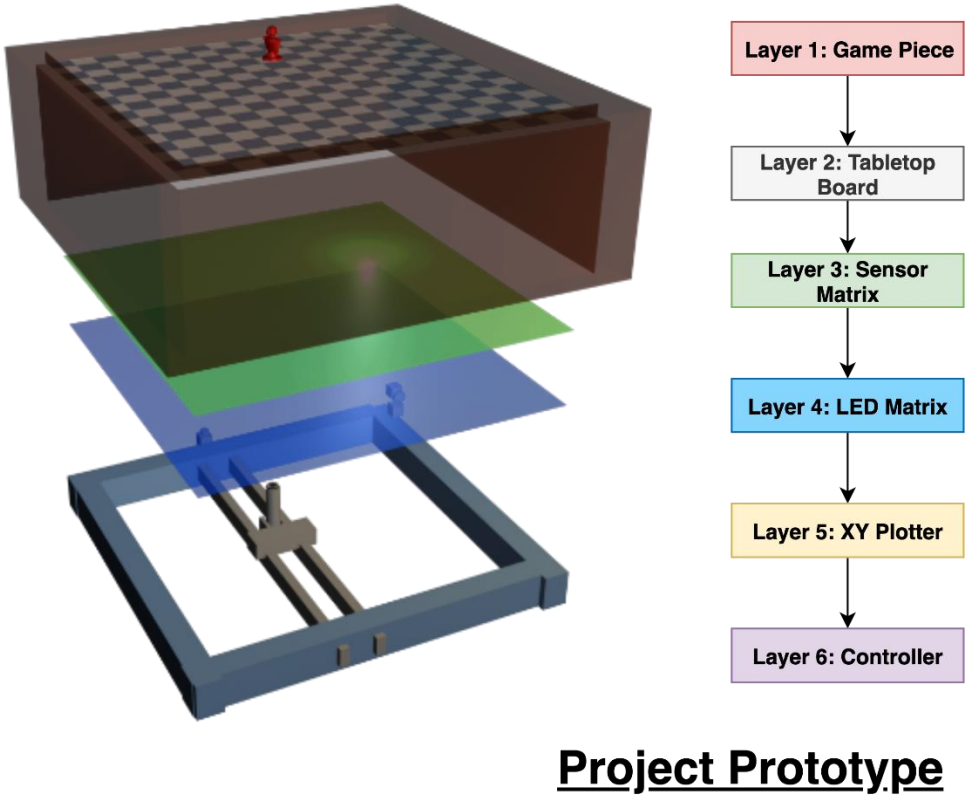

Figure 3: Project Prototype I

3.0 Research

This project could be a continuation from other projects that were made in the past. From there, information can be acquired from these documents and use them as guide for the making of the project.

3.1 Project References

For the group to develop a tabletop game that is dynamic and innovational, the group conducted research into existing projects for the purpose of gathering data and information that could be helpful. These projects have similar design or features that are good examples to us while the group develop a tabletop game. The group will look into the main ideas implemented into these projects that could be applied and improve them.

3.1.1 Magic Chess

Magic chess is a hands-free, voice activated chess board game that was built by another senior design students group here in the united states. It has the option for the player to go against another player or the computer. One of the primary features of this game is the absence of a player's need to physically move a game piece as well as the inclusion of an intelligent chess engine that will allow a player to play alone.

The structure of each game played has a simple series of event, when a new game is started, a player can access an easy-to-use interface via an LCD screen which presents the player a few simple options such as the number of players and the difficulty level of the computer. A human player then can make a move by vocalizing a command, the board will interpret this command via voice recognition software and use the electromagnet controller to carry out this move.

If a player attempts an illegal move, the board will inform the player via a message on the LCD screen and will wait for them to attempt another move.

This project has many similarities with their project hence why it was chosen for research and to improve on, although the project is not a chess game, it does use game pieces and controls them using an X/Y board powered with sensors and moves the pieces without the player physically touching them via a web application built.

3.1.2 Telepresence Chess

Telepresence Chess board game is an interactive game that takes on the classic chess game and presents it with modern flair. Chess has long been digitalized and been playable throughout the web but lacks the same gratification that a player gets from an actual board and pieces in front of you which is what their project works on.

Each chess board can recognize the game pieces in play and move them without human interaction, the board recognizes when a move has been made by a player and communicates through the internet to the other board what that move was. The board that received the move then automatically moves the piece for the player, just as if they are playing against another person on the same board.

This part is accomplished through a magnet implanted in each chess piece underneath the playing surface that is hidden to the user eyes, also it contains a Radio Frequency Identification(RFID) tag to uniquely identify each piece on the board which avoids moving a piece that was not called and to identify the position of any piece at any movement. Other features include saving games and loading previously started games which had piece locations saved before quitting.

This project relates players the same real-life experience from an actual board and pieces in front of them without having to touch them. Their Radio Frequency Identification (RFID) is a very interesting aspect since it is excellent to identify pieces and their locations, this feature will be considered in the project.

3.1.3 CyberChess

CyberChess is another project that has helped the group significantly with researching this project. It was made by another senior design group at UCF in Fall 2012. The biggest difference from their project and this project is that their project is another chess board game like the other related projects and that its voice activated like one of the other related games. The features int his game includes being entirely voice activated to command the pieces with what to do and where to move.

The way they're able to do this is with a wired microphone. Like the other related projects, including this project it also utilizes an XY plotter to move the game pieces around as commanded. This board also uses LED's, but not for same purpose as this project. LED's in the CyberChess project are used to just give notifications to the player as to what is going on with the game now. One other thing that the CyberChess project has that this project doesn't have is the use of audio to be able to communicate ideas to the player.

One idea that was really investigated in the CyberChess project and will now be used in this project is the fact that they used reed switches to make their sensor matrix. Before researching into the CyberChess project the group was strongly considering using and only using hall-effect sensors to make their matrix and it was honestly going to turn out to be a big challenge for the group to wire each of the 256 sensors together and need additional circuitry to even be able to make it work. The CyberChess group discussed about how they were considering using hall-effect sensors for their project and how they preferred not to use them because of all the wiring and circuitry that it would require to make a matrix of them work.

That's when they mentioned reed switches and how they don't need a power source or wiring to work in a matrix. That fact is extremely helpful for the group because now they know that sensor matrix can be much easier to set up and using reed switches instead of hall-effect sensors will save them a lot of time. Assembling a reed switch matrix will still be time consuming for the group since there will be 256 of them. So, if it takes that long to be able to assemble a reed switch matrix. Imagine how long it would take for them to assemble a hall-effect sensor matrix.

Without having found this project beforehand it still would've been certain that the group would've found out about them, but there wouldn't have been much guidance as to how to build and set up the matrix. The CyberChess project definitely gave the group a helping hand when it came to see an example as to how the matrix would be set up in a chess game in an 8x8 matrix. Since this project

is not a chess game and is Dungeons and Dragons instead it will be a 16x16 matrix, but this project still offers great helping hand and blueprint as to how it would be designed for a 16x16 matrix also. The CyberChess project is a major contributor to this project.

3.1.4 Knight Light LED Chess

Knight Light LED Chess is another project like the other ones and has also helped contribute to this project. This project is different from the other related projects because it focuses more on the aesthetic parts and for guidance of using the LED's to bright up the board.

This project was also made by a senior design group from UCF in Fall 2012, same semester as the CyberChess and as mentioned before even though they are similar the biggest difference between these two is their use for the LED's.

In CyberChess the LED's are used to just give notifications to the player, but not really for anything else and in Knight Light LED Chess the LED's are used to light up the whole board and to light up the path or spots as programmed for the game, which is the same set up and purpose that the group wants to set up the LED's for this project.

One of the other big differences between the Knight Light LED Chess project and the other related projects is how it also has a learning tool to teach players or help them out on how to make their move, especially for beginners in the game who are inexperienced.

The Knight Light LED Chess project just like this project are making these projects just for the goal of making something more fun and putting a different perspective on a games that are thought to be as boring or complicated to most people that are not familiar with the game.

The reason the Knight LED Chess project is helpful for this project is because of how the LED's are being implemented for their project. It is an 8x8 chess board and the LED's are being used to light up pathways as to where the player should move their game piece. As the Knight Light LED Chess project provides guidance to new players or beginners to the game.

For this project the LED's are desired just for the aesthetic purposes, so it looks nice and to give more life to the game. It will be used to light up the path to where the player chooses to go and will light up on a character when it's their turn to make a move on the game. Chess is a strategy game, while Dungeons and Dragons is also considered a strategy game, but is more for fun and games, than actually being complicated like chess.

Another thing about the Knight LED Chess project that is helpful to this project is the explanation that is given to how it's set up. It gives many helpful details and is

thoroughly explained in every step how it's done to LED's themselves to the LED drivers. It was also helpful to know what LED drivers were used and how they were implemented to power the LED's. The Knight Light LED Chess project turned out to be very useful to help the group with this project. Just like the other related projects it uses an 8x8 board and it is a chess game, but it gives lots of guidance and help as to how this project can be done.

3.2 Relevant Technology

This section outlines all research done regarding technology that will be implemented to the design to make it function as described by the specifications and executive summary. It's important to look at all the different technologies that can be useful for the purpose of the project to know the options and what can be used in case it does not work with the main preference.

3.2.1 X/Y Stage

The X/Y stage is a very important part of the project; therefore, the group has evaluated spending a good portion of the budget on it to make sure it is made as well as possible. Two possible options for the X/Y stage are either purchasing a pre-assembled stage or for the team to assembly it.

Assembling the X/Y stage could be very time consuming and complicated since it requires some mechanical engineering knowledge. It also needs to meet the requirements and specifications that were laid out in the requirements sections and most important need to remain in the budget set for the project. As previously mentioned, the group will most likely not assemble the X/Y stage due to potential complications resulting from it.

A pre-assembled X/Y stage would be the most ideal option for the project since there is no mechanical engineering students in the group. The pre-assembled stage would also meet specifications and not go over the budget limit set.

3.2.2 Wi-Fi Communication

Wi-Fi is a technology that uses radio waves to provide network connectivity. A WIFI connection is established using a wireless adapter to create hotspots. A project will use this capability to exchange information between the physical gameboard and the digital board.

Wi-fi works by allowing a device to send and receive information via radio waves. Every device has an adapter that translates data to radio frequency signal. This signal is then transmitted via an antenna to a wireless router. Once the router receives the signal, it decodes it and sends/receives data from the internet in a local area network, which is called LAN.

Once all steps are performed, the router sends data from the internet/other devices back into the original device. For the project, we will use a wireless LAN to transfer data from the microcontroller to the server in order to execute commands as well as synchronize game states between two users. The group is considering using this operation for a multiplayer mode gameplay if applicable. For any other mode, where there is only one player exploring or just playing the game, no information synchronization is required since the board will use sensors that will let the microcontroller the current state of the game.

The Wifi Alliance is a global non-profit organization that was formed in 1999. They deal with products from different manufacturers that are certified by the basis of IEEE 802.11 standard for the operation of many wireless devices. Their goal was to organize, stablish and enforce standards for Wi-fi enabled devices and products.

Security standards were maintained according to the WPA and WPA2 security standards with EAP authentication standard. The Wi-fi certification on the device can be obtained when these standards are maintained by member organizations of the Wi-FI alliance. This allows for the product to use the Wi-fi seal as a trusted device for backward combability. Nonetheless, if a product uses the Wi-Fi seal, it can then function with other devices with the same certification as well as with other devices following recently outdated standards. The project will be designed with these parts to avoid any difficulties when integrating parts to the system. By comparing when Wi-Fi was established back in 1999 until now, prices have lowered and keep on lowering which allows Wi-FI communication to be used in more systems. LAN(Local area networks) allows for devices to be connected wirelessly in many environments.

There were other wireless connections the group considered using such as Bluetooth but Wi-Fi had many advantages over it such as increased transmission range and power, more speed and can manage more devices. One downside of implementing Wi-Fi into the project is that Wi-FI signals can be interrupted by neighboring access points which causes a loss in connection or results in slower internet speed. These interruptions are caused because of overlapping channels in the 802.11g/b spectrum. As a result, data transmission is slower as inaccuracies appear because of the decreased signal-noise ratio.

The tabletop game does not require high performance equipment, it will not transfer long distance data and will not use it hear sources of interference, therefore there is no concern with using Wi-FI technology. One concern for using Wi-Fi is going to be power consumption and configuration. If the system has a large power source, it will be able to maintain communications with devices without any problems because Wi-Fi has strong security protocols which protects users from attackers, although security threats are not a concern to us since the project is a concept-proof type and not commercial so this will not be considered more of an extra rather than a must have feature. The biggest obstacle the group will face when setting up a wi-fi connection will be the Wi-Fi communication between the microcontroller and the devices that are around. Team members will have to do

more extensive research on the communication, one option they found is using automated configuration features, this will allow for a simpler integration of parts.

3.2.3 Bluetooth Communication

Bluetooth is a wireless technology that has been around for more than 20 years. It allows many devices to interact, sync and connect without the need of setting up complex passwords and networks. These days, Bluetooth is everywhere from mobile phones to laptops as well as car stereos. It supports a wide many device and it can be set up in only a few minutes.

More recent Bluetooth versions have made it possible for users to use hands-free phone calls through a mobile device and other examples like connecting to music playlists. Bluetooth technology can simplify tasks, for example, with a Bluetooth enabled printer, one can connect wirelessly with a desktop, laptop or mobile device to print documents. It is also possible to sync a table-style device with a wireless keyboard like an Apple iPad or kindle fire.

Potentially using Bluetooth has advantages as well as disadvantages, the main advantage was connection establishment to be very easy, this can be crucial since having an easy connection can give us more time for other parts of the project such as the interface between the microcontroller and server which could potentially take some time. It also has a lower power consumption unlike a Wi-fi connection. Other advantages include a better range than infrared communication, used for voice and data transfer and the technology can be adapted by many products like printers, webcam, GPS systems, keyboard, etc.

Just like it has advantages over other wireless technologies like WI-fi, it also has some disadvantages. The main one found was that it is very slow compared to Wi-FI,, its data transfer rate will be in the kbs to few mbps compared to a new Wi-Fi module which uses 5GHz spectrum with MIMO technology to achieve speeds as high as 1.3 gbps. This can get complicated when transferring large files so it could potentially make the project interface slow.

Other disadvantages are that it has a very short range, a signal can be lost if the displacement is roughly 10-20ft and it will not be ideal to use this type of connection worldwide.

Regarding the project connection, the group has decided that Bluetooth will be used as a secondary, backup function. They will be using Bluetooth when bug testing as well as for a prototype to test connections. If the team members cannot stablish a Wi-Fi connection, then Bluetooth will be the technology used. The main problem is that Bluetooth cannot be used to play the game because most of the functionality of the device runs through the database and the need for a connection to the internet.

3.2.4 Motors

This section shows research done on many types of motors that could potentially be used to build the XY plotter.

Stepper motors are DC motors that move in discrete steps. They have many coils which are organized in groups that are called “phases”. When each phase is energized in sequence, the motor will start rotating one step at a time.

They come in three forms which are permanent magnet, variable reluctant and hybrid but their functionality is the same. Each winding set is energized one after another, when they are energized it makes the rotor align its own magnetic field with the one that is being produced by the windings.

These types of motors are relatively easy to obtain and less expensive than others. it also has the advantage of having simple controls and it eradicates a closed-loop control system to determine location. Because of these features and the easiness to get the group has determined using stepper motors will be the first option for building the XY plotter

A direct current or DC motor converts electrical energy to mechanical energy. It consists of a rotor, an stator, an armature (coil or wire) and a commutator with brushes.

It is equipped with magnets, either electromagnetic windings or permanent magnets that produce a magnetic field. When current flows through the armature placed between the south and north poles of the magnet, the generated field by the armature communicates with the field from the magnet and applies torque to it. In a DC motor, the magnet forms the stator, then the armature is placed on the rotor and the commutator switches the flow of the current from one coil to another. Once this is finished, then the commutator connects the stationary power source to the armature via the use of conductive rods or brushes. Furthermore, DC motors operate at a fixed voltage.

Acquiring DC motors and spare parts is very easy, they also include easy speed regulations. After doing some research, the group has determine that DC Motors will be a second option in case the group no longer implement stepper motors.

Servo motors are rotary actuators that allows a very precise control in terms of angular position, velocity and acceleration, these capabilities other regular motors do not have. They are different from DC motors and stepper motors because they have a controller as well a set of reduction gears in their housing. It makes use of a regular motor and pairs it with a sensor for position feedback. In these types of motors, the controller is the most sophisticated part of it, since it was specifically designed for their purpose.

There are two different types of servos: Continuous and standard. Standard servos go to a position and keep it on hold until the user sends a new location, whereas continuous servos go to a velocity and hold that velocity. All servo motors require a closed loop control system which consists of external sensors to give it a new position or velocity to match it.

Using servo motors has some advantages for the project, it has minimal noise production which the group has found important since the team want the users to have a focus, in game experience and if there is a lot of noise this could distract players. It also has high seeds, works very well for velocity control.

3.2.5 RF-ID

Another type of technology relevant to use and is considered being used in this project is RF-ID. RF-ID stands for radio frequency identification. It's another form of wireless communication like Wi-fi and Bluetooth which was previously discussed. RF-ID uses the radio frequency portion in the electromagnetic spectrum to work, with the use of electromagnetic or electrostatic coupling it is able to identify objects, like animals and people or other objects. That is how it would be used in this project to be able to identify the different game pieces and communicate to tell them what to do in the software.

An RF-ID system includes three components a scanning antenna, a transceiver, and a transponder. The transponder is the RF-ID tag which includes a microchip, memory, and antenna. An RF-ID reader is what would need to be used for this project because it's portable or can just be attached to the board. The way the reader will work will be by transmitting signals using radio frequency to be able to activate the tag. The tag when activated will then be able to wave at the antenna which then it will be translated into data.

For this project, any of the two types of RF-ID tags can be used. The two types are active and passive. It is preferable for the project to use a passive RF-ID tag because an active RF-ID tag requires that it has its own battery or power supply. The passive RF-ID tag doesn't require any batteries or power supply and instead relies on getting power from the antenna, and the antenna supplies power to it by making a current that goes into it through an electromagnetic wave.

Another type of RF-ID tag that there are is the semi-passive RF-ID tags and this one is a mix of both active and passive filters. The semi-passive RF-ID tag uses a battery or some power supply to power the circuitry and then the communication is processed through the RF-ID reader. A semi-passive RF-ID tag would be useful but is not necessary for the purpose of the project and is probably more expensive than either an active RF-ID or passive RF-ID. Those are the options for the project, but they are expensive choices.

There are also three types of RF-ID systems, they are low frequency, high frequency, and ultra-high frequency. There is also microwave frequency, but it's

not necessary for the purpose of the project. For the purpose of this project only low frequency would be applicable and high frequency can be considered but is not necessary. Low frequency just goes into short ranges from just a few inches to less than six feet at most, which is perfect for the purpose of the project.

High frequency ranges from just a few inches to several feet, which is still useful for the project, but not necessary and probably more expensive than low frequency. Ultra-high frequency and microwave frequency are used to read things that 25 or more feet away. That is extreme and definitely not necessary for the purpose of the project because everything that would need to be identified and read in the board is just inches away from each other.

RF-ID is something definitely being considered to be used in the project, but the main reason that the group is not using it as the main source of communication is because of how expensive it would turn out to be and how complicated it may be to set up compared to the other options of Wi-fi and Bluetooth. It is a very good idea and a good technology that would be useful to identify the game pieces in the game, but if it is too expensive, too hard to set up and not necessary for the purpose of the project. Then there is no need to get it or use it when there is cheaper options and easier ways to set it up.

4.0 Software Design

The overall software design is sectioned between the Web application, the database, and the Microcontroller application. The Web application shall be always synchronized with the current state of the database, and two controls within this system is the end applications of the Web app and controller app. Each can influence the database, and since there can be multiple users performing different actions at various times, a need for a non-blocking application is key to minimize possible errors between the applications.

4.1 Initial design

The initial design is the starting idea for how the software will be structured. With this project, the application must be responsive and be able to receive multiple actions with a minimal error margin. These events can happen at any time, while the only action that is set to be synchronous is the movement of a game piece.

When it comes to movement for most tabletop games, it expects a defined two-part action of lifting a game piece and placing it down in a different location, so any movement action within both applications will be expecting a complete movement action. Other actions such as pinging the map, doing a spell effect, and adding a new game piece can be done asynchronously.

4.1.1 Web App Design Flow

The design flow starts from the very beginning with the user loading the URL of the webpage. The intended design is to go for a single page dynamic website, that won't require the website to redirect or reload the page for changes to update for the client. Since multiple users can connect to the web app, there is a need for a front-end login system, with three types of users. There will be the player, the Dungeon Master (DM), and the admin logins. Once past the login page, the 1st design in mind is to have a single room where all game actions can take place. Future iterations of the application could have a multi-room lobby system, but this design is for a single tabletop in mind.

Once inside the web room, the user interface will clearly portray the different functions that the player can perform. In one section will be a 16 by 16 grid, showcasing the main playing area. Another section contains the player's character information, and below that section has button functionalities to affect the game board by moving their character, pinging the map, or performing character abilities that influence the game board. In the top right will be a logout functionality. This overall design is portrayed in Figure 4.

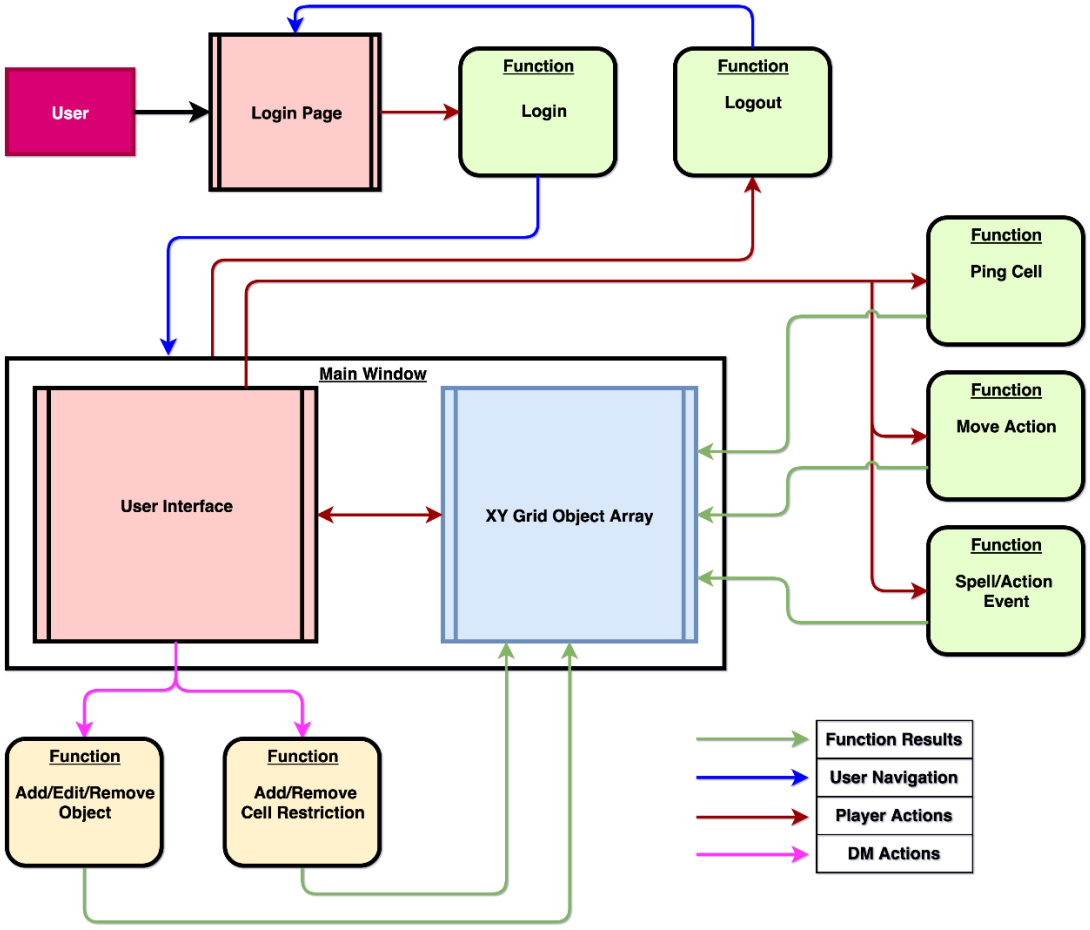

Figure 4: User Software Block Diagram

A DM will have extra functionality that a regular player can't perform. Their privileges allow all the same functionality of a regular players, with the added benefit of being able to move any character's or tokens on the game board. They also have an assortment of extra functionalities they can perform. They can designate grid spaces to become impassable or clear at any time, to simulate a map change. Some examples include exploring a cave system and finding a dead end, simulating a trap, or supernatural obstacles. The end effect is to have a grid space become blocked, so that the player will have to be creative or navigate the obstacle.

Another features the DM will be able to perform is to add or remove tokens on the game board. If a token is added on the tabletop application, a prompt will display on the DM's user interface to confirm a new token. If accepted, this token can be given attributes which contain the name, health points, armor class, and speed. This feature implementation is further explained in detail in section 4.3.5, while how this data is handled is within section 4.5.4.

4.1.2 Tabletop Application Design Flow

The design flow for the Tabletop application depends on what microcontroller the group will utilize. The first choice was a Raspberry Pi, but after careful consideration on pricing and the functionalities the group would need, the group has opted for the Mega Arduino 2560.

The Tabletop application is a two-part software scheme. One is communication API, where event communication and data manipulation are performed, and Input and output block, where sensor and control actions is performed. The application will always be in sync with the database and socket connections is used for functionality transmissions.

When a move event is transmitted through socket communication, it references the database, retrieves the specified path plan, and sends this in a proper format to the controller to perform the XY plotter positioning moves. When a ping or effect event is received, this translates to a LED action where the computer references the database for the proper LED array, and sends the data to the microcontroller's LED control for proper utilization.

This representation of the various blocks of the software is displayed in Figure 5 below.

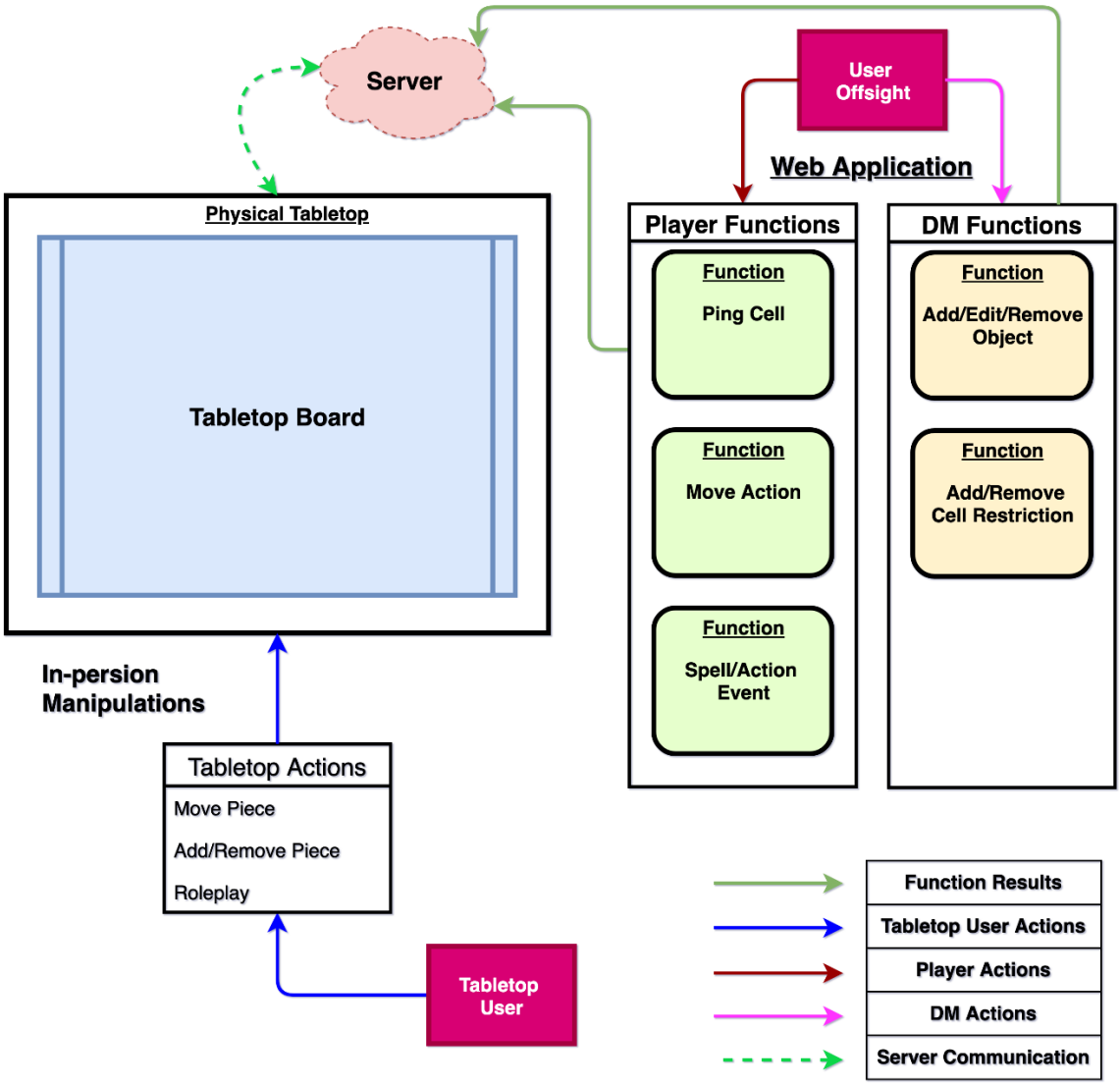

Figure 5: Tabletop Block Diagram

4.1.3 Front/Back End Design Web Frameworks

Various frameworks were researched for web application, and the tabletop application. The group want a responsive and well documented framework, and research went into Model, View, and Controller (MVC) frameworks. Another line of research is done into Model, View-Controller, View-Model (MVVM) Frameworks as well. They both serve as very reliable web frameworks for the job that the group wants done, but when it comes to specific functionalities, the group wants to to go with the best framework in the beginning to reduce development time and improve scalability. The primary goal is to create a single page application and have real-time communication between the web app and the tabletop app.

The initial choice is to go with an older model such as MVC, where the framework is designed for modularity and ease of development. One example of an MVC framework is CodeIgniter. It is widely used framework that can do the job for the web app, but primarily runs as a WAMP stack. For the project, the group has decided for higher performance and asynchronous communication.

This direction pointed me towards using a backend that utilizes node.js. Using NodeJS will allow to do both the front and backend with only JavaScript and without the overhead of other programmers having to learn backend-based languages such as php. The database will also involve using MongoDB over MYSQL, due to JavaScript being a good cross platform language and not having to learn SQL is another perk of using the database choice.

4.2 User Interface

The web application user interface is one of the most important elements on the project since it will be the portal in which all users will interact with the board and receive feedback.

It displays all the functionality in such a way that it can be easily understood and performed with little to no training, as well as being a hub to receive all changes that occurs on the main tabletop application. There are different ways to interact with the board system, for the project the group will be considering two different approaches and see the advantages/disadvantages of each when it comes to how users will be able to interact with the system.

The first approach is command line interface, out of the four options discussed this is the oldest method of use interface. It involves the computer responding to commands that are typed by the operator. For the project, this type of interface has the drawback that it requires the operator to remember a range of different commands, this makes it very difficult for novice users to manage. Therefore, unless the other user interface methods do not work, the group will not be implementing this type of interface.

The second type of user Interface is Graphical UI. It is also referred as WIMP since it uses Windows, Icons, Menus and Pointers. The operator uses a pointing device (such as a touchpad, mouse) to control a pointer that is on the screen which then interacts with other elements on screen. This allows the user to interact with devices with graphical icons and visual indicators. Using this type of interface has some advantages as well as disadvantages which are explained in Table 23 below.

Table 23: Graphical UI Advantages vs Disadvantages	
Advantages	**Disadvantages**
– Relatively easy to use, ideal for a beginner.	– GUIs take a large amount of hard disk space compared to other interfaces
– Easy to explore and find way around system using the WIMP/GUI interface method	– Need significantly more memory(RAM) to run compared to other type interfaces
– No need to learn complicated commands	– Use more processing power compared to other type of interfaces
– Help system available within the WIMP interfaces	– Slow for experienced programmers. – If experienced, CLI interfaces are better
– Allows you to exchange data between different software applications	

4.2.1 Web Application User Interface

A client/server program which the client can run in a web browser is called a web application. The web application is delivered to the client through the internet using a browser interface. This design is delivered to the client through internet using a browser interface.

Since the web application will run within web browsers, there will be no need to develop web applications that are compatible with multiple platforms since the application depends on the browser and not the OS. There is a long list of frameworks and libraries the group can use in order to develop the web application in an efficient, fast and convenient matter. After doing some research, the group will discuss the best UI libraries that were found that could potentially use for the web application.

The first one found was Kendo UI, it is a JQuery-based development framework. It is a collection of scripts, styles and images. When installed, the team members receive a lot of JavaScript files, stylesheets, images into the project and Kendo UI leverages them. The group is considering using this UI because it will allow us to build modern web applications very quickly and very easily as well. It has over 70 UI components, a customizable and preconfigured theme and built-in support for

Angular 1.x. Kendo UI provides all the tools needed in one package so there won't be any need to download many libraries to make the web application look better.

The second framework the group has found was angularJS, this HTML is very good for declaring static documents. It lets the group use HTML as the template language and extend HTML's syntax to express the application's component clearly. AngularJS is great because it simplifies application development by presenting a higher level of abstraction to the developer. On top of this, it has an improved server performance since it supports caching and many other processes. This framework although it has excellent tools to help us with the project, it also has disadvantages that come along. The first one being that it is difficult to learn, it has a limited documentation available which affects the learning process. It also has not been built for mobile devices, since the project is featuring a web application, this framework could potentially not work.

The third and last framework we found was Bootstrap, it is an open source tooklit for developing with HTML, CSS and JavaScript. It allows us to quickly prototype ideas as well as build the entire web application with their Sass variables and mixins, extensive prebuilt components, responsive grid system and powerful built on JQuery. Since Bootstrap is a good candidate for a framework we will use, we have done some extensive research and found the advantages and disadvantages of using it which will be discussed below in Table 24.

Table 24: Bootstrap Pro's and Con's	
Advantages	**Disadvantages**
Great Standardized platform with all components and basic styles needed	Styles are verbose, can lead to lots of HTML outputs not perfectly semantic
Supports all major browsers	JavaScript is tied to JQuery
Fixes CSS compatibility issues	Requires lots of overriding styles or rewriting their files if many customizations were done.
Consistent UI, looks good out of box.	Websites look the same if colors and styles have not been customized too much
Lightweight and customizable files	
Designed with responsive structres and styles for mobile devices	
Several JavaScrip plugins included	
Good documentation and community support	

Lastly one more framework the group found helpful was Vue.JS. It is an open-source JavaScript framework great for building user interfaces, websites as well as single page applications. It features an incrementally adoptable architecture that focuses on component composition and declarative rendering.

They found many good reasons to consider using Vue.JS as one of the frameworks for the web app. It provides very good performance, very easy to start with and offers plenty of essential features out of the box thanks to its component

library based on HTML, CSS and JavaScript. It has a routing and data management covered by official libraries. It is very flexible to design the app structure any way we want it and thanks to its reactivity, data binding between HTML and JS code is easier than ever.

Just like it has advantages, we have found some disadvantages for using Vue.JS. The first one being that it is a relative new platform and therefore it has a small community. It is not as popular, and most of its users are non-English speakers, this could be troublesome in case we need support. It can also have Over-Flexibility since it has so many options within its framework but for the project since it is considered a bigger project it can over-complicate it and lead to more errors and irregularities within the code, which can make the project delayed and more expensive

When discussing the type of frameworks, we will use. We believe Bootstrap will be the most appropriate due to its many advantages it has over the others. We will start off making a prototype of the project and with Bootstrap it will allow them to quickly build it without having to spend so much time and money. Due to its great community support, we strongly believe we will be able to get help from the community in case we run into any issues.

4.2.2 Layout Design

The Layout of the software will have the login screen, which on successful user verification, lead to the main user interface. The initial design of the interface will have three main sections. These three sections have subsections for proper layout of the different functionalities and will expand or contract with all the content being displayed properly. The range of display ratios should accommodate for different devices, ranging from desktop computers to smart phone displays.

The biggest section layout is the 16 by 16 XY grid display. This display will contain all the game objects that are currently on the board, such as creature's, user tokens, and grid space obstacles. Each grid square is interactable, depending on the selected action or pointer event. When an game object is selected, a pop-up module window will appear next to that object if it can be modified by that current user. Selecting the object also displays any accessible data on the user information panel, which is explained further ahead. Each game object is color defined by their classification, in which green is the current user's game object(s). Blue defines game objects controlled by other players, while red and yellow defines hostile and friendly NPC's respectfully.

These actions events are within their own section, which is called the game control panel. This panel has separate sections for the types of users. Regular players can only use their specified actions, such as shown in Figure 4, while GM's will have an extra set of tools that they can use. These extra tools are not visible to the regular user.

Another main section is the client connection window. This section keeps track of all connected clients and updates its list when a new user logs in or when a user logs out. This can be done by either closing the window or pressing the logout button that will be placed at the top right of the browser window. This window also serves another purpose to show what type of user privileges that user currently holds. User permissions are fully covered in section 4.3.5.

The last main section is the user information panel, which displays to the player the character data of selected game object that are on the board. The regular user can only see information on objects they own, while GM's have access to all available object data that is on the board at that time. The representation of this user interface is displayed in Figure 6 below.

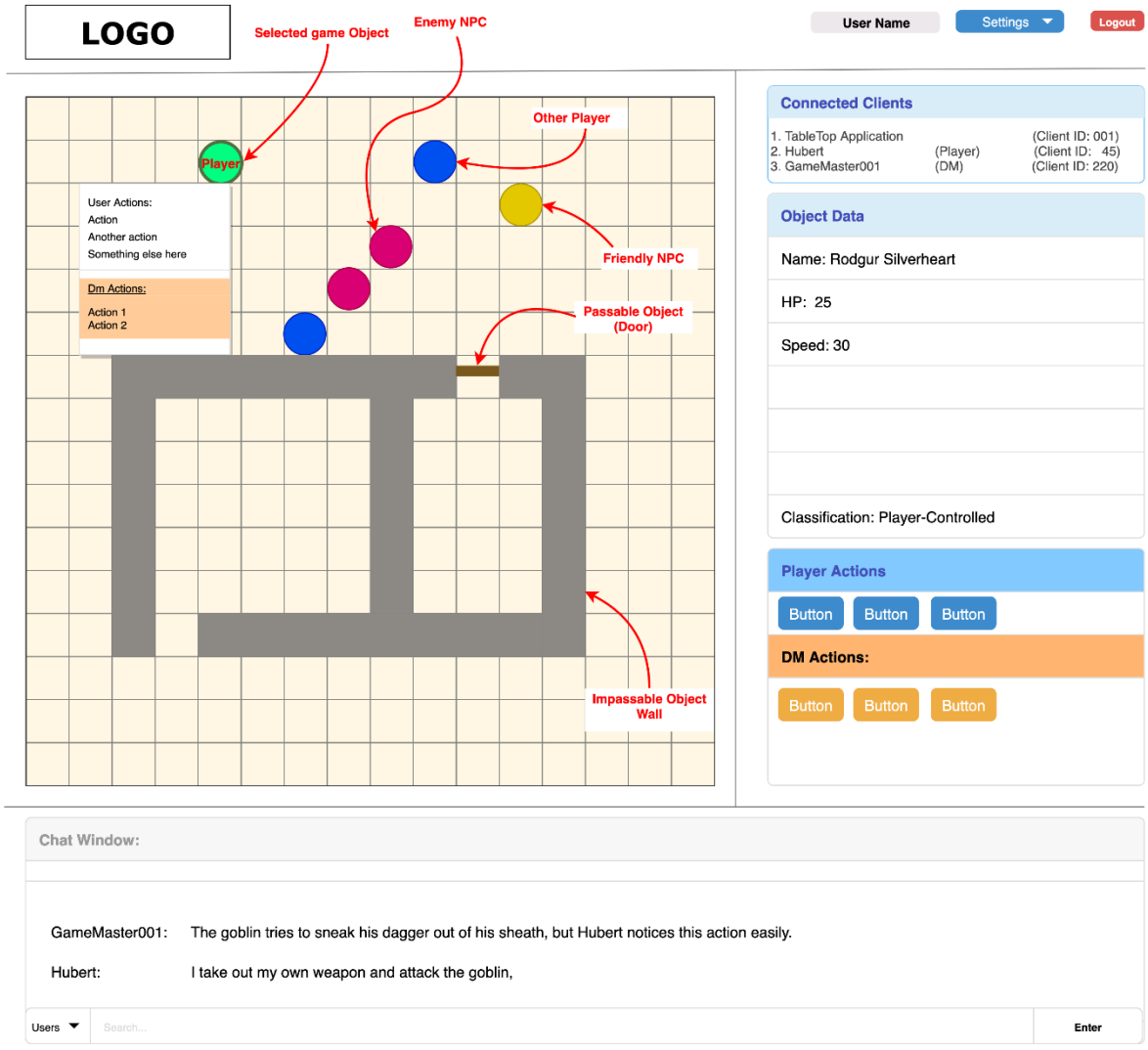

Figure 6: User Interface (Version 0.1) Diagram

This diagram is the first iteration on how we would build the main interface where most of the events will take place. The theme and various elements are not

considered final, and some functionalities will be removed or added as development progresses. Implementation of front-end libraries, such as Bootstrap, will help speed up this task and help in refining the user interface to its final version.

When it comes to user's arriving at home page of the web application, they will first arrive at the login screen, where proper credentials will be needed in order to progress any further. This window will contain the basic requirements of a login screen, which includes the username, password, a confirmation button, and a register new user button. When a new user is made, all passwords will be hashed/salted to secure the user's account and the user will be able to log in right after registration.

4.2.3 XY Grid Array

There are 256 objects in the grid array, each has several properties including mainly X/Y coordinates. An array will be designed to holding the statues of all 256 game pieces squares. When designing this array, it will be set up so that a "1" means that a game piece is in that location and a "0" means the location is empty. Applying this reference the microprocessor will very if a game piece is in the destination place or not. If the destination place is empty then the game piece will be moved directly to it and if the destination place is full the game piece that is occupying it needs to be removed first.

This method of using a "1" or "0" for every statue in each square is very common and straightforward which is why it is being considered. We may however implement a more sophisticated approach that could allow more flexibility in the game engine.

The amount of game pieces or objects on the board could possibly reach the amount of grid space we have but it is not a typical number a game usually goes through. It will most likely reach an estimate 20 different game objects in one session. Below is Figure 7, with a graph displaying the 1 and 0 method for empty and full squares. For each empty space a 0 is in place.

1					1					1					
		1					1								
											1				
					1										
												1			
1						1									
				1						1					
														1	
1		1					1				1				1

Figure 7: 16x16 Grid Array

If there is a game piece in the destination square, the database needs to remove it. We will call a function “MOVE” by the main program. It will receive three different values necessary to remove the game piece that was in place to the graveyard. The initial and final coordinates for the game piece will be discarded as well as the initial coordinates of the XY plotter. It will start off by first receiving the current location of the X/Y plotter. Secondly it will receive the coordinate for the piece in hand, with this coordinate now the software can calculate how far it must go in the X and Y direction and the order in which it is going to make those moves. Once it follows these steps the X/Y plotter will be positioned directly under the game piece to be discarded. Once this occurs the magnet will remain in an up position and will remain there until the game piece has been discarded.

For the graveyard, their coordinates will follow the same steps as when a game piece is removed by calling a MOVE function destination. The X/Y plotter will then move the game piece to the graveyard. Once this process is finished, the memory that contained the X/Y coordinates location will be now updated to the graveyard’s coordinates. After this the software can now move into the empty statues.

Although the move function will be implemented for moving pieces to destinations that are already in place, for the game itself game pieces will be moved but not into each other’s destination since the game works in a way that it Is a cooperation-type game rather than an elimination-type. For the empty statues, they will be

reached when either the destination statues was empty and the program moved it there directly or the destination was full and the program executed the previous program described to move the game piece to the graveyard and make it empty. The MOVE function will retrieve the initial coordinate of the X/Y plotter as well as the beginning and destination point of the game piece to move it to an empty square. This function will be very useful into the game since we will be moving game pieces throughout the game to new empty place.

4.3 Game Piece/Action Control

Game Piece and Token control is a cornerstone requirement between the web application and the tabletop application. All actions and events are associated with an object.

4.3.1 Piece State

A game piece or token will have various modes to represent its current state. These states are displayed in Table 25.

Table 25: Game Object State Table

State	**Description**
Standby	The object is waiting for the next event.
Executing	The object is performing an event.
Move	The object is in motion.

When an event function is executed for a game object, the database is referenced for what state the object is currently in. If the standby state is confirmed, then the type of event will be performed as well as updating the object to the execute state. If this event is a movement action, the game token and the tabletop piece perform verification if they are in their proper locations on the board, then updates their object to the move state. After the performed event, a finishing action will prompt the Tabletop app to update the game piece state to the standby state. Further detail on placement verification and movement is explained in their dedicated sections.

4.3.2 Piece Placement

Tracking piece placement and new game pieces will be all considered single actions. A new detected piece on the tabletop grid square will prompt a notification window asking for confirmation that this is a new game piece. Implementing movement of a game piece can be done via dragging and dropping the token which is explained more thoroughly in section 4.3.4.

Piece placement will be verified in through the tabletop application, but all placement data will be referenced through the database. The reason why the tabletop app is the main device is that the board is where most of the action takes place and where game pieces can be interacted with without having to verify the server beforehand.

4.3.3 Piece Selection

For this project, one of the requirements is to make sure real pieces will be moved without the player touching them. The pieces will be placed through the board and the player will be able to move them by using the web application. The web application needs to be synchronized with the table top application. For any type of changes the player makes the database will be utilized, where it will record where the piece is placed and its movement and repeat. Once the game is over the database will clear all the game actions.

The player will be able to select their game piece from many options given, once the piece is selected the database will record this information and as previously mentioned, record all movements made by the player. There are a few ways to verify that the selected game piece will be synchronized, and this is represented in Table *26* below.

Table 26: Game Piece Verification Comparison Table

	Magnetic Assumption	RFID
Pros	• Magnetic fields can be utilized in movement and sensing • Easier implementation	• Unique identification • Identification between data and object is assured.
Cons	• Piece data can possibly reference the wrong object	• Extra API utilization • Can only be used to sense the game objects • Extra expenses towards chips and chip readers

The first solution is magnetic assumption, where the game pieces locations are saved in into the database, with the game object data associated with that grid position. Whenever there is a change to the objects data, the database will reference the location to verify if that selected object for change is in its correct location on both boards. This can be done by making checking if there is magnetic field triggering the sensor on the grid position, as well as checking the array position on the web app. This verification process will make sure that the state of the board is consistent and reliable between the devices.

The 2nd solution can be RFID, where each game piece could have a RFID chip at the bottom of their base. This can absolutely make sure that the object data is associated with the correct game token or piece. This direction though introduces another API that would have to be programmed to read the RFID chips and adds a layer of difficulty to identify various game pieces. This also means that we would need chips for each game piece and the readers on every single grid square, which increases the expenses dramatically.

The chosen solution involves using magnetic fields to detect the various pieces that are placed on the physical board. This means that game pieces that have been placed on the board will be assumed to be in their correct positions to match the game data that is associated with them. Making sure that the game pieces are matched correctly is solely up to the group who are currently playing in that game session with the physical tabletop board. The algorithm that will make sure that game pieces are in their current positions cannot differentiate between different magnets that are placed on the grid spaces. Even with this drawback, using magnets allows the game pieces to be manipulated with the XY plotter that will be placed beneath the board.

4.3.4 Piece Movement

When it comes to moving the pieces on the physical board, there are elements that need to be kept in place. All pieces will have to move without collisions or changing the location of the other pieces in the board as it would affect the current locations and cause errors to the software that handles pieces location. The Movement system will be either kept small so that the board doesn't become unwieldy or utilize an algorithm that can take into account all the obstacles that are in place upon the board.

For the pieces to be able to move as indicated by the player, the system will be interfaced with a microcontroller who will connect with the XY board to simplify the number of possible moves that are available for the piece in place in any situation, will also give direction of starting and finishing positions.

Once the movement system is in place, it will be able to work with the surface underneath the board itself. It must also not interfere with any other systems that are in place such as the LED's and sensors. The goal is to make the movement

mechanism to be hidden during play so that the game has an extra touch of realism and does not disturb or distract players.

When it comes to executing the piece's movement, the flow chart within Figure 8 below displays the actions and requirements that will need to be done and fulfilled to make sure that the piece be repositioned correctly. Each action is considered a function or a physical action and is displayed at a high-level design. Each function stated within the flow chart that can be considered to have multiple actions needed will be explained thoroughly below.

For the Send Web Socket event, this will involve a communication API where we will establish a socket connection with the web server and be assigned an ID per connected application. For this piece movement, the starting situation determines on when the event is sent. If the movement starts from the physical board, an initial socket event is sent to the DM to verify if this a move or delete operation. This single action has operations involved with Section 4.3.5, since a physical move requires a person to remove the game object off the board in the first place.

In the situation where the piece is slid around board to facilitate a movement, this can possibly trigger multiple sensors and at the same time give multiple event notifications. To combat this possible bug, clauses can be put in to only record a single operation at a time and to add certain time limit to the final placement of a game piece. To explain, if a game piece is removed from its starting position and placed on a different grid location, the web application will wait for a certain amount of time before finalizing that the position is the end point and then calculate the valid move event, which checks for obstructions and the amount of squares that were traveled with the pathing algorithm. Since there is only going to be a single move action that can occur on the application,

The full description of the Web Socket Communication is covered in Section 4.6.1.

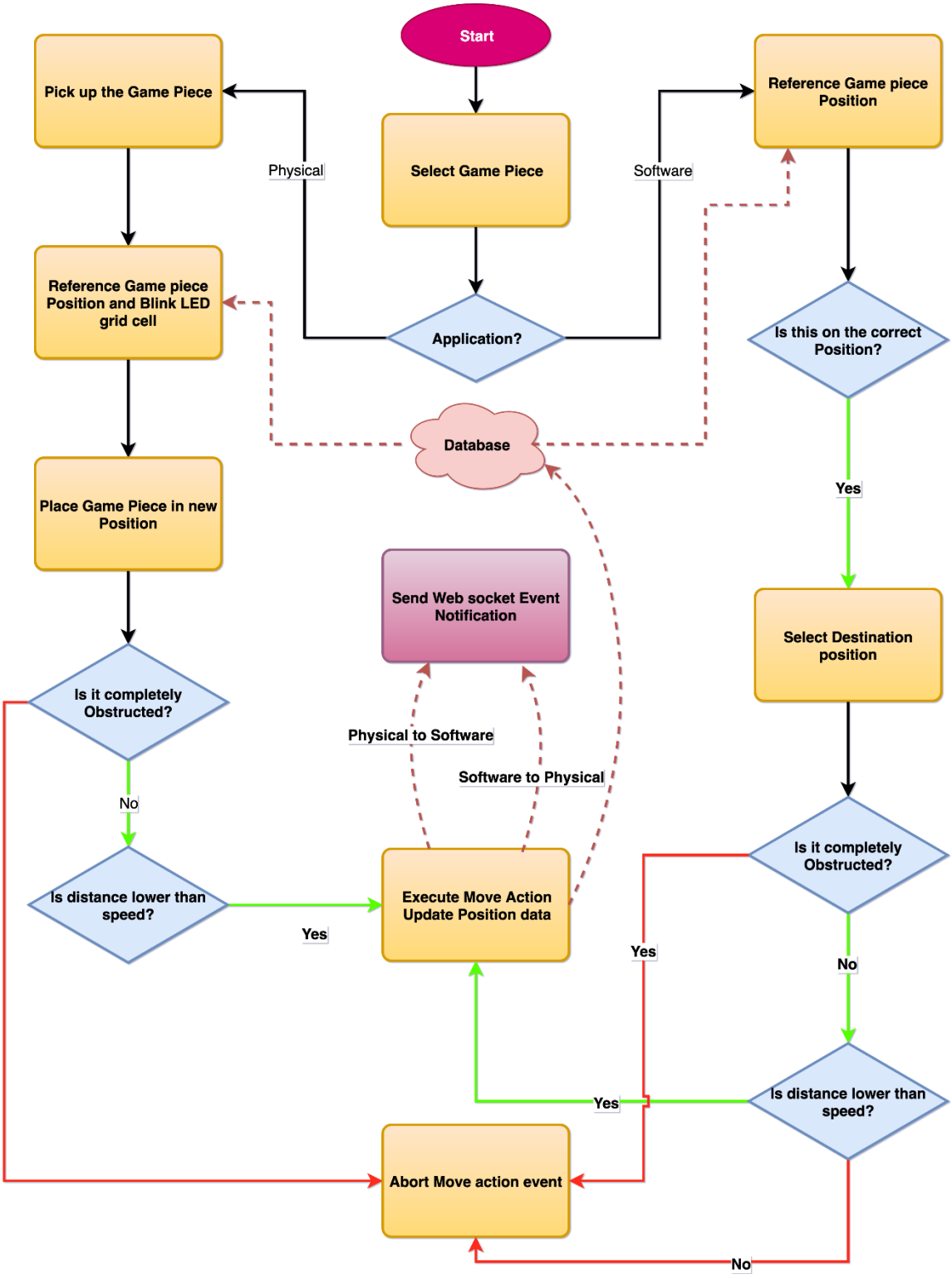

Figure 8: Move Event Flow Chart

When a game piece or token is selected to be moved across the grid, the type of event flow depends on what device we are trying to move the object across. If we

are attempting to move the object across the tabletop application, it follows a certain set of events and then checks if this event was a correct action. This set of checks is matching how the web application deals with piece movement, but the final results of rolling back this action is done differently between the two.

Since all specifications have been established previously, we will now discuss how the software will be set up for what has been discussed. The microcontroller must receive first the beginning and final coordinates of the piece that is going to be moved as well as the current coordinate of the XY board and the statues of the final destination square. Once all this information has been received and processed by the micro controller it is now ready to begin processing all data received. First off It will start at looking at the destination statues, If the status returns 1, the software will read and follow the full statues code and continue to the empty statues code. If the status is ‘0’ then the software will read and go directly to empty statues and skip the full statues code.

4.3.5 Piece Modification

Modifying the game pieces can happen on both the web application and on the tabletop. If the DM adds or deletes a token on the Web application, this adds or removes the appropriate field within the database, in which the Tabletop application will pick up as a change to the physical game board.

One solution to match the tabletop to the web app board is to color code the removal and add action. A green blinking LED will symbolize an add action, while red blinking symbolizes the removal of a game piece. To see this represented implementation, refer to Figure 9. Red Dotted lines indicate that the origin of the request was from the physical tabletop, while green dotted lines are sourced from the web application.

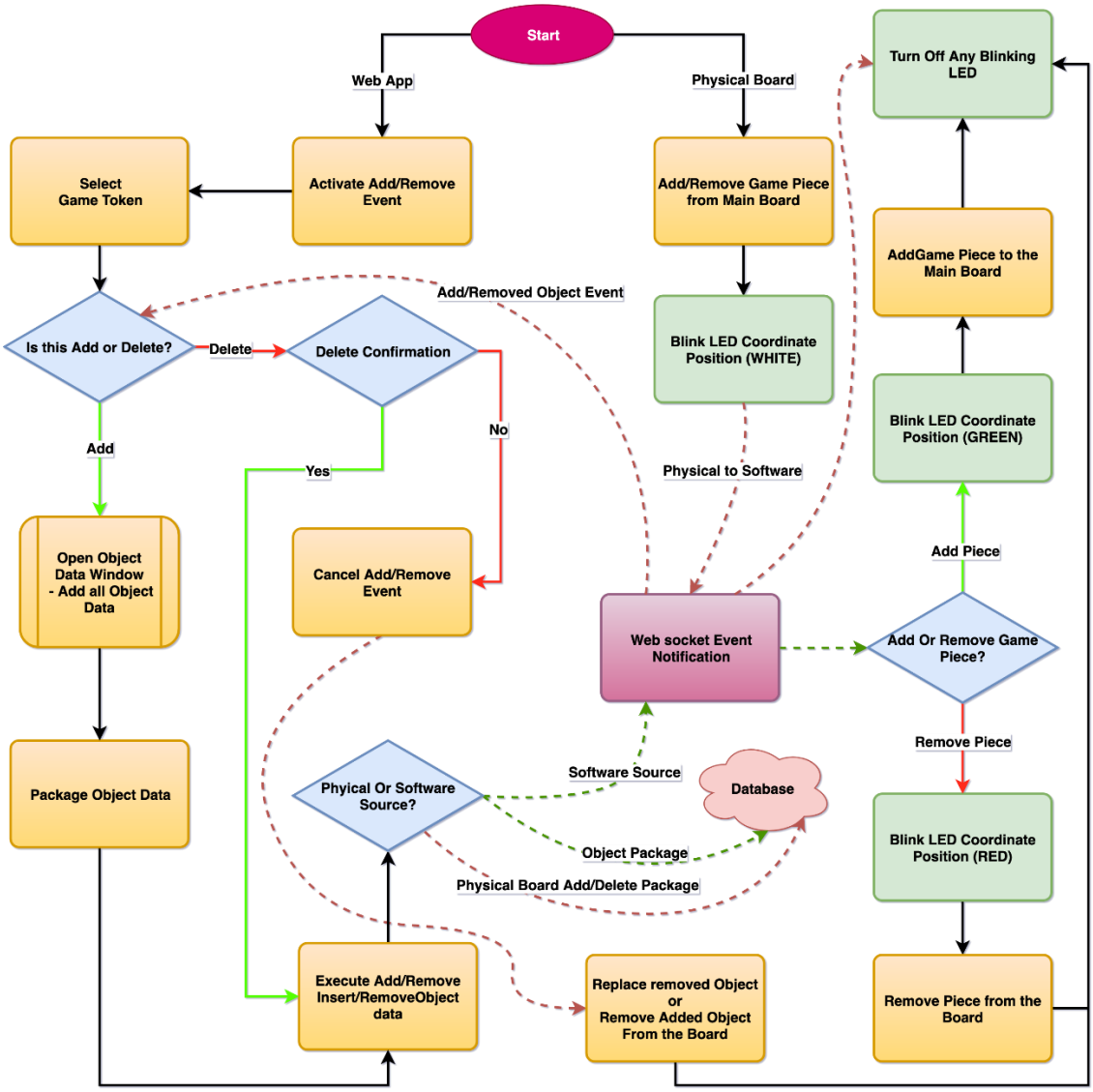

Figure 9: Piece add/remove Tabletop LED procedure

Figure 9 contains many high-level elements to reduce the number of events that could be shown within this flow chart. At start, the action that is committed is done on either the web application or the physical tabletop application. For the web app, you must select an object or space on the grid board and activate the add/remove functionality that will be displayed on the user interface. This display representation calls back to the user interface on Figure [#], where the add and remove buttons is shown in a section that pops up at a game object selection. Activating either functionalities puts application into a ready state for input data or deletion confirmation.

On adding an object, a display window will pop up in the middle of the screen where you can input the object data. Only the DM will receive this notification and is the only one who can input new data into the database. The different data types

are shown in section 4.5.4, and is the required data needed for the game to progress smoothly without adding optional data types and fields. Once the data is inputted and is confirmed by pressing the finish button, then the data formatted and packaged into a json. This data package is inserted into proper table or collection, and assigned a unique Id, while a data insertion confirmation is sent back to the web server. From this point, the webserver will send a socket event to all connected clients on the WebSocket to update their grid positions by referencing the database. For the tabletop application, this socket event will also contain the addition info and coordinate position that needs to be updated. This is done by activating the LED position id with a green light and wait for a new reed switch activation on that position. Once the game piece is placed on the board and triggers the reed switch sensor, the new grid object position is complete, and a deactivation event is relayed to the LED to turn off.

Adding an object straight away on the tabletop application makes the events flow in a different way, but ultimately ends up going through the same process of inputting information of the object on the DM's client. The process of adding the piece on the board on the final area can be considered as a final check if the game piece is in the proper grid position.

Deleting a game object goes through shorter algorithm but still requires multiple checks to make sure that the action that is occurring is a final choice. On the software side, it moves straightaway into a confirmation window if you are sure you want to remove the game object and piece, while on the hardware side, it sends a event notification over the connected socket to the DM's web application for confirmation.

4.3.6 Path Planning

Each path the software creates can be broken down into either the entrance/exit of the game piece and its displacement on the XY board. To set this up, we will use a main grid. This main grid is composed of two different grids which are the minor and major grid. The minor axis will be used to direct the entrance and exit portion and the major axis will be used for the X/Y displacement.

We will start off the software by testing Xfinal and Xinitial with each other so that we can see whether they are equal or if Xfinal is less than or equal to Xinitial. The same test will be made on the Y axis. Each combination between them will give up to eight possible outcomes. Each combination has a set algorithm that will allow for a path to be created.

For the X/Y displacement, once we game piece is on the grid it can only move on the X and Y direction. For the exit & entrance the game piece has only 4 possible directions in which the game piece can enter or exit any of the squares on the board.

When it comes to navigating a game object on the board, we must worry about obstacles and designated static grid spaces that are considered impassable. Moving a physical object on the board can have possible collisions with other objects due to the XY plotter not being capable of considering the surface obstacles. So, a path plan must be made at every move action that is considered final. This path plan is not implemented when doing physical movement actions from an exogenous event, such as a physically present player moving their game piece.

One possible solution for pathfinding is implementing a method such as Dijkstra's algorithm. It performs everything required, from finding the shortest path from the starting point to the goal, while taking in account obstacles that are in the way. It is also one of the simpler algorithms to implement, so that can help towards time considered in the development. The biggest flaw that Dijkstra's introduces is that in the worst-case scenario, in which there is multiple large obstacles and the goal position is far, the algorithm is very computationally expensive.

A solution to solve this worst-case scenario is to use a best-search-First method combined with a heuristic, such as the A* algorithm. It is a very efficient method to get a comparatively good path compared to Dijkstra, in a short period of time. This outcome is good for the application, where this algorithm will perform its calculations on the microcomputer. This algorithm can significantly improve the response time between different moves, but when it comes to implementation, the algorithm can be complex to program. A comparison chart between A* and Dijkstra's algorithm showcases the pros and cons between each method in Table 27 below.

Table 27: A* and Dijkstra's Pros and Cons

	Dijkstra's	A*
Pros	• Finds the best path from entry to goal • Easy implementation	• Fast algorithm •
Cons	• Computationally intensive • Exponentially slower	• Difficult to implement

The planning algorithm chosen as the final choice is A* to calculate pathing. It has the speed advantage over its counterpart and less intensive in its operations over long distances. This algorithm is very popular in different applications and including in a library that has this algorithm can make code implementation much easier.

Some issues that was initially addressed is if we should allow the algorithm to include diagonal movement across the grid, how it would interact with the different game pieces that are currently on the board, and the possibility of it triggering multiple grid sensors at the same time. D&D allows diagonal movement which is a requirement that the application would have to follow. Solving this problem could involve adding a different type of movement that the XY plotter would have to execute, where instead of orthogonal movement, we would have the included diagonal movement.

Since we would have eight directions to travel from a grid space, we could trigger sensors that are not in the direct path of the game objects travel plan. This can be solved so that while the XY plotter is in motion, triggered sensors during that duration will not be tracked for any events. This though would assume that the game piece will arrive at its destination coordinate, while disregarding possible problems such as collisions.

When it comes to collisions, the pathing plan will take care of possible head on collisions. What it cannot plan for is possible indirect collision on game objects that are sticking out in various directions above the grid square. One way to take care of collisions is to follow the sensor plan for piece movement on section 4.3.4, where it goes on keeping the tracking sensor detections but will have a delay on the destination. The plan can be to add on top of that, where if any game objects near the path plan is suddenly detected on a different grid location, it can mark the original locations with lit LED’s and ignore the new triggered sensors. Once those marked sensor locations are all triggered and after a small delay to determine the final movement, the tabletop application can go back to being in a ready state. This flow is represented in Figure 10 below.

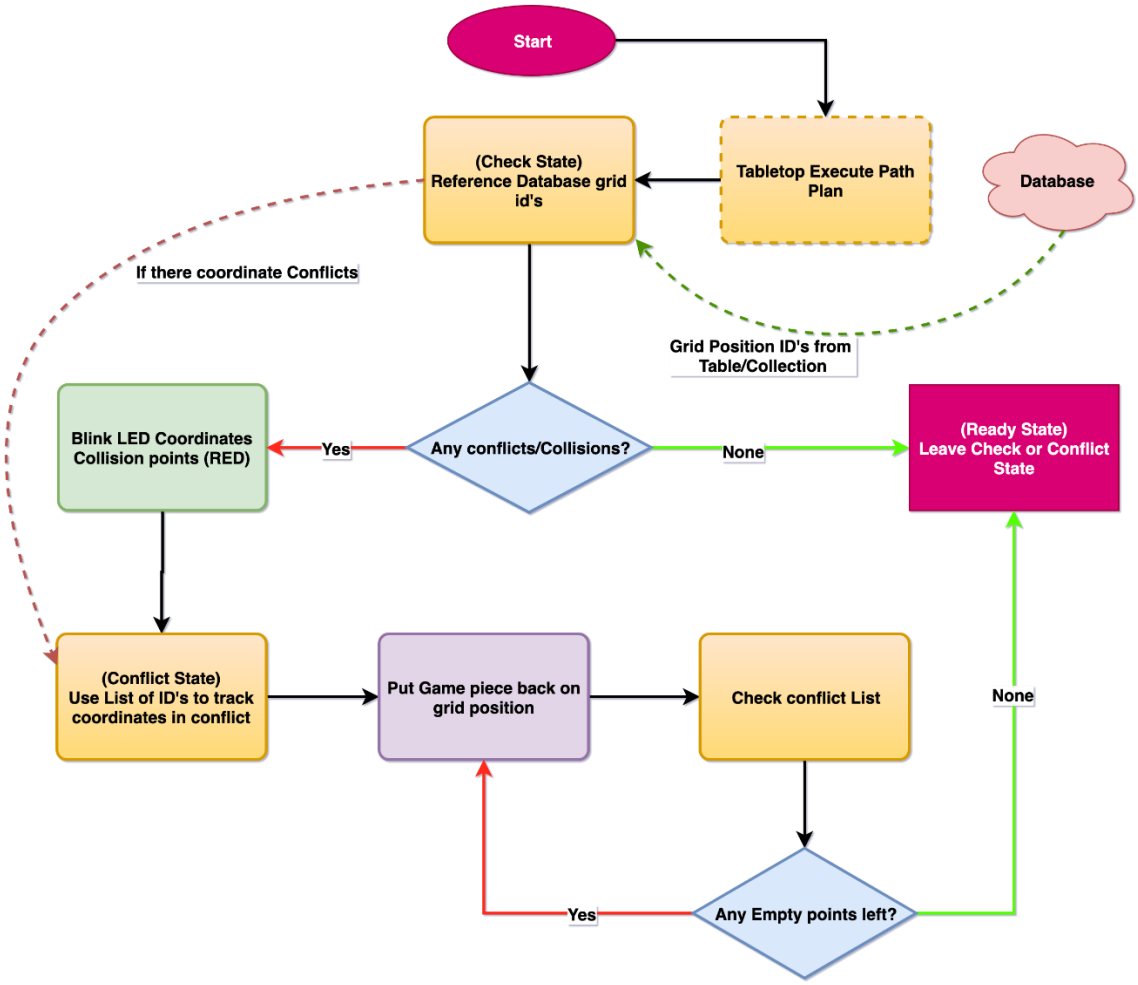

Figure 10: Collision Conflict Correction

4.4 Server Hosting

How the data is stored is important in making sure that all the assets and game objects are synced between the two applications. The main reason why we are going towards web hosting is to allow the web app to be useable in all devices. This means that the layout of the web application is key to making sure that all functionality can be accessed with little difficulty. Pricing is also very important due budget constraints and we also are not computing large data packets.

4.4.1 Hosting Platform

A Variety of platforms were researched for hosting the webserver and database. Since the requirements call for a real-time application, and preferences towards a JavaScript based backend, we looked at node JS as the webserver and MongoDB as the database. They also need to access to the server for custom installations and configurations, so for most hosting services, this is not allowed by default. We are also looking at having a solid web development stack so choosing a service

that can support a solid package is preferable. Price is a major factor that has to be accounted for as well.

The choice of going for a Platform as a Service (PaaS) or Function as a Service (FaaS) depends on the usage and the development of the application. FaaS architecture requires a different methodology of designing the backend, so sticking with a more traditional architecture and host platform will smoothen the initial development.

The first hosting service the group looked at was HostGator. It has its options at a very cheap price level and their services allow for easy setup. Included into their service package is NPM, which allows for various modules to be installed in a simple manner. The downside to using HostGator is that their pricing model for using these services is too expensive, since you need a VPS package or a dedicated server package.

Heroku was another hosting platform that was considered for the web app. It has a free plan and is great for small projects. The free plan comes with 512 MB of memory, with a given sub-domain. This free package comes with a few pitfalls, such as a single user access to the NodeJS server and 30-minute inactivity timeout. This restriction on users does not fair well with the team, since multiple people will need access and slows down development.

Another service that was noted is A2 Hosting. It has specific plan options for NodeJS hosting and its pricing is affordable. It integrates cPanel access, which would allow for simpler navigation of the server elements. One of the biggest perks of using A2 Hosting is that all their packages contain unlimited storage and bandwidth. Its great for future expansion if further development is made on the application.

NodeChef is specifically for NodeJS and utilizes Docker containers. It showcases its dynamic system to using their services and scaling up resources when needed. One great aspect of Docker is that it allows for an easier learning curve for its setup and is great for development teams. One example is its straightforward method of having its local environment closely matching to the production environment, so that integrating the newly developed container full of feature changes will be as smooth as possible.

AWS (Amazon Web Services) is another direction that the project can go for hosting. The amount of resources and support is top-end and the multiple options for Node JS setup, such as using Amazon's Elastic Compute Cloud (Amazon EC2). Another option is to use Amazon Amplify, with both choices helping in deploying the application faster, with the 1st choice more suited for large data analysis and processing. Amazon Amplify provides a full work flow for git development and full stack serverless applications.

One other hosting service that has been factored for was Microsoft Azure. Its powerful features allow NodeJS deployment to simple through containers such as Docker or Kubernetes. It also integrated Visual Studio Code within its build process and extends the development process with built-in git processes. It fits all the requirements except for pricing, which is priced by hour or by month, and is to expensive for the budget.

The last service that was considered is RedHat Openshift. It allows for three simultaneous processes within Node JS and it is part of its free plan. This also includes 2GB of memory, so for the usage it is considered fair since we are not dealing with heavy data manipulation. The downside is the 30-minute inactivity timer, as well as having a Maximum active usage timer within a 3-day period. Gaming sessions within D&D can easily reach 6 or more hours of usage per session and can happen at any time. This would mean this service would be more fit for long downtime sessions and will not be able to accommodate multiple sessions per day.

When it comes to choice, A2 Hosting and NodeChef are the top choices to go with due to their competitive pricing and features.

4.4.2 Web Server/Stack Selection

Node JS will be the chosen webserver to utilize a single page web application. This decision was done after analyzing the functionality of using an apache-based web server, and its capability in solving the issues that will be involved with the project. It is fully capable of being the back-end that can support a dynamic and modular web application, but to utilize that full functionality would require a lot of complex programming and 3rd person libraries and API's.

The web developers who would be working on the backend would have to integrate PHP, JavaScript, and HTML in a cohesive manner without causing bugs or extra issues. This extra overhead will introduce more development time, so the choice of sticking NodeJS will eliminate one programming language we would have to learn. The following table displays different web stacks which includes the advantages and the disadvantages in terms of learning requirements, different functions from web stacks.

Table 28: Web Stack Comparison Table	
LAMP	– LINUX, APACHE, MySQL, and PHP. – open-source coding framework and free for users. – Multiple languages to learn can increase learning curve.
MEAN	– MongoDB, ExpressJS, AngularJs, NodeJs. – Popular with various computer science and engineering fields. – Relatively new software stack – Smaller community of developers could mean less support.
METEOR	– Possible second choice other than MEAN. – Contains NodeJs and MongoDB database. – Generally used for smaller applications
RUBY ON RAILS	– Easy learning curve compared to other stacks – Due to its ease, there is less control on certain functionalities. – Could lead to code quality issues if not managed correctly.

For the web stack LAMP, this consists LINUX, APACHE, MySQL, and PHP. This is a free web stack that contains open-source coding framework and free for users. However, this web stack is difficult to use due to multiple coding languages being unrelated.

MEAN stack has MongoDB, ExpressJS, AngularJs, NodeJs. This web stack can be a favorable choice since computer engineering students have knowledge of NodeJs. This web stack is relatively new in terms of software development which means that it contains lack of community of users and/or developers that can troubleshoot any problem that may arise in the project.

If MEAN web stack is not a favorable choice for the project, this METEOR web stack may be the second choice. This contains NodeJs alongside with MongoDB database which can make the coding framework easier. However, this stack is meant to run small applications which it would not be a problem for this project.

Ruby on Rails could be a favorable choice for many novice coders and developers which can be the ideal for the project, however, there will be no control of the web application. This web stack will often ignore coding fundamentals and can potentially crash the web application and lead to long debugging sessions.

From these possible web stack choices, METEOR can be the effective option for software development due to this specific coding framework NodeJS.

4.4.3 Database Selection

Mongo DB and MySQL are the two main databases that are considered for this application. They both have their pros and cons when it comes to usage and integration. So, to show this comparison in a straightforward manner, we compared the main subjects that are related to the project within a clean table. This representation is shown below in Table 29.

Table 29: ***MongoDB vs MySQL Database***

	MongoDB	MySQL
Pros	• Well Documented • Fast Data retrieval • Realtime transactions • Dynamic Schema • Single Language • Direct usage of JSON	• Classic/Legacy • Well Documented • Structure Relational Data • Relational-base Tables • Good for large datasets
Cons	• No Joins • Not relational	• Schema is usually static • Requires knowledge on SQL • Conversion process to JSON

Choosing between MongoDB and MySQL depends on what will be easier to develop vs its capabilities in meeting the requirements and more. NodeJS can employ either database and each have a fair number of pros and cons against each other. Going for MongoDB would have the benefit of only using JavaScript as the backend language and, for the most part, the front-end as well.

4.5 Database Design

The database design is important for making sure that the data tables or collections are optimized, efficient, maintainable and that the design is also scalable. When it comes to the long term, the schema is expected to evolve to include other

elements, so MongoDB was the excepted choice. But when it comes to the short-term goal, a certain set of data is expected to be the same at this time so MySQL can also be considered for this application. Whatever the choice, the schema can be adapted to use the chosen database to its best potential.

4.5.1 Database Schema

The schema contains multiple sets of data for various types of functionalities. It will be separated into major sections, all of which are interconnected in some way. MySQL uses a relationship setup, while MongoDB uses Document oriented connections, such as linking. This emulates the same process of having a one-to-many relationship and being able to normalize the various collections. There is also embedding a sub-document to parent documents, which helps towards reducing read and write calls, but can have the side effect of increasing the document size and data repetition. Both methods are ways to structure the data, and to improve the throughput, embedding sub-documents will likely be the most utilized method within the database.

Even though MongoDB has a schema-free structure to its database, it is important to have a schema design to the collections and documents so that the data can be retrieved in easy manner.

The overall design looks different between these two schemas, but the goal is to separate the data into their own categories. These categories include User data, Game Token/Piece Data, and Hardware data, and are covered in the following sections in full detail. The initial MongoDB schema is represented in Figure 11 as shown below. Every collection that has some sort of connection to another is referenced within their collection.

The move list collection is a special set of documents that will be used to record the coordinates for the move action.

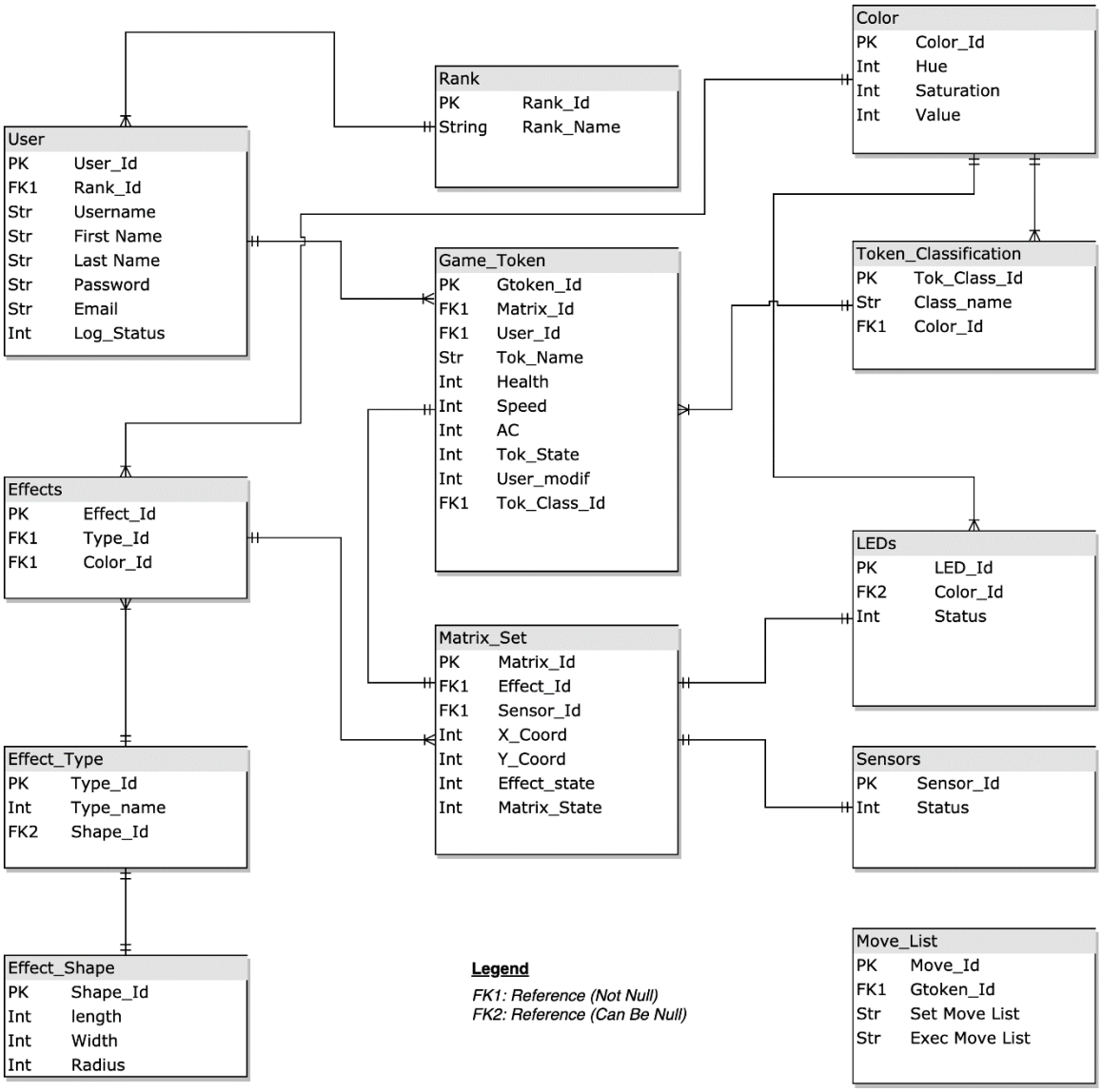

Figure 11: Initial MongoDB Schema

4.5.2 User Data

The data that is applied to users will need personal information for logging in and keeping track of their logged in status. This information covers the username, first and last name, and an optional email. Leaving email as optional will be a personal choice for the user, while the username, first, and last name are mandatory. Each user will have primary key User ID for their account, as well as a rank ID. Ranks are a sub-document to the User Document collection, and will contain the rand ID, and name for that rank, which is separated into “Player”, “Dungeon Master”, and “Administrator”, with each following rank having more privileges than the last.

Ranks are important because they represent what actions a user can perform while using the web application. A user with the Player rank can only control the specified

game tokens that an Admin or Game Master assigns to them. The limit of controllable game tokens is set by either of those roles, and technically this means a user could have numerous tokens under their control, but this number is controlled by the amount of available spaces that are left on the tabletop. For a 16 x 16 board, there is a limit of 256 different tokens that can be properly placed on a grid space, not counting restricted grids.

4.5.3 User Security

Storing passwords as a plain string field for users is not a valid solution, so to ensure user security, hash/salting a password will be required for all user entries. Bcrypt.js is a JavaScript NPM library that has been considered for hashing passwords and most likely will be the choice for establishing the website security. Other security plans have been considered, but a free option is the main objective to reduce costs.

A Third-party software such as Twilio's 2-Step Authentication API has also been considered to improve the security. It would drastically increase the security of the website and has a well-documented procedure to implementing the feature on various types of website. This would also involve having to sign-up for a free plan, but this would limit the user count and the authentications are set to less than 100 per month. Work-arounds can be implemented to circumvent this limitation but further research would have to go into setting up an extra user interface to confirm trusted devices for the selected user account.

4.5.4 Game Piece and Token Data

Token Data contains the unique ID associated with the token, Reference ID's and its basic information. This includes the name, health, speed, and armor class (AC), its current game state, and its coordinates. The reference ID links to the User and Matrix ID that it is associated with. This data represents a single entity across all the connected clients and the tabletop application. As such, every token data is unique and must be on a specific location on the 16 x 16 matrix.

When a change is executed on a token on the web app or the matching game piece on the tabletop, its state is updated to the execution state and the User_modif field is updated with the data representation of the User ID. This is part of data synchronization and will insure that only one person can make changes to a specific game piece at a time, and to prevent conflicts between user actions.

4.5.5 Hardware Data

Hardware data is all the changes that are coming in from the Tabletop application. Sensor and LED data must always be synchronized and when it comes to the overall session, since the tabletop is the most used device between all connected clients. Each sensor and LED have a unique ID associated with it and their

respective collections are at a fixed size. They are linked or sub-documented to the Matrix Set collection, which in turn has a unique ID with a fixed coordinate set.

The matrix set is set to 256 rows or in MongoDB, documents, of data. This equates to the 16 by 16 grid that is the main playing area for all the users within the session. This 256 data limitation is set in place due to budget constraints, since increasing the tabletop space introduces large increases of sensor and LED components. When it comes to the software back-end, this grid space can be easily scaled up due to the ease adding more documents to the matrix set collection. To represent the extra cost due to physical hardware, Table 30 is displayed below, to show the overall cost increasing the tabletop space, while Figure 12 shows a visual of the increase of price vs the increase of grid space. A single component was estimated to be $0.40 each.

Table 30: Grid Size vs Cost

Grid Length	# of LED	# of Sensors	# of Components	($) Overall Cost
2	4	4	8	3.20
3	9	9	18	7.20
4	16	16	32	12.80
5	25	25	50	20.00
6	36	36	72	28.80
7	49	49	98	39.20
8	64	64	128	51.20
9	81	81	162	64.80
10	100	100	200	80.00
11	121	121	242	96.80
12	144	144	288	115.20
13	169	169	338	135.20
14	196	196	392	156.80
15	225	225	450	180.00
16	256	256	512	204.80
17	289	289	578	231.20
18	324	324	648	259.20
19	361	361	722	288.80
20	400	400	800	320.00
21	441	441	882	352.80
22	484	484	968	387.20
23	529	529	1058	423.20
24	576	576	1152	460.80

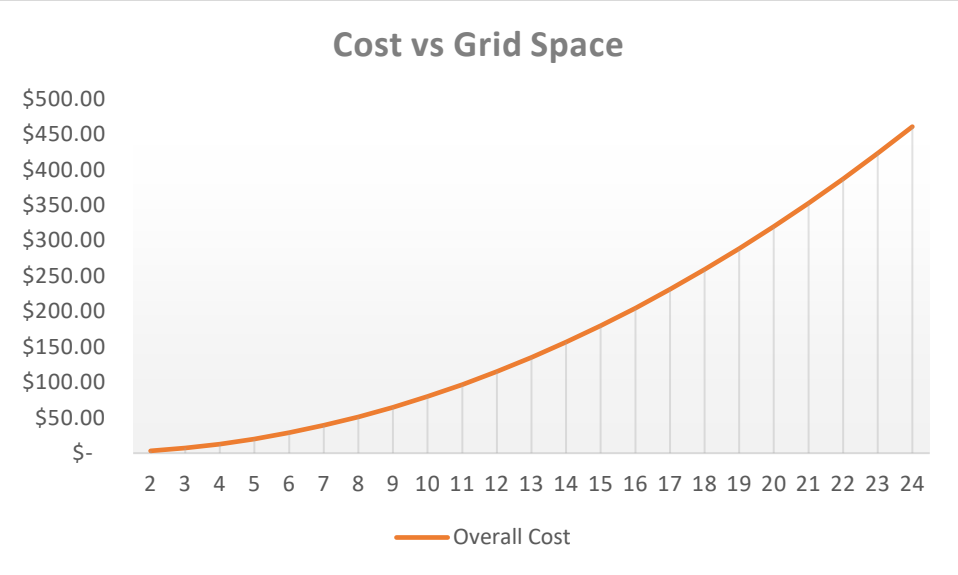

Figure 12: Cost Vs Grid Space

4.6 Data Synchronization

Data Synchronization is extremely important to making the sure that every web client and device is synced correctly and utilizing the same data set. There should be no discrepancy with the data that is used with all the connected clients and the physical board application. That means that a peer-to-peer connection is a poor solution to making sure that all the data on each client is matched correctly to every other client. The direction that is preferred is a client-Server, where the tabletop application is connected to the server, while the web app clients are doing the same.

To facilitate this equilibrium between all the devices, the group have an event and messaging system for any action that is taken on the web apps, as well as on the tabletop app. This does not include the sensor loop algorithm that is required for the tabletop app. This is also buffered by the state system that makes sure that when a game piece is being executed with an event, that piece can only be modified at by one person at that time.

Data communication will ensure that for the project, that regardless of data modifications on local application, all changes are merged with the original data source.

4.6.1 Web Socket Communication

Socket Communication is key to making sure that every client is updated with the current state of the server. This implementation would involve a user activating a functionality within a single client and this client would send a web socket event to the server, and then a server message to all connected clients.

Web sockets are useful within this project because it allows for asynchronous real-time communication. This also makes it valuable for the single page web App, since all the functionality must run continuously.

In order to communicate using the WebSocket protocol, we need to create a WebSocket object; this will automatically set up a connection to the server. Some protocols that are needed can be put into a string or an array. These strings will allow us to indicate sub-protocols, so that we can implement multiple WebSocket sub-protocols. This will allow the server to be able to handle many different types of interactions.

4.6.2 Database Validation

Data that is inserted into the database needs to be valid, since faulty data can lead to errors that could be harder to track. These are harder to track since the database collections are expansive and can possibly include hundreds of entries throughout the course of a couple of game sessions. There is already a set number of entries for the sensor, LED, and matrix set collections and if invalid data is set within any of those collections, it would automatically cause an error on the first loop of a game session cycle.

There are numbers of validation types we can do to check the data that is being entered. The following validation types Table 31 and their explanation are displayed below.

Table 31:Database Validation Types		
Validation Type	**How it works**	**Example usage**
Check digit	The last one or two digits in a code are used to check if the other digits are correct	Bar code readers in clothes use check digits
Format check	Checks data is in the correct format.	Check digit is computed from the characters given and compared to the given check digit
Length check	Checks data is not too long or too short	A password that needs a certain amount of letters long
Lookup table	Looks up acceptable values in a table	There are only 24 hours in a day
Presence check	Checks data has been entered into a field	In many databases a key field can't be left black
Range check	Checks that a value falls within the desired range	Number of hours studied for a test must be between 5 and 15
Spell check	Uses dictionary to look up words	Word processing

4.7 Communication

For both the physical tabletop board and the web app VTT to work towards the specifications, the communication between both applications need to be in sync.

Also, any actions used to communicate between an offsite player and the rest of their group must be user friendly and recognizable. The Database is main repository for all action and object data. It also serves as verification for any events that can happen on both applications.

4.7.1 Server to Application Communication

Androids app can communicate many different to the server in many ways. Any server-side technologies like JSP, Servelts or PHP is able to provide services and Apps can consume them via Rest API. Below Figure 13 which represents how the format would look.

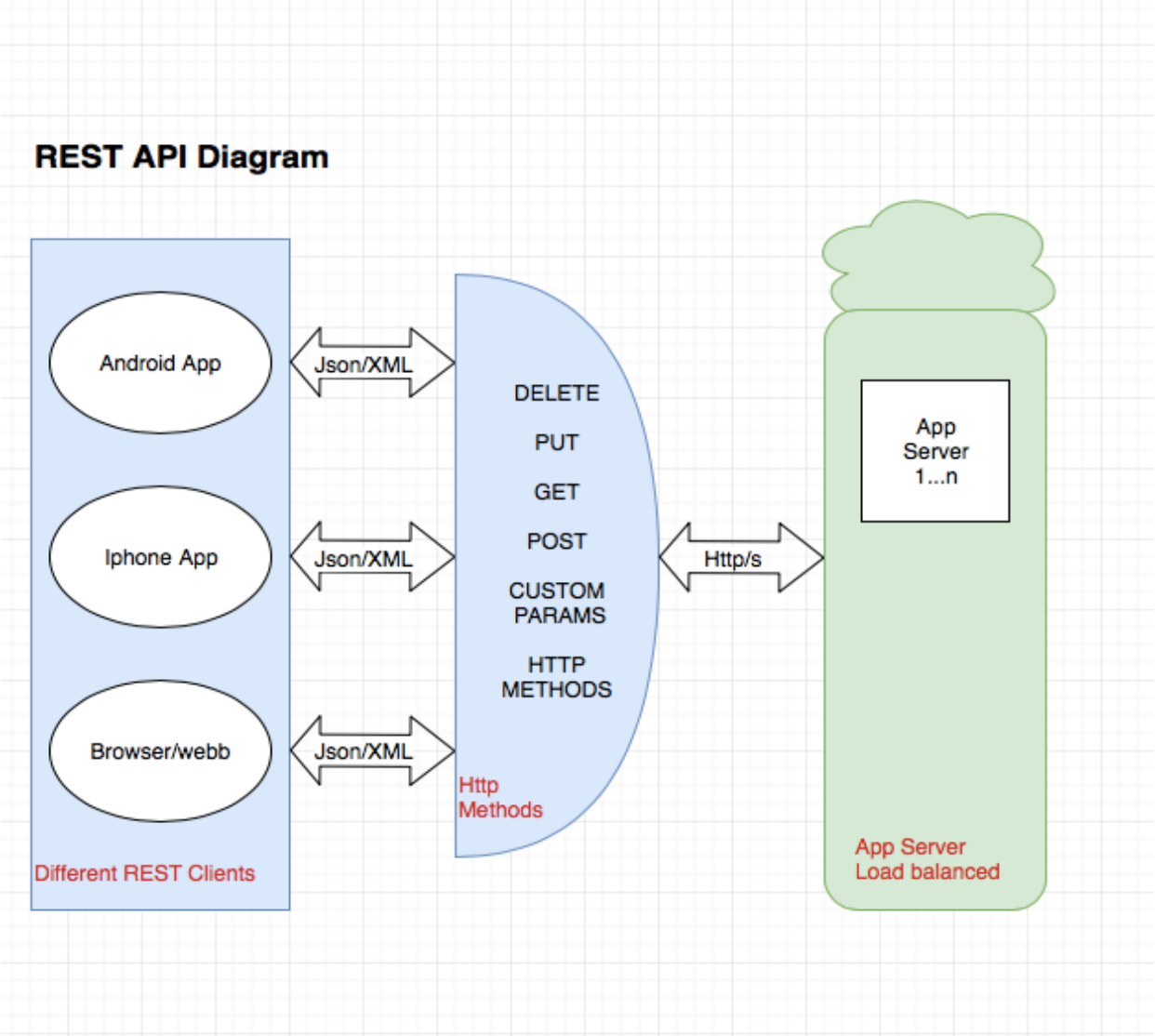

Figure 13: Rest API Diagram

The purpose of the REST API is to break down a transaction to create small modules, each module addresses a particular underlying part. This type of modularity gives us a lot of flexibility but for beginners may be challenging to start from scratch. As explained above, the group will be using HTTP request to GET, PUT, POST and delete data. GET will be used to retrieve a resource; PUT will be used to change the state or update a resource, this can be a block, file or object. When doing POST, the group will create the source and lastly DELETE is done to remove it.

For using a RESTful API, there are some constrains needed to be evaluated. The first one is that it is Client-Server based. This means the group needs to make sure the client and the server are separated from each other and allowed to evolve individually. The group cannot mix UI and request-gathering which are the client's domain with Data access, workload management and security which are the server. Otherwise potential conflicts can come from it.

Since RET APIs are stateless, calls can be made independently of one another, and each call needs to contain all the data needed to complete itself successfully. The resources should catching, because a stateless API can increase the requests overheard by handling many large amounts of incoming and outbound calls.

One disadvantage of using REST APIs is it can lose the ability to maintain state in REST under the sessions created. For the group which are all new developers, REST could result challenging due to their latency in request processing times and bandwidth usage but overall because of its great flexibility, lower maintenance costs, high scalability and simplicity the group will be using REST API for server to web app communication.

4.7.2 API Utilization

To facilitate the communication between both the physical and virtual devices, a variety of API's must be used in order to streamline the development process and to reduce workload. These API's include socket event communication, and database communication.

4.7.3 LED Utilization

Utilizing the LED's is straight forward using the FastLED library. This library can be loaded into the Arduino IDE and be used to control each led on the 16 by 16 matrix. This library supports the favored LED design that are expecting to use on the project, which is a WS2812B addressable LEDs. Their simplicity and broad utility will allow to light up the board with various patterns and gives a tool for the web app users to interact with board and communicate more efficiently. The overall LED design is covered in section 5.2 and other considered LED products.

The functionalities that the LED's will display are controlled by the web app users. These include pinging, moving, and action events such as spells. The set of colors the group will be using for the LED's will be stored on the database and can be referenced to multiple LED's with a call function. Pinging is an action where a user wants to call attention to a single spot. This can be a simple utilization of calling the LED's array position with a color and blinking the led with a delay function.

Moving a user will also utilize the LED's to highlight the pathing of a game piece moving across a board. The initial starting point will be marked with a blue lit LED, and the path traveling to the destination point will be marked green. The final grid position will be marked with a red LED and will turn off once the game piece has traveled its path to its goal. Possible collisions have been covered in 4.3.6, and the collision grid spaces will be marked with red flashing LED's.

The most challenging LED algorithms is the action and spell events. Certain actions can be singular LED actions, but the spells include complex shapes that can be a challenge to implement correctly. There are five different type of shapes a spell can take. These include a cone, cube, cylinder, line, and square shapes. If these shapes were set, the group would be able to just store a set amount of prefixed shapes per type of spell but many of these spells can be directed in in nearly any direction. To simply the dimensions, the group are leaving out the three-dimensional aspects of the spell and restricting the effects to two-dimensional space.

To calculate the effected grid spaces, a line will be drawn from the origin grid space and projected out to the designated distance of the spell. Every spell in DND is counted in increments of 5 feet, in which the grid spaces are 5 feet in diameter within the game. From there, the type of spell is calculated, and the algorithm will determine the grid spaces are that are affected. The visual representation of these spell effects is shown in Figure 14 below.

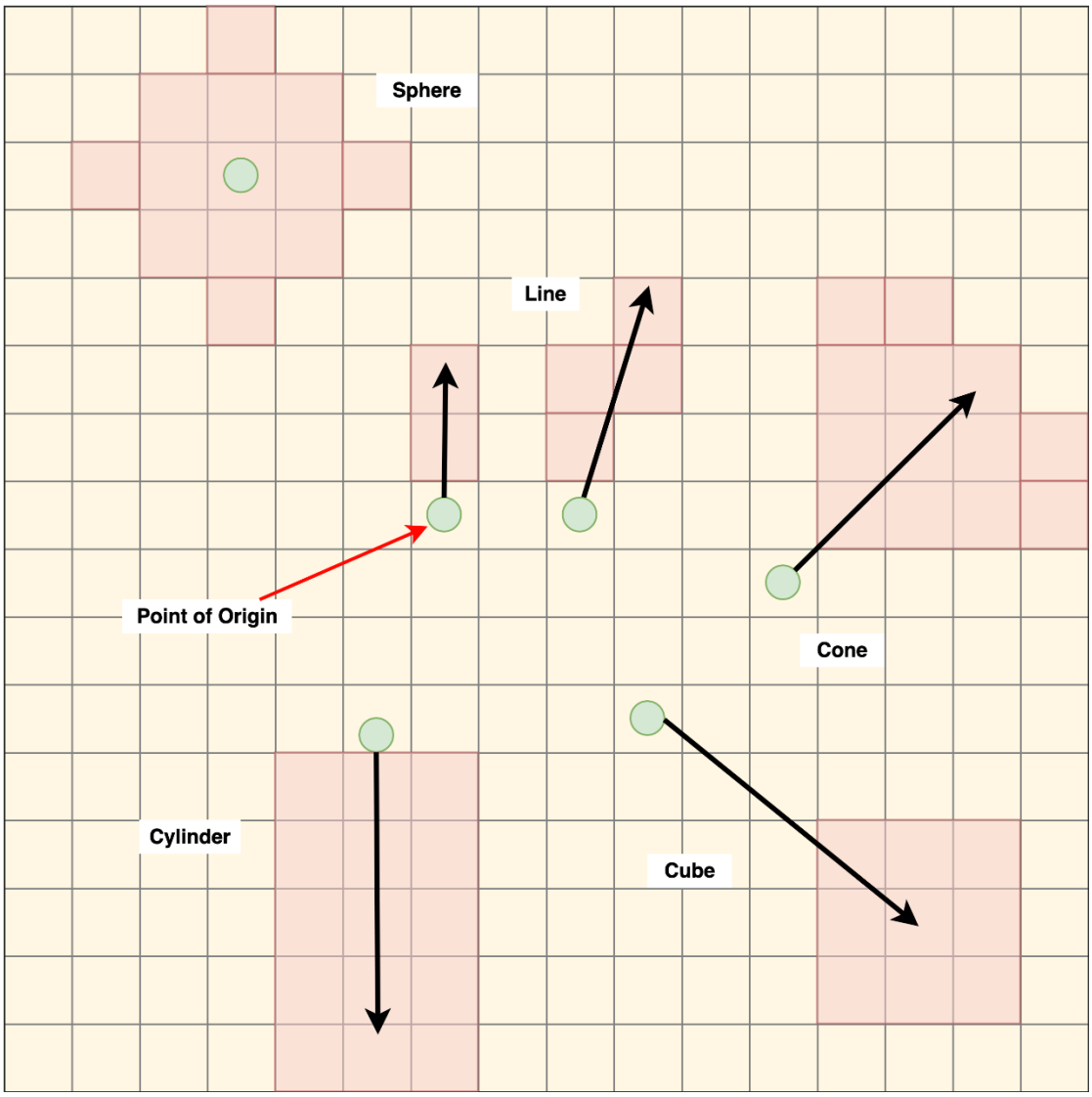

Figure 14: Spell Area of Effects on a Grid

The spells that can be pointed in a direction need to be drawn out from within the web tool and their corresponding spell effect will be applied based on what type of spell is being used.

4.7.4 Microcontroller and/or Microcomputer

There will be a few microcontrollers considered for this project. The MSP430, Arduino Mega 2560 and Raspberry Pi. The MSP430 is a 16-bit microcontroller that has a number of special features. It is known to be extremely low power consumption having only 4.2 nWper instruction while also having high speed 300 ns per instruction hence why used in many projects. Arduino Mega 2560 is designed for more complex power as it has 54 digital I/O and 16 analog inputs which makes it more suitable for 3D printers and robotics projects.

The Raspberry PI is also a low cost, credit card sized computer that has the capability of doing everything expected in a desktop computer, it has the capability to interact with the outside world and has been used for digital maker projects such as music machines to parent detectors to weather stations.

The group has done extensive research for each micro-controller mentioned and when it came to price, availability of part and easiness of use, it was determined that the Arduino Mega 2560 would be the best suitable microcontroller. What makes this micro controller very suitable for the project is that on top of being low cost, low power consumption and high speed it also has the capability of having wireless LAN and Bluetooth connectivity which allows it to connect with the other components such as the sensors, LED's and X/Y plotter.

The Arduino Mega 2560 has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs, a USB connection, power jack, an ICSP heater and a reset button. It has everything needed to support the microcontroller. The group need to connect it to either a computer with a USB cable or power it with a AC-to-DC adapter to get started. For the sensors used in the project, their outputs will be fed into the microcontroller that is being used, they represent the equivalent electrical values of any physical quantity. Sensors generally measure physical quantities like distance, light intensity and acceleration. When interfacing with the microcontroller, the microcontroller's digital input pins will directly accept the sensors digital output. Once a good communication has been established between the sensors and microcontroller, the group will be able to send signal to the output devices to which in the project are the X/Y plotter and LEDs in order for the tabletop game to work as expected. Below is Figure 15, a detailed graph explaining the connection.

Figure 15: Sensor Diagram

Many interface methods were considered by the group in order to solve the complex problem of balancing circuit designs criteria such as cost, features, size, power, weight consumption, manufacturability, etc.

For the sensors output signal, the group has considered some options that would fit better for the project criteria's, some of these options include having an analog voltage output or digital output. When it comes to Analog output, they are voltage-based control and monitoring, their voltage currently ranges from 0 to 5V with a current range from 0 to 20mA.

Following an analog output has some advantages as well as disadvantages, the main advantage the group found beneficial to the project is that is has a simple interface process. This was very beneficial since there is many complications can come from the interface such as when the sensor’s output-voltage range is much smaller than the ADC’s input-voltage which results in a drop in resolution, having a tight error budget, using a thermistor but having a linear temperature-to-code transfer function and having limited ADC inputs. When the interface process is simple, all of these complications are greatly reduced. Other advantages of using an analog output include low programming overhead, high speed and low cost for low resolutions.

Although some of these advantages are great, it also comes with some disadvantages, the main one the group found was having a high cost for higher resolutions, since the microcontroller has 40 inputs this can result in a very pricey output connection and just a high cost project all together. Other disadvantages are it complicates the circuit design when external ADC or DAC are needed, has a very short distance (only few feet maximum) and lastly not all microcontrollers have analog inputs/outputs built in.

Digital outputs connect to digital input ports and only communicate through a serial protocol. These sensors are auto-detected by the climate monitor, the signal measured is converted into digital signal output inside the sensor and then it is transmitted through cable digitally. Lately, they have been replacing analog sensors as they can overcome the drawbacks that analog sensors have. Just like with analog outputs, there are advantages and disadvantages of using digital outputs. The main advantages were that they have higher performance, higher reliability and are easier to design and maintain. This is very important for the project because for most people in the group this is their first big project and having an interface method that is easier to design and maintain can result in less time and money spent on it for tight error budgets.

The drawbacks of using digital signals are that it requires data conversion, to which if not familiar with converting data from one format to another it could take a long time getting familiar with, it also cannot provide continuous output for every change in input parameters which analog sensors can and lastly it costs more than analog. Below the group have Figure 16, which is a graph explaining the interface with analog/digital sensors with the microcontroller using a temperature sensor as an example.

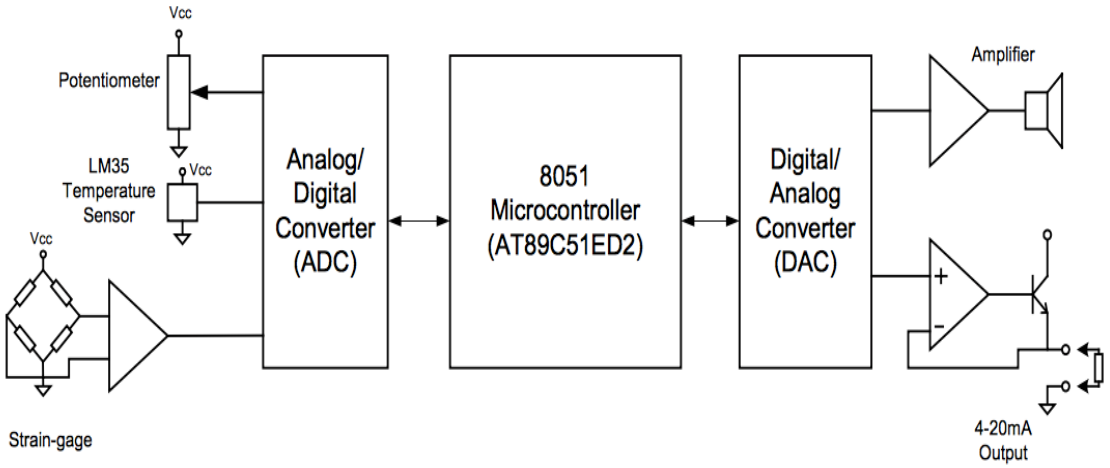

Figure 16: Analog Input/Output

4.8 Code Library Usage

A software library is a suite of data and programming code used to develop software programs and applications. It will help us assist the programmers working on this project and the programming language compiler in building and executing software.

The group expects to find pre-written code, classes, procedures, scripts and more to benefit for. Also, in order to reuse code for the project there is some guidelines that needs to be followed

There are restrictions in using code libraries because of the easiness it is to get them. Since a programming language is somebody's intellectual property, all code is therefore inherently copyrighted, and the group need to treat it as such. The code obtained is no different from the text in a book, so for us to use the code, the group have to pay the original author a listening fee. Using code without regard to the creators' right is both illegal and unethical and could get the group some potential legal trouble.

As mentioned previously, fortunately the team can obtain rights to use a code library by obtaining a license. One license obtainable is a creative commons license. This dictates whether the code that is wished to borrow can be used for commercial applications or strictly for non-commercial applications. It also lets us modify the code the group has borrowed; this is important since most code written is applicable to the owner's project but by modifying it, it can use it to the project or any project desired

Even with a code license, abiding by all terms can become tricky. For us to avoid any legal problems, the group need to make sure license limitations are met. A good plan that can be developed is to submit code libraries for review as they are introduced into the project, this practice would allow us to potentially cut weeks or

even months from the project development schedule. The IPO can start the process of inspecting the code libraries while the software or application is being developed, a complex license could take up to month or more to review so it is important for us to request a license review as soon as they start designing the project.

5.0 Hardware Design

The hardware design in this project consists of the sensors, LED's, LED drivers, FET multiplexer/demultiplexer, and the XY plotter. This chapter covers the different types of sensors, LED's, LED drivers, FET multiplexer/demultiplexers and their alternatives that are used in the project. With the XY plotter there are many things that go into it like the stepper motors and the magnet holder that it will have. Each of these hardware parts are critical to get the project working and for it to perform its physical functions for the game. Keeping all this in mind it is also critical that the hardware that is chosen in the project can also be compatible with the software parts because they need to be able to be programmed to do what is necessary for the game.

5.1 Sensors

Sensors are important and needed for the project to serve the purpose of moving the game pieces around without having to physically touch them or having the users to move it themselves. They are an important part because they will contact the XY plotter's magnet and that way they will react to it and then move the game pieces around. Research was done to find out what type of sensors would be needed to apply and work in the project.

Since they need to react to the XY plotter's magnet that means they must be magnetic sensors, in this section different types of magnetic sensors are discussed and compared to show which one would be best to use for the purpose of the project. The two found to work best for the purpose of the project are reed switches and hall-effect sensors. There's also another magnetic sensor that would work well in the project called a magnasphere but is not necessary. Now, to explain them more in detail.

5.1.1 Reed Switches

Reed switches are one of the two types of sensors that are strongly being used and will most likely be used for the project. To explain what reed switches are and how they apply to the project, reed switches have two ferromagnetic blades, when a magnet gets near the two blades will close and touch when normally the blades are open and allow the electricity to flow. Then, there are reed switches made from non-ferromagnetic material and the difference is instead of closing when a magnet gets near it to let the electricity flow it opens and the blades separate from each

other instead to let the electricity flow. Either a ferromagnetic material or non-ferromagnetic material reed switch would work for the project. They also do not rely on a power source or need to be wired to anything to work. A reed switch, with it being magnetic will connect with the XY plotter's magnet and move the game pieces around.

5.1.2 Hall-Effect Sensors

Hall-effect sensors are the other type of sensors that are strongly being used in the project, but most likely will not be. To explain what hall-effect sensors are and how they apply to the project: first, hall-effect sensors are magnetic, which is what they need to be for the project, so they can connect with the XY plotter's magnet holder and move the game pieces around. They are semiconductors and depend on a power source to work. There are two types of hall effect sensors, the two types are latched and non-latched. For the project, latched hall effect sensors would be the ones preferably used. This is represented in Table 32 below.

Table 32: Latched vs. Non-Latched Comparison Table

	Latched	Non-Latched
Reaction to Poles	– Hall-effect sensor detects and reacts when the north pole of a magnet is near it.	– Hall-effect sensor detects and reacts when the north pole of a magnet is near it.
Magnet Activation	– Stays activated even when the magnet is removed.	– Only stays active when the magnet is near it.
Magnet Deactivation	– Only turns off when the south pole is introduced.	– Turns off when the magnet is removed.

As shown, latched hall-effect sensors would be the best option for the project if it were to be used because it is desired to keep the sensor active even when the XY plotter's magnet is removed. The sensor is desired to be kept active, so the game pieces stay in place magnetized to the board and, so they are not easily knocked off.

5.1.3 Reed Switches vs. Hall-Effect Sensors

As explained, both reed switches and hall-effect sensors can be used for the project. They both will perform the same function that is needed for the project to connect with the XY plotter's magnet and move the game pieces around without needing to be physically touched. Making a comparison of both reed switches and hall-effect sensors shows that price-wise they are both similar and it's not a significant factor to choosing one over the other, but the research shows that reed switches significantly will work better and are more efficient for the purpose that

they are needed for the project. Also, even though the sensors themselves are similar in price a hall-effect sensor would turn out to be more expensive because of the power and circuitry they need to work. The Table 33 below shows the comparison of both.

Table 33: **Reed and Hall-Effect Comparison Table**

	Reed Switches	Hall-Effect Sensors
Resistance	– They do not face as much electrical resistance because of the closed contacts that they have. – Can be measured to be as low as milli-ohms in resistance.	– They have a lot more electrical resistance. Can measure in the hundreds of ohms.
Efficiency	– They work with a variety of frequencies, voltages, and load.	– Very limited with the amount of frequencies, voltages, and load that it can work with.
Connectivity	– They work whether they are connected or disconnected to a wire and don't need a power supply.	– They need to be wired and require circuitry to even work.
Durability	– They are durable and withstand a three-foot drop without being damaged.	– Not as durable and can be damaged easily.

As shown above, reed switches are undeniably the best and most cost-effective magnetic sensor to use for the project. It significantly surpasses the hall effect sensors in every way and one thing that is especially important is the fact that the reed switch only needs 5 Gauss time to work compared to the 15 Gauss time that the hall effect sensor needs to work. That fact is important because that means bigger magnets would have to be placed underneath the game pieces if the hall-effect sensors were to be used and the problem with this is that the bigger the magnets are they will possibly attract each other and cause the game pieces to collide and that is something that is not desired for obvious reasons.

Reed switches also significantly make it easier to assemble the project's sensor system because there is no worry and no need to wire them up with each other or to provide a power supply and additional circuitry to it, unlike hall-effect sensors where they do require to be wired to each other, need a power supply, and circuitry to work. Reed switches ultimately will save the group a lot of time and errors to assemble the sensor system.

5.1.4 Alternative Sensors

There was research done about other sensors that could've been used and applied to the project, but the biggest factor that took into account that meant they couldn't seriously be considered for the project was the cost. One sensor that was found to be vastly superior to the hall effect sensor and even reed switch is the magnasphere. The magnasphere is completely metal and is the most advanced magnetic sensor recently made in the last 70 years. Even though, it's the most advanced magnetic sensor there's reason to believe that the group should use this sensor then, but there are many factors that were considered when it came to choosing reed switches or hall-effect sensors over magnaspheres.

Table 34: Sensors Comparison Table

	Hall-Effect Sensors	Reed Switches	Magnaspheres
Pricing	– Much cheaper than magnasphere and similar to reed switches in price. – Most are under a $1 each.	– Much cheaper than magnasphere and like hall-effect sensors in price. – Most are under a $1 each.	– Much more expensive than both hall-effect sensors and reed switches. – Cheapest researched was $7 each.
Efficiency	– Not as efficient and more work to assemble for the project than reed switch and magnasphere.	– More efficient and easier to set up than hall-effect sensors and are perfect for use in the project.	– The most efficient out of the other two magnetic sensors, but it is a bit extreme and not necessary for the project.
Quality	– More fragile than reed switches and magnasphere. – For the purpose of the project it's ok.	– More fragile than magnasphere, but not hall-effect sensors. – For the purpose of the project it's ok.	– Virtually indestructible, but it is not necessary for the project.

The comparison of the three sensors within Table 34 indeed does show that the magnasphere is the superior of the three, but it's just a bit extreme, extra, and too expensive for the purpose of the project. They are used for things such as

generators and motors and for the project all that is needed is a sensor that can just move around the game pieces and connect with the XY plotter's magnet sensor.

There's no need or reason to pay over $1000 for the 256 sensors that are needed for the project just because they are magnaspheres, when only under $300 can be spent on reed switches or hall-effect sensors which are perfect for the project and are convenient enough. It doesn't matter that magnaspheres are superior in every way because for the purpose of this project the magnetic sensors don't have to be perfect, very advanced, or indestructible. This is just a table-top game that is trying to be built, not anything robotic, industrial, or in the automotive industry where the magnetic sensors need to be very strong, durable, and efficient as possible which is what magnaspheres aim to be.

5.1.5 FET Multiplexer/Demultiplexer

In this next section, the different types of FET Multiplexer/Demultiplexers that can be used with the sensors in the project are discussed. When doing research on previous projects like this one like the Cyber Chess project they use a 3 to 8-line decoder, for this project a 3 to 8-line decoder cannot be used. In the Cyber Chess project, they were able to use a 3 to 8-line decoder because a chess board is always in an 8x8 block set up. In Dungeons and Dragons, the board is always in a 16x16 block set up and for this reason a 3 to 8-line decoder can't be used. The decoder that can be used is a 4 to 16-line decoder.

The reason the project needs a decoder is to reduce the number of pins used to information from the reed switches. The decoder will also be used to make it compatible to link the reed switches to the microprocessor that will be used, which will be either the Raspberry Pi or Arduino. The way the 4 to 16-line decoder will work is that it will have the 16 input pins from the reed switches connect to the outputs of the 4 to 16-line decoder and then to the microprocessor.

5.1.6 Sensors Summary

As shown and researched above, there is still a debate on whether the group should use reed switches or hall-effect sensors. Ultimately, reed switches are the best one's cost-wise and efficient-wise to use on the project. The alternative sensor the magnasphere that is a vastly superior magnetic sensor compared to both is not necessary for the purpose of the project and is also very expensive. Reed switches and hall-effect sensors end up being a similar price, but the reed switch is just easier to set up, don't require circuitry or wiring, don't need a power supply to work, and are more efficient overall compared to hall-effect sensors.

The largest deciding factor of choosing reed switches over hall-effect sensors is the setup, the efficiency, and the fact that there is more variety and flexibility with

reed switches. The easier things are made for the group, the better, leading to less errors, less complications, saving time.

5.2 LED's

LED's are another part of the hardware that is needed for the project. The LED's are being used mainly for aesthetic purposes to make the board light up and look nice. The LED's will also be used to light up the path that needs be taken of the game or to show where the start and end of the path is for a quest and to also light up on a specific game piece or character when they are the focus of the game at the moment.

The LED's needed for the project must be programmable so they can be controlled and show the specific pattern or spot that needs to be lit up during the game. They also must be LED strips or LED matrices because it is desired for them to be under each block of the 16x16 board. They also must be cost-effective because there is no need for them to be very advanced or industrial for the purpose of the project. They just need to work, look nice, and be individually programmable.

The research done for the LED's that can serve the purpose of the project showed that individually addressable LED's would be the best ones to use because they can individually be programmed. There are different types of individually addressable LED's and they are compared and discussed in this section.

5.2.1 Outdoor RGB LED Strip Light Kit

When first researching LED's this LED strip called the Outdoor RGB LED Strip Light Kit - Weatherproof 12V LED Tape Light was originally being considered because it looked nice and because the group members were not even aware that individually addressable LED strips even existed. The problem with LED strip is that it's only meant to be used outside for decoration and they are not individually addressable.

This one is only controlled with by a remote and it's not worth the price either, so this one would have not worked like desired and would be extremely inefficient for the project. With a bit more research the group then found out that programmable and individually addressable LED strips existed and would perfectly serve the purpose of the project.

5.2.2 KAPATA Digital RGB Strip

The KAPATA Digital RGB Strip Individually Addressable LED Strip WS2812B WA2812 5m 30IC-30LED/M White PCB Waterproof Dream Color DC5V are one of the LED's strongly being considered being used in the project because it's individually addressable, can be programmed, and controlled like is needed for the project. In just one meter of the strip it has 30 LED's and the order brings five

meters of the LED strips making them a total of 150 and only being worth $33. For the 16x16 board there needs to be 256 individual LED's under each square. Just buying two quantities of this product will provide the group with more than enough LED's for the 16x16 board, since it will bring 300 in total, which is desired because they will provide the group with extra supply if some of the LED's don't work or break for some reason. It also can be programmed to flash, strobe, and fade which is also desired for the project. The only problem with these is that they need a bunch of LED drivers as a power supply adding additional costs to setting up the LED's and making them work.

5.2.3 Adafruit NeoPixel Digital RGB LED Strip

The Adafruit brand of LED strips is better quality and has less spacing between the LED's than the KAPATA. The Adafruit NeoPixel Digital RGB LED Strip - Black 30 LED performs how it's needed for the project, it's individually addressable, can be programmed, and controlled. It also can be programmed to flash, strobe, and fade which is also desired for the project, just like the KAPATA. The problem with this one is that it's significantly more expensive being $11 for one meter and it has 30 LED's per meter, like the KAPATA. Just three meters of them would cost the same price as the KAPATA that brings five meters instead.

Only for this reason alone the Adafruit NeoPixel is not worth it and is really not necessary for the project since the KAPATA does the same thing that is needed for the project at a cheaper price and it brings more LED's (300), while the Adafruit would only bring 90 LED's for the same price. On top of that, similarly to the KAPATA they also need a bunch of LED drivers as a power supply adding additional costs to setting up the LED's and making them work.

5.2.4 Adafruit RGB Matrix for Raspberry Pi - Mini Kit

This LED product: Adafruit RGB Matrix HAT + RTC for Raspberry Pi - Mini Kit was made specifically to connect with the Raspberry Pi which is the microcontroller strongly considered being used in the project, is more advanced and looks nicer than the other two products, and it is also individually addressable as needed in the project. But, it's a very small matrix that would not be useful for the project. It is much smaller than is needed to be for the project, so several would then be necessary and cost wise be very expensive. Only one of these matrices costs $25 with two already being $50 and surpasses the amount of the LED's being considered for use in the project. It really would not be efficient and cost-effective for the project.

5.2.5 Flexible 16x16 NeoPixel RGB LED Matrix

After doing more research this might just be the perfect one to use in the project because it is exactly a 16x16 matrix, which is exactly the size of the board for the project. The LED's are also individually addressable as needed also, and because

it's a more advanced matrix the patterns can be visually much better and be arranged much nicer and sharper than a normal LED strip is capable of. Significant problems with this LED matrix is the price of being $95 making it much more expensive than all the other LED products that the group has in mind to use and also the fact that even though it is a 16x16 matrix it may not match exactly with the measurements of the board and then be off by a few inches in either the length, width, and height, or all three of them. The only benefit of the 16x16 matrix cost-wise is that it will need fewer LED drivers to power it up, but it doesn't matter since the price of the matrix alone is much more expensive than the price of the LED strips and LED drivers that are needed to power it alone. Therefore, still making the LED Strips the best option to use for the purpose of the project so far.

5.2.6 WESIRI 16x16 Pixel 256 Pixels Flexible LED Panel

When doing previous research on LED matrices it was believed that the Flexible 16x16 NeoPixel RGB LED Matrix was the only one of its kind and was not being seriously considered to be used even though it is individually addressable because of it measurements not matching the physical board that is being made and also because of how expensive it is.

The difference with the WESIRI 16x16 Pixel 256 Pixels WS2812B Digital Flexible LED Panel Individually Addressable Full Dream Color DC5V is the price and the matrix are chainable and extendable. It is also compatible with Arduino and Raspberry Pi, which is not decided yet which of these microcontrollers will be used. Having the option to be programmed with either is important. The only problem that was found with this product is that there are no reviews on it in Amazon, but that's just a minor inconvenience that is not important. The group just doesn't want to spend time and money on something that may not work well.

5.2.7 CHINLY WS2812b Pixel Matrix, 16x16 256 Pixels

With even more research done on finding 16x16 individually addressable LED's matrices. The CHINLY WS2812b Pixel Matrix, 16x16 256 Pixels WS2812B Digital Flexible LED Panel Programmed Individually Addressable Dream Screen DC5V was found to have the exact same features as the WESIRI LED Panel, except this one has more reviews and the group can put more trust and confidence into this product.

It is few dollars more than the WESIRI brand matrix panel, but it is better to pay a little bit more for a product that is more reliable and that is better quality. The fact that it is chainable, extendable, and can also be programmed by either the Arduino or Raspberry Pi is the part that is most critical for the project. After enough research being done on different LED's it seems like this one will be the easiest to set up and will work just as good as the other ones.

5.2.8 BTF-LIGHTING 16x16 256 Pixels LED Matrix Panel

The next and final LED product that was researched was the BTF-LIGHTING WS2812B RGB 5050SMD Individually Addressable Digital 16x16 256 Pixels LED Matrix Panel Flexible FPCB Dream Full Color Works. The features on this one is no different from the WESIRI and CHINLY, but this one just had more customer reviews than the WESIRI and CHINLY with pictures and even videos to show the quality and performance of the product. Like the CHINLY and WESIRI, it has the most important features needed to work with the project. To make sure that it can be compatible with the board's dimensions and that each individual LED is under each board block it is chainable and extendable.

Also, similarly to the CHINLY and WESIRI it can also be programmed with the Arduino and Raspberry Pi, which is important because like said before the group hasn't decided on which of these microcontrollers to use yet. The BTF-LIGHTING is also priced similarly to the WESIRI and CHINLY, which cost is the other important factor for the group. This being the last product to be researched and being a product commonly used by people shows that the group can rely and put confidence and trust in this product. The reason the group researched brands that aren't popular like these is, so they don't have to spend so much money on a popular brand one, like Adafruit and Neopixel.

5.2.9 LED Summary

Out of all the LED's researched one of the cheapest and the one of the ones best suited for the project is turning out to be the BTF-LIGHTING WS2812B RGB LED Matrix. It is one of the best ones in price and does exactly what is desired for the project. It's individually addressable, so it can be programmed as desired to light up the board and make whatever pattern is needed for the game.

It can also be programmed with either the Arduino or Raspberry Pi, which is perfect since the group hasn't decided yet on which microcontroller will be used. Even though the WESIRI 16x16 LED Panel and the CHINLY LED Panel will do the exact same thing as the BTF-LIGHTING LED panel, it has more reviews and more proof that it's a product that will be reliable for the purpose of the project.

Therefore, the group can put more trust and confidence on the BTF-LIGHTING. The Outdoor RGB LED Strip Light Kit is not even individually addressable and costs a lot more than the BTF-LIGHTING. The other matrices, like the Adafruit and Neopixel are not necessary for the project even though they're more advanced and efficient.

The other matrices are too expensive, and the BTF-LIGHTING can do the same thing even if it is not as advanced as the other ones. The best or most advanced and the most efficient LED strips or matrices aren't needed for this project. They

just need to work and be individually addressable for the paths, start points, end points, characters, and objects in the game.

Recently, the group bought the LED that was researched to be the best for the project called the BTF-LIGHTING LED panel. After it was received from the mail and physically analyzed it was then concluded that this LED panel cannot be used in the project unfortunately. It was thought that the panel could be cut and adjusted like needed because it was advertised as extendable on Amazon. When physically looking at the panel though it was shown that by extendable what it meant was that it is compatible to connect to other LED panels, not that the panel can literally be extended itself.

Even though a bunch of good alternatives were researched, one of the group members researched an LED strip that turns out will work much better for the purpose of the project. It's called the BTF-LIGHTING WS2812B 144 LEDs/Pixels/m Black PCB Individual Addressable Full Color led Pixel Strip Dream Color Non-Waterproof 3.2FT 1m. In the Table 35 shown below a comparison between the BTF-LIGHTING LED panel, the other LED strips researched, and the newly found BTF-LIGHTING LED strip is made.

Table 35: LED Product Comparison			
	BTF-LIGHTING Panel	**LED Strips**	**BTF-LIGHTING Strips**
Pricing	– The Panel is a similar price to the other LED strips. – More expensive than the BTF-LIGHTING strips.	– All the LED strips researched are more expensive than the BTF Strips. – All around the same price. – Similar pricing to the BTF Panel.	– Cheaper than all the LED strips and BTF Panel. – Only $20.88 for 144 individual LED's.
Programming	– Each LED can be individually programmed with the Raspberry Pi and Arduino.	– Each LED can be individually programmed with the Raspberry Pi and Arduino.	– Each LED can only be individually programmed by the Arduino. – This is the microcontroller that the group will use.
Customize	– Extendable only by attaching other LED panels to it. – LED's cannot be cut or extended.	– Can be cut to the desired length. – Each LED can be cut and extended. – This function needed for the board size.	– Can be cut to the desired length. – Each LED can be cut and extended. – This function needed for the board size.
Reviews	– Many great reviews on Amazon about the product. – Not compatible for the purpose of the project.	– Most LED strips have minimal reviews. – KAPATA even that only had 5 reviews.	– Many great reviews on Amazon about the product. – Exactly what's needed for the purpose of the project.

In the table above the comparison of the products is shown and it compares why the LED product that was originally thought to be the best for the project wasn't the best.

The alternatives were considered then after, but after more research on the BTF-LIGHTING brand which is apparently a good brand according to the reviews on their products through Amazon. The BTF-LIGHTING LED strips were found and turns out to be much cheaper than the other LED strips that were researched and the product also having 153 reviews most of them being very good shows that this is a reliable product that can be used for the project.

Yes, it was mentioned that it can only be programmed with an Arduino and the rest of the products can be programmed with both an Arduino and Raspberry Pi, but this doesn't matter. The group originally thought that the Raspberry Pi would be the microcontroller used for this project, but it turns out that the Arduino is the best microcontroller to use for the purpose of the project, so the BTF-LIGHTING LED strip is perfectly fine to use for the project.

5.3 LED Drivers

In the previous section, the different types of LED products being considered to use for the project were discussed. In this section, the different types of power supply or LED drivers will be discussed. The LED drivers are needed and are a power supply to turn on the LED's and get them to work. LED drivers can be comparable to transformers for low-voltage bulbs and ballasts for fluorescent lamps.

The reason LED's need to have a specific power supply is because they are made to run on low voltages (12-24V) under direct current, but the problem with most places is that they have higher voltages (120-277V) under alternating current. What LED drivers do is convert the higher voltage that's ran with alternating current to a lower voltage and to direct current. That's why LED drivers are essential as a power supply to LED's.

Another important thing that LED drivers do is to protect the LED's from voltage or current fluctuations. The voltage changing can cause the current to change in the LED that it's supplying. For LED's to work properly they need to stay in a specific current range. The light output in an LED is directly dependent on the current being supplied to it. With all of this explained this means that too little or too much current can cause the light output to be unstable or wear out and raise the LED's temperature.

There are also two different types of LED drivers, they are called internal and external drivers. The one that will be used for the purpose of the project is an external driver. The reason an internal driver is not applicable is because they are used mostly for household lightbulbs. External drivers are the ones made to power the LED strips and matrices that may be used in the project. Now, the different type of LED drivers that can be applied to the project will be discussed.

5.3.1 BTF-LIGHTING Power Supply Adapter Transformer

The BTF-LIGHTING DC5V 6A 30W Plastic Power Supply Adapter Transformer for WS2812B APA102 LED8806 WS2801 LED Strip Modules Light is the first power supply that was found because it was suggested through Amazon in the BTF-LIGHTING product page. It is made to work specifically with the BTF-LIGHTING LED Matrix Panel. Sure, it is compatible with the LED product that group is strongly considering using and is also not expensive.

The problem with this product is not any of the features, but the fact that it does not have the best reviews from customers. It also does not come with a power chord. That's not good for the group because they want to make sure that they can get a reliable driver to power the LED Matrix Panel and the group doesn't want to do extra work to get or make a power chord for the driver either, it's not efficient.

That means more research needs to be done to find a better product that can work with the LED's and maybe not just be compatible with the BTF-LIGHTING LED Matrix Panel, but also with the other LED matrices like the CHINLY and WESIRI, in case it doesn't work out with the BTF-LIGHTING LED Matrix Panel.

5.3.2 ALITOVE 5V 15A AC to DC Power Supply Adapter

The next product that was found is the ALITOVE 5V 15A AC to DC Power Supply Adapter Transformer Converter Charger 5.5x2.1mm Plug 100V-240V AC Input for WS2811 2801 WS2812B LED Strip Pixel Light. It is compatible with the BTF-LIGHTING LED Matrix Panel and WESIRI LED Matrix Panel since its capacity is 5V and 15A.

It is a bit pricier than the BTF-LIGHTING power supply by ten dollars, but it has a lot more reviews from customers, overall looks like it's better quality, and it comes with a power cord, unlike the BTF-LIGHTING power supply. Therefore, the group can make a better judgment on whether to get this product or not. Still, more research must be done to see if there's an even better product or cheaper product of the same quality that can be used instead.

5.3.3 5V 15A 75W Power Supply

The 5V 15A 75W Power Supply 100V-240V or 110V - 220V AC to DC Adapter 5V 15 amp Switching Converter Charger 5.5x2.1mm Plug for WS2811 WS2812B WS2813 2801 LED Strip Pixel Lights only other product found through research that is compatible in every way with the BTF-LIGHTING LED Matrix Panel and WESIRI LED Matrix Panel. Anything beyond 5V and 15A will destroy these LED matrices.

It has the same features and does the exact same thing as the BTF-LIGHTING power supply and ALITOVE power supply, but it has the same problem as BTF-

LIGHTING power supply and doesn't have enough reviews from customers for the group to decide whether or not the product will work well or is good enough quality for the project. This and the above LED drivers are only compatible with the WESIRI LED Matrix Panel and the BTF-LIGHTING LED Matrix Panel. There is not much variation between the ones needed for the project because the matrices share the same voltage and current capacity.

5.3.4 5V Power Supply, CHINLY 20A

After even more research being done a regulated switching power supply was found from the CHINLY brand call the 5V Power Supply, CHINLY 20A Universal Regulated Switching Power Supply Transformer for WS2811 2801 WS2812B WS2813 APA102 LED Strip Light that can also be used with the WESIRI LED Matrix Panel and the BTF-LIGHTING LED Matrix Panel. With the CHINLY LED Matrix Panel not having a current capacity in the Amazon page different power supplies that are used to power it show and this one was one of them and the one found to be compatible with the other two.

The problem with this product is that the current capacity for the WESIRI LED Matrix Panel and BTF-LIGHTING LED Matrix Panel is 15A. Even though the current can be manually adjusted if it's accidentally adjusted over the 15A it will destroy the LED's, which the group really does not want to happen because they don't want to spend more money to get a whole new set of LED's.

Another problem with this product is or it can be possibly something that works to the project's advantage depending on how the group wants set it up is that it's a universal regulated switching power supply and the way that it's plugged in is different from just a direct to the wall plug-in. Ultimately, it doesn't seem like it's necessary and its bit too advanced for the purpose of the project.

5.3.5 LM3402 and Implementation

For visual effects, the LM3402 electronic chip to will be required to deliver constant current to the LED drivers and able to change the brightness level by using a PWM signal from the microcontroller.

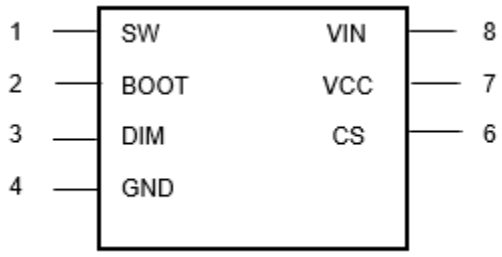

Figure 17: LM3402 Pin Diagram

Table 36: LM3402 Function Table		
Pin No.	**Function**	**Name**
1	Connecting to a Schmick Diode and output inductor	SW
2	MOSFET drive boot trap. Connects to the 10nF capacitor	BOOT
3	It will reduce the light of LED array using the PWM signal	DIM
4	Connects to ground	GND
5	To stabilize light of LEDs	CS
6	Setting the time light up the LEDs	RON
7	No need for this pin. Connects to a minimum of 10nF capacitor	VCC
8	Input voltage (6V to 42V)	VIN

Once a specific type of LEDs is chosen, the number of LED drivers must be determined in order to determine appropriate number of LM3402's, such as shown in Table 36. Those electronic chips are quite inexpensive so purchasing them is no concern. Once these chips are connected to the LEDs and to the microcontroller, they could change the brightness and colors to add scenery during gameplay.

The Dungeon Master, an individual that can create campaigns and stories for the players, can add brightness and colors depending on the situation that they are experiencing. For example, the players are being ambushed by some enemies; the Dungeon Master adds a reddish or some darkish color to add the mood of the gameplay. If the players find a treasure or some type of reward, the Dungeon Master can add a bright color on the gameboard.

Changing the brightness and adding colors into the game can create a significant impact during the game and getting an interesting experience.

5.3.6 MAX16802B Implementation

For this type of electronic chip, its application is most widely used for industrial lighting was the primary choice for the light of LEDs. However, it can deliver a lot of current which means that it can deliver high-level power into the system. This can cause a safety concern for the participants of the project; therefore this choice can be neglected.

5.3.7 LED Drivers Summary

There is not much to be said or researched on any of the different types of LED drivers needed for the project to supply power to the LED's. The WESIRI LED Matrix Panel and BTF-LIGHTING LED Matrix Panel both can use the same power supply because their capacity is 5V and 15A. With the CHINLY LED Matrix Panel it also has a capacity of 5V, but the current capacity is not specified, it's assumed that it's the same or like the CHINLY and BTF-LIGHTING current capacity.

With each of these power supplies only one is needed to power the 256 LED's that will be used in the project. The group will make the decision on which of these power supplies to use, they all do the same thing, but one does have better customer reviews than the other ones. In the end they all do the same thing and have the same features, so it's just on the discretion of the group for which one to use for the project.

After the group discovered that the BTF-LIGHTING LED Panel could not be used for the purpose of the project and the BTF-LIGHTING LED strips will be used instead this made the decision easier for the group to choose which LED driver to use for the project. In the link for the Amazon page for the BTF-LIGHTING LED strips a power supply was recommended to go with it called the ALITOVE 5V 10A AC to DC Power Supply Adapter Converter Charger 5.5x2.1mm Plug for WS2811 2801 WS2812B LED Strip Pixel Light. It has 53 reviews on Amazon most of them being positive and is made to be compatible with the BTF-LIGHTING LED strips. There is a Table 37 shown below making a comparison between the LED drivers.

Table 37: LED Drivers Comparison Table

	Researched LED Drivers	ALITOVE 5V 10A Power Supply
Compatibility	– Not all of them are compatible for the purpose of the project. – They all support the voltage that the LED's need. – None of them support the current.	– Most compatible with the LED product that will be used for the project. – This product supports exactly the voltage and current that is needed for the BTF-LIGHTING LED strips.
Usability	– All the LED drivers were meant for the LED product that was thought would be used in the project.	– The LED driver is meant to be for the current LED product that will be used on the project now.
Pricing	– For these LED drivers the prices are all very similar.	– The price of this LED driver is similar to the other ones researched.

As shown in the table above, the decision to use the ALITOVE 5V 10A AC to DC Power Supply Adapter Converter Charger 5.5x2.1mm Plug for WS2811 2801 WS2812B LED Strip Pixel Light turned out to be the best because of the sudden change in LED product that is needed now for the project. Since two BTF-LIGHTING WS2812B 144 LEDs/Pixels/m Black PCB Individual Addressable Full Color led Pixel Strip Dream Color Non-Waterproof 3.2FT 1m will be needed for the project because 256 LED's are needed, then that means that two power supply adapters will be needed to be able to provide power to all of those LED's.

5.4 L293D Stepper Motors and Implementation

When building the XY plotter, the electrical components are essential in order to move the game piece around the surface. In the beginning phase, the L293D may be the chip to connect two stepper motors for movement.

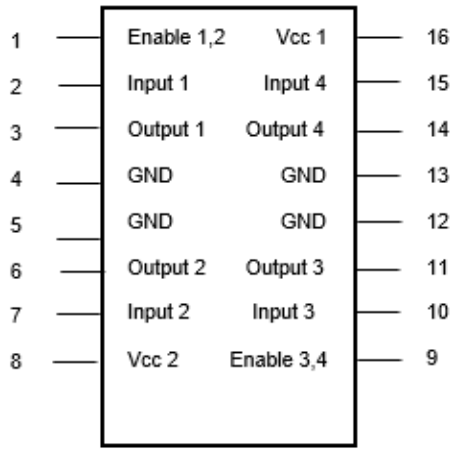

Figure 18: L293D pinout diagram

Table 38: L293D Function Table

Pin No.	Function	Name
1	Enable Pin for Motor 1 (Active high)	Enable 1,2
2	Input 1 for Motor 1	Input 1
3	Output for Motor 1	Output 1
4	Ground	Ground
5	Ground	Ground
6	Output 2 for Motor 1	Output 2
7	Input 2 for Motor 2	Input 2
8	Supply Voltage for Motors (9-12V)	Vcc 2
9	Enable Pin for Motor 2 (Active high)	Enable 3,4
10	Input 1 for Motor 1	Input 3
11	Output 1 for Motor 1	Output 3
12	Ground	Ground
13	Ground	Ground
14	Output 2 for Motor 1	Output 4
15	Input 2 for Motor 1	Input 4
16	Supply Voltage (5V)	Vcc 1

Buying enough L293Ds can be feasible to connect the two stepper motors for this project. The reason for this is that when connecting them in multiple ways and regulating power may damage the L293Ds in the long run so it is best to buy them in bulk just in case.

At first, the ULN2003 was the choice for the stepper motors however, the L293D has the advantage of making the motors reverse their positions and they can operate independently due to the H-bridge concept which means that the stepper motors will move clockwise or counterclockwise depending which can add more flexibility in the system when playing the game. By using the PCB software, other things must be considered of what type of a stepper motor must be used for the XY plotter.

5.5 ULN2003 Implementation

Previously, choosing the ULN 2003 would have been ideal choice for the stepper motors. It can be useful when connecting to the Arduino MEGA 2560 due to amplification. It consists eight outputs which each of them has the functionality of amplifying signals from the Arduino MEGA 2560 to large devices. However, it consists of having one sink current which only allows to only work for unipolar stepper motors. In this project, bi-polar stepper motors may be used for complex movement.

5.6 XY's Plotter Magnetic Holder

The pencil holder is mostly used in most XY plotter design. However, the pencil holder will change to a magnetic holder. The pencil will be replaced with a magnetic piece and will be inverted in order to make a near contact with the gameboard underneath. It will move millimeters away from the surface to avoid any magnetic sensor and the touch the surface to the specific game piece and drag the game piece to the designated location by the player by the function of the micro servo. Once it is done moving the game piece, it will go back to the center of the board millimeters away from the surface.

5.7 Microcontrollers

This project will be executing multiple tasks in one single gameplay, a microcontroller is an important component in building the project. They generally contain multiple pins and each of them have certain function. Since an application is involved which contains a user interface, a microcontroller will be connected during this process. Two microcontrollers are considered for this project which are the Raspberry PI and the MEGA Arduino 2560. However, only one of them will need to be chose for the project. These are be possible critical components that connects the user interface and the hardware system which includes the stepper motors and motor driver for movement and sensor operations.

5.7.1 Raspberry PI and Implementation

Considering codes are going to be used during this project. RASPBERRY PI is an electronic chip that allows for gaming visual effects and moving the XY plotter. It a low-cost microcontroller and contains a decent memory.

This can be widely used on the visual effects and media which are essential into the game. It might as well include HDMI quality when illustrating on the users' gaming application when showing the HP and Armor Level with a custom interface. Also, this microcontroller can manage sound effects and distinctive audio in the game. It can also selectively light up LEDs and change the brightness with the help of LM3402 electronic chip. It can send commands to the L293D to activate the Stepper motors in order to move the XY plotter.

At first, the other microcontroller was MEGA 2560 due to multiple features, however, Raspberry PI microcontroller is familiarized by computer engineers in this project. They have a strong foundation of Raspberry PI's programming code and Raspberry PI can behave like a little computer and it can manage high level power which is necessary for this project.

For this microcontroller, the appropriate coding framework is the phyton rather than using C programming. The reason for this is that the computer engineering students are familiar with the modules and object instructions for this type of code. That being mentioned, the Raspberry PI is the most efficient microcontroller for this project.

5.7.2 Arduino MEGA 2560 and Implementation

The Arduino MEGA 2560 may be another choice as a microcontroller. It may not have as many external pins as the Raspberry PI, but it can function the same way and accomplishing the specifications of the project. When there is an external power connected to the Arduino MEGA 2560, the board can operate up from 6V to 20 V, but the recommended to avoid overheat and damage to the board is 6V to 12V which is more than enough for the project to work especially when the stepper motors are involved.

The problem will arise when connecting to the LEDs, motor driver, and the Stepper motors. By using the PCB software, a schematic will be developed with the Arduino MEGA 2560 along the connections of these main components. Also, it has a feature that can protect the USB from damage.

There is no significant modification on the board when it comes to connect the LEDs, however, the board will be dealing with the stepper motors which means producing higher current. From that, an IRF520 MOSFET needs to be implemented with a 1N4007 diode connection. This MOSFET will control the bigger loads when initiating the stepper motors on the XY plotter and the diode will

be used to protect the overall circuit. This can be very effective on using the PWM signal for these types of operations and this Arduino MEGA 2560 can provide this process.

5.7.3 Raspberry PI Vs. Arduino MEGA 2560

The Raspberry has a lot of functional pins that are not going to be used in this project due to limited time. Raspberry Pi is described to be a “mini-computer” due to its complexity. After having advices from experts and online articles that elaborate more on the Raspberry PI, it was concluded that this microcontroller is not a viable option for this project even though the requirements are achieved by it.

The problem of this situation is that the microcontroller can do much more rather than doing simple functions for a higher price which can be counterintuitive. Therefore, the MEGA 2560 is an Arduino microcontroller that fits for this project. This type of the microcontroller is meant to do simple functions that are necessary for the project. The main goal is to achieve the requirements and implement them as simple as possible in order to budget and avoid complexity during the making of the project.

Arduino MEGA 2560 can consume significantly less than the Raspberry PI which means there will be no problem in setting high voltage in the project. Also, Raspberry PI can do a very well job in using for HD screens or large screens since it contains a HDMI, however, this project will consist no such thing. For the durability, the Arduino MEGA 2560 is the right choice for the project making.

5.8 XY Plotter’s Stepper Motors

These XY plotters are widely used for printers since the main functionality is drawing or scan documents. However, the XY plotter would be used just to have a magnetic holder which will be pointed upwards the base of the transparent surface.

The XY plotter will move the game pieces just underneath the 16x16 transparent surface. The essential components are the step motors for smooth movements on the gaming board. Since the stepper motors can simultaneously move game piece to the designated location rather than moving it in a rigid motion and they are extremely reliable.

Two stepper motors are going to be assigned to move in X and Y motion respectively and they can move in different rates and deliver the game piece to the designated location once the magnetic holder grabs the game piece. DC would have the choice, however, once assigned to their respective axis of motion, they will cause the game piece to move rigidly. For the stepper motors, that will not be

the case since they can set different rates of speed which can cause the game piece to move smoothly.

The next motor would have been the servo motor, this motor could have been the ideal choice for this project due to precision in terms of acceleration and velocity, however, the complex circuity for this device is quite overwhelming and requires a difficult search to acquire such a device so the most feasible choice is still the stepper motors.

Also, the stepper motors have external pins that can be used for the microcontroller which can essential for the project since the connection between the user's application and the XY plotter is used by using the Arduino MEGA 2560 microcontroller.

Another significant consideration is the stepper motors are needed to be unipolar since they are easy to configure, there is no need for a bipolar stepper motors since they are complex to connect and difficult to drive them. With the help of the L293D, it consists of a H-bridge circuit which can help the unipolar stepper motor to have better torque and efficient.

5.8.1 Appropriate Frame Size for Stepper Motors

The XY plotter will require amount of torque and adequate speed for the game pieces to move around and other components. The bigger the frame size of the stepper motor, the higher amount of torque, speed, and power it can deliver. In this case, the XY plotter will required only a medium-sized stepper motor to accomplish medium speed and medium-level power. The stepper motors can be measured in terms of NEMA. The appropriate stepper motor that can be used for this project will be NEMA-17 in terms of price and the amount of 'holding torque' it can provide in this project, with this shown below in Table 39.

Table 39: NEMA 17 Specifications

Holding Torque	59 N-cm
Rated Current Per Phase	2 A
Frame Size	42x42 mm
Rated Voltage	12-24 V
Resistance per Phase	1.4 Ohms

This is the optimal choice because it will be within the project budget and the frame size is adequate for the XY plotter assembly. Another thing to consider is the power

supply per stepper motors. The rated voltage is the important parameter to choose a chopper driver controller.

5.8.2 Stepper Motors' Power Supply/Chopper Driver Controller

The power supply for the stepper motors is critical for operation. The power supply voltage should be slightly higher than the rated voltage of the stepper motors for better performance in terms of speed and torque. However, the more voltage and current the power supply delivers, the more heat will dissipate on the system which can cause to overheat and damage the system. It is best to choose a stepper motor with adequate voltage limit in order to avoid this possible predicament. They cannot connect straight to the power supply; the chopper driver controller must be presence to avoid damage to the stepper motor.

The chopper driver controller can give high constant current to give the stepper motors more torque and keep stepper motors safe. They can 'chop' unnecessary high voltage that can damage the stepper motor.

It is imperative to choose carefully what type of chopper driver controller is necessary to use a specific stepper motor. In order to avoid any damage, important specifications of the stepper motor must be considered such as "amps per phase" – how much current can the stepper motor can withstand without overheating and "resistance per phase"-resistance per phase. Calculating these two parameters gives voltage. Usually these chopper driver controllers are rated by voltage.

5.8.3 TB6600 Stepper Motor Driver

By general knowledge, stepper motors cannot be connected straight from the power source. Between the power source and the stepper motors, there will be a chopper driver controller so that the stepper motors can operate. The various specifications are shown in Table 40. This chosen stepper motor driver will be bigger than the stepper motor themselves, however, this is not vital for the project because this motor driver and accomplish well with the NEMA 17 stepper motor.

Table 40: TB6600 Stepper Motor Driver Specifications

Current Control	0.5-3.5 A
Frame Size	96x56x33 mm
Rated Voltage	9-42V

This is generally used by most stepper motors due to specifications in terms of current and voltage. The location of this stepper motor driver will be a challenge in this project. The best way to accomplish this is to put the motor driver next to the stepper motor. Based on this model, two motor drivers are required for the two stepper motors.

Once the XY plotter is assembled, the motor driver and the stepper motor will be right next to each other and will be place on the edges of the XY plotter to avoid physical interruption when the gameplay takes place. Another thing to consider is to be aware how the power source will be connected to the motor drivers. The connection between the power source and the motor drivers must modified.

5.8.4 Motor Controller

The motor driver could be the ideal choice for the project due to cheap pricing. However, the disadvantage is to put so much thought in building the circuit with the motor driver. The motor driver does not have feedback like the motor controller if an error occurs.

Even though the price for a motor controller is relatively higher than the motor driver, the motor controller will be the choice for the project due to feedback from the functions of the stepper motors when moving the game piece on the 16 X 16 grid. The feedback system allows for the motor driver to correct the devices themselves when an error has occurred which is an effective use for the project.

5.8.5 Pololu DRV8833 Dual Motor Controller

The right choice for the project will a motor controller due to its feedback functionality. It will correct itself if the execution is incorrect due to the interference with other magnetic sensors or the code in general when testing the XY plotter. The Pololu DRV8833 is chosen to execute physical movements from the XY plotter by using NEMA 17 stepper motors. This specific type of this motor controller is chosen when following the parameters. The rated voltage of the motor controller must be higher than the rated voltage of the stepper motors. This dual motor controller can operate only one bipolar stepper motor, therefore, there will be two motor controllers, which is shown .in Table 41

Table 41: Pololu DRV8833 Dual Motor Specifications

Current Control	13 A
Frame Size	75x43 mm
Rated Voltage	5-30V

5.9 Configuration

In the project, the configuration will be initiated by connecting the appropriate chips so they can do individual tasks in the XY Plotter as well the assembly. The Arduino MEGA 2560 microcontroller will be connected to the LED drivers and the L293D electronic chip in order to move the stepper motors. LEDs will be placed right underneath the surface connected to the microcontroller Arduino MEGA 2560.

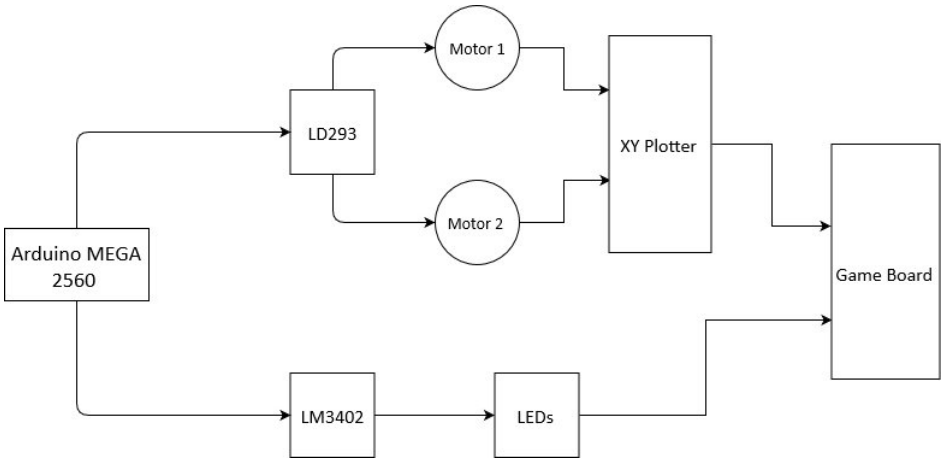

Figure 19: Simple hardware configuration

The XY plotter will be right underneath the transparent surface (game board). The Arduino MEGA 2560 will be considered the main microcontroller and connects the LD293 and the LM3402 electronic chip which they can do their tasks respectively. The Arduino MEGA 2560 will receive all data commands from the players and the Dungeon Master and sending those commands to its respective electronic chips. The LD293 chip will be used for movement and the LM3402 for visual effects. This whole system can be operated by using the linear power supply. The Figure 19 represents the general flow of the configuration.

Most components will be connected to the Arduino MEGA 2560 microcontroller from which, it can send commands from. The great advantage about the Arduino MEGA 2560 is that it consists multiple connections and ports and have a function of a small version of a computer.

Since the project can consists multiple features including audio interface, color brightness for each multiple scenarios of gameplay, and directing command movements to the stepper motors which then move the magnetic holder that can hold or attach the game piece and drag from one position to another at the time of the player's choosing during his or her turn.

5.10 Testing

For the hardware aspect of the project, it is essential to test the connectivity between Arduino MEGA 2560 and the electronic chips for optimal performance.

The XY plotter will be tested by selecting a location on the gameboard so that it can carry that game piece to that location. The connectivity between the stepper motors and the data chip LD293 is then altered if the XY plotter do not have the capability to transport the game piece to the designated location. The LEDs can be tested by the Dungeon Master to use a specific color to see if the LM3402 can receive that command from the Arduino MEGA 2560.

The modification for the XY plotter is having a magnetic holder and getting close to the gameboard as close as possible. The magnetic holder must be intact when the XY plotter starts moving the game piece and observe if it can operate appropriately when selecting specifically the game pieces whilst avoiding other magnetic sensors therefore, the connection between the Arduino MEGA 2560 and the magnetic holder must be tested for the project to work.

Since the project will be required to use high-level power, it is imperative to take extreme caution when testing the linear power supply in order to power the XY plotter and the LEDs. To test this aspect, a small prototype of the project will need to create which will consists small number of LEDs, LED drivers, along with a spare Arduino MEGA 2560 and run a sample gameplay scenario to observe their functionality.

6.0 Project Design Summary

Whenever the XY plotter is to be purchased or to be assembled, some steps are needed to be taken account in regards of configuring the XY plotter which includes the stepper motors, motor driver, and the use of the Arduino MEGA 2560. In the software section, the interface is going to be developed for gaming players and the development of the data path that will be taken place on the 16x16 grid for the movement of the game figures during gameplay.

6.1 Hardware

The connection of the magnetic sensors, LEDs, and the stepper motors are vital for the project. The assembly of XY plotter will consists two stepper motors, magnetic holder, and other parts which then can be dependently connected to the electronic chip LD293 to generate movement of the XY plotter with the help of the stepper motors which ultimately can be connected to the Arduino Mega microcontroller.

For the LEDs, the Arduino MEGA 2560 can connect the LM3402 which is the appropriate device to connect to the LED drivers and then to the LEDs. The LEDs are going to be located underneath the gameboard since the surface itself is going to be transparent for visual effects. For the power source, the AC-to-DC linear power supply will involve a transformer for the change voltage level, rectifier, and numerous capacitors along with a voltage regulator.

6.2 Software

In the software aspect of the project, coding will take part for the Arduino MEGA 2560 to function including place movement by using data path which will create multiple algorithms or possibilities of movement and choosing the optimal path for the game piece to move around the obstacles that can be created on the 16x16 grid game board.

When the player can choose a location to move, the Arduino MEGA 2560 microcontroller will send programming algorithms for sensing communication which then communicates to the XY plotter to choose a game piece and move to a certain location. Also, the Raspberry will display a visible interface indicating health and armor level of the character created. From there, the interface can store and modify data to upload certain statistics after finishing a battle or doing some certain action during gameplay.

7.0 Project Prototype Construction

If assembling the XY plotter is the right choice for the project, then the main components are needed to be taken account when building it. Parts are going to be acquired when assembling the XY plotter will be shown in the following tables and a summarized procedure on how to assemble the XY plotter.

7.1 Parts Acquisition

The parts are going to be obtained for the building of the XY plotter along with the main components. The general aspect of constructing the project is shown in Table 42.

Table 42: Hardware Parts Acquisition	
2	NEMA 17 Step Motors
2	TB600 Stepper Motor Drivers
2	LM3402 Electronic Chips
2	LD293 Electronic Chips
2	Beam 0824-496
2	Beam 2424-504
2	Linear Motion Shaft D8x496mm
1	BTF-Lighting LED Driver
256	Reed Switches
256	CHINLY WS2812b LEDs
1	Arduino MEGA 2560 Microcontroller
1	Magnetic Holder
1	16x16 Transparent Gameboard

7.2 Assembly

Building the XY plotter will require multiple components including the stepper motors, motor controller, the magnetic holder, LEDs, and the Reed switches. This could be choice in order to avoid any waiting time after purchasing an XY plotter. Multiple main steps must be considered in order to assemble the XY plotter. This assembly process is described in the Table 43.

Table 43: Assembly Steps for the XY Plotter and Additional Components	
1	Acquire parts and main components
2	Start building the outer layout of the XY plotter
3	Confirm that the XY plotter should be nearly equal to the 16x16 grid
4	Convert the pencil holder to a magnetic holder
5	Apply a stepper motor (NEMA 17) on the side of the XY plotter
6	Apply another stepper motor (NEMA 17) on the opposite side of the XY plotter
7	Connect the each L293D electronic chip to each stepper motor
8	Connect two chopper driver controller (TB6600) to each stepper motor respectively
9	Acquire LEDs and Reed Switches for the 16x16 grid
10	Connect respective LED drivers to the LEDs and place a Reed switch for each individual square grid
11	Connect an additional LM3402 electronic chip for each LEDs for Pulse Width Modulation (PWM)
12	Connect additional wires from the LED drivers, L293D electronic chips, LM3402 to the Raspberry microcontroller

The placement for these components would be a challenge. The Arduino MEGA 2560 and other main components would be placed on the edges of the XY plotter and building some type of cover walls to hide those components for the project to be more presentable which is referenced in figure 3. In the figure 3, it shows the whole outline of the project.

Ideally, the Reed switches on would be placed on the top of the XY plotter with a transparent surface of 16x16 grid gameboard. Once this project is built for presentation, the weight may be an overwhelming concern since so many components are involved and the extra weight from the XY plotter may add the overall weight and dimension, therefore extra caution is needed.

7.3 XY Plotter Assembly Vs. Purchasing

The assembly of the XY plotter will be beneficial to have a strong comprehension on how the XY plotter works, however, the time to assemble and the test its features is going to take longer than expected even though if outside help is involved. For that reason, purchasing XY plotter is the only viable option due to limited time given for this project. The ideal parameters of the XY plotter should be slightly larger or equivalent to 16x16 grid. It is imperative to see if the XY plotter can be modified to satisfy the conditions and requirements for the project. The types of XY plotter may also be a factor to consider as well.

7.3.1 EleksDraw XY Plotter Pen Writing Machine

Since buying the XY plotter is the most appropriate option in doing the project, the EleksDraw XY plotter will be bought and used for testing when connecting the Arduino MEGA 2560. However, the size is quite smaller than expected. The working size of 11 X 7.9 and the cost are quite high if the purpose of buying the XY plotter is to test the pin functions from the Arduino. This product may need to be modified including changing the stepper motors to NEMA 17 stepper motors and the magnetic holder as well.

7.3.2 ETE ETmate XY Plotter

For this XY plotter, the ETE ETmate is slightly bigger than the previous product. The working area for this specific XY plotter is roughly 8.3 X 11.7. However, this product is more accurate which is essential to the project when transporting the game pieces on the gameboard and a linear power system may not be required. With that considered, the power source would be 12V DC. C programming language is needed for this type of XY plotter.

7.3.3 Autek Laser Engraving Machine

After searching three products that were nearly satisfying technical parameters which are voltage requirements and the grid size. Since the XY plotter had to be bigger than 16 X 16 to work, the Autek Laser Engraving Machine XY plotter is the right choice for this project. The working size of this XY plotter is the 17.7 X 17.7 which is bigger than 16 X 16 to work with. The problems will arise when configuring this XY plotter to have a magnetic holder and a micro-servo installed.

7.4 Project's Transportation/Storing

Once the project is built and tested, the temperature must take account when storing the project in a house. The temperature in Florida is usually very hot which can damage the circuits all together. To prevent this from happening, the ambient temperature should be calibrated to 65 degrees Celsius for storage. The project should be avoided from pets and moist environments for safety purposes. The location to where the project will be built will on one of the member's apartment due to space. Since the project will be built by 16X16 size, the room provided for Senior Design will be small and inconvenient for the project. The size of the doorway will be too small to get the project out of the room once it is built and completed. Therefore, the place will be in one of the team member's location.

Due to the construction of the project, the weight would be too overwhelming to transport for presentation. In order to easily transport the project, a platform constructed slight bigger than 16x16 size can be built along with four wheels on each side if necessary. Since the project would be constructed in one of houses of

the participants, a truck would be necessary to deliver to the presentation. To lift the project to the truck, it would simply require all four participants to do such action. These parts acquired may be subject to change in order to minimize the weight of the project to avoid any complications regarding of transportation.

7.5 Power System AC to DC Converter

The game board will come with many electronic components that will require a DC voltage supply. The power supply purchased may not have enough watts to power up all components hence an AC to DC converter circuit will need to be researched to guarantee all parts have enough power to operate.

7.5.1 Power Cord

To start off, the first thing needed is an AC power cord. It should come with a standard plug that will fit into any wall outlet. The power cord should be long enough (estimate 6-9 meters).

7.5.2 Power Transformer

The transformer is needed in the converter circuit design since the input voltage from any regular wall outlet is 120v and this may be higher than the voltage required for any of the components such as the microcontroller and electromagnet on the game board, therefore a transformer may be needed to bring the voltage down to a more desirable and manageable level for the electrical components.

7.5.3 Rectifier

A full wave rectifier will be needed for this circuit, it consists of two diodes with a transformer or a diode bridge made up of four power diodes which is called a bridge rectifier. For converting from AC to DC signal, a bridge rectifier has more advantages than a full wave rectifier since it does not require a special centre tapped transformer which in return reduces the size and cost for their project. The single secondary winding is connected to one side of the diode bridge network and the load to the other side.

7.5.4 Voltage Regulator

A voltage regulator generates a fixed output voltage of a preset magnitude that remains constant regardless of changes to its input voltage or load conditions. Even though after proceeding with all the previous steps most of the signal is already a steady DC signal, the many variations in voltages can potentially harm the components in their board that are being powered up hence why a voltage regulator is necessary. It can consist of a resistor is series with a diode, the purpose of the resistor is to dispose of any unnecessary voltage from both the

capacitor and rectifier. The resistor and diode also take the signal input from the rectifier and smooth the signal out into their desired voltage output.

After the group have successfully set up the transformer, rectifier and voltage regulator. The expected voltage should now meet the voltage required for the components in their gameboard to work suck as the microcontroller, LED, sensors. If needed, two AC to DC circuits will be used if the motherboard power supply is not enough to power the components mentioned below.

7.6 Alternative Power Source 12 V DC

The AC-to-DC converter was the viable option for the project, however, the assembly for this circuit will create potential electrical risks and safety. This task would be somewhat a distraction for the real focus and objective for the project.

Most of the focus would be on configuring on a XY plotter and implementing a data base which includes web server connection on a 16X16 grid.The LED drives have their own power source and each of the them can power up to 144 LEDs which is more than enough. Also, the cost would be relatively expensive especially when constructing a transformer component in the power system.

8.0 Project Prototype Testing

The idea of testing this project is to produce a small scale XY plotter to test its functions along with the connection with the Arduino MEGA 2560, the LEDs, and the stepper motors. A few scenarios of gameplay will be taken place and test the movements of the game figures on a smaller size than 16x16 grid.

8.1 Hardware Test Setup

The procedure is to test the LEDs and the LED drivers while using the LM3402 and the Arduino MEGA 2560 once the code and the software setup has taken place This is to see how the electronic LM3402 can receive the commands from the microcontroller when a user, the Dungeon Master in this case, can manipulate the level of brightness and the intensity of the color from the LEDs before placing the LEDs on the transparent 16 x 16 game board.

When the XY plotter is assembled and the L293D is connected to the stepper motors. The Raspberry will be connected to it and ran sample run of code to see if the XY plotter can drag the game piece to the specific coordinate. The power supply must be carefully observed since it may draw to much heat into the system when operating the XY plotter.

8.1.1 Sensor Setup

The sensors being used for this project called reed switches will be setup as a 16x16 matrix, which means that 256 reed switches will be needed to make the matrix. After research being made it has been discovered that to set up the matrix using reed switches that it will also need diodes. The specific type of diode that will be used in the reed switch matrix is called 1N4148. Other components that will also be needed to make the reed switch matrix are as follows in Table 44.

Table 44: Reed Switch Component Table

	Quantity	Component
Reed Switches	256	Reed Switches
Diodes	256	1N148 Diodes
Resistors	36	10 kOhm resistors
Shift Register	2	74HC595
Shift Register	2	74HC165
Microcontroller	1	Arduino Mega 2560

As shown above, all of these components are needed to make the reed switch matrix work, it is specifically being used to be programmed with the Arduino Mega 2560. The reason why the reed switches need diodes is because “ghost” connections can occur as in the microcontroller mistakes some of the reed switches as being activated when they’re not. The diode is what takes care of the problem by it being placed in series with the reed switches.

The resistors are needed to be able to connect the reed switches-diodes to the Mega 2560. As a way of making it possible to create the reed switch matrix one of the group members will create a PCB that will make it possible to connect the components to the Arduino Mega 2560. This will all be tested on a small scale before it’s built on a large scale to make sure that it will work and be compatible for the purpose of the project. Below is a diagram on how the reed matrix by itself will look like.

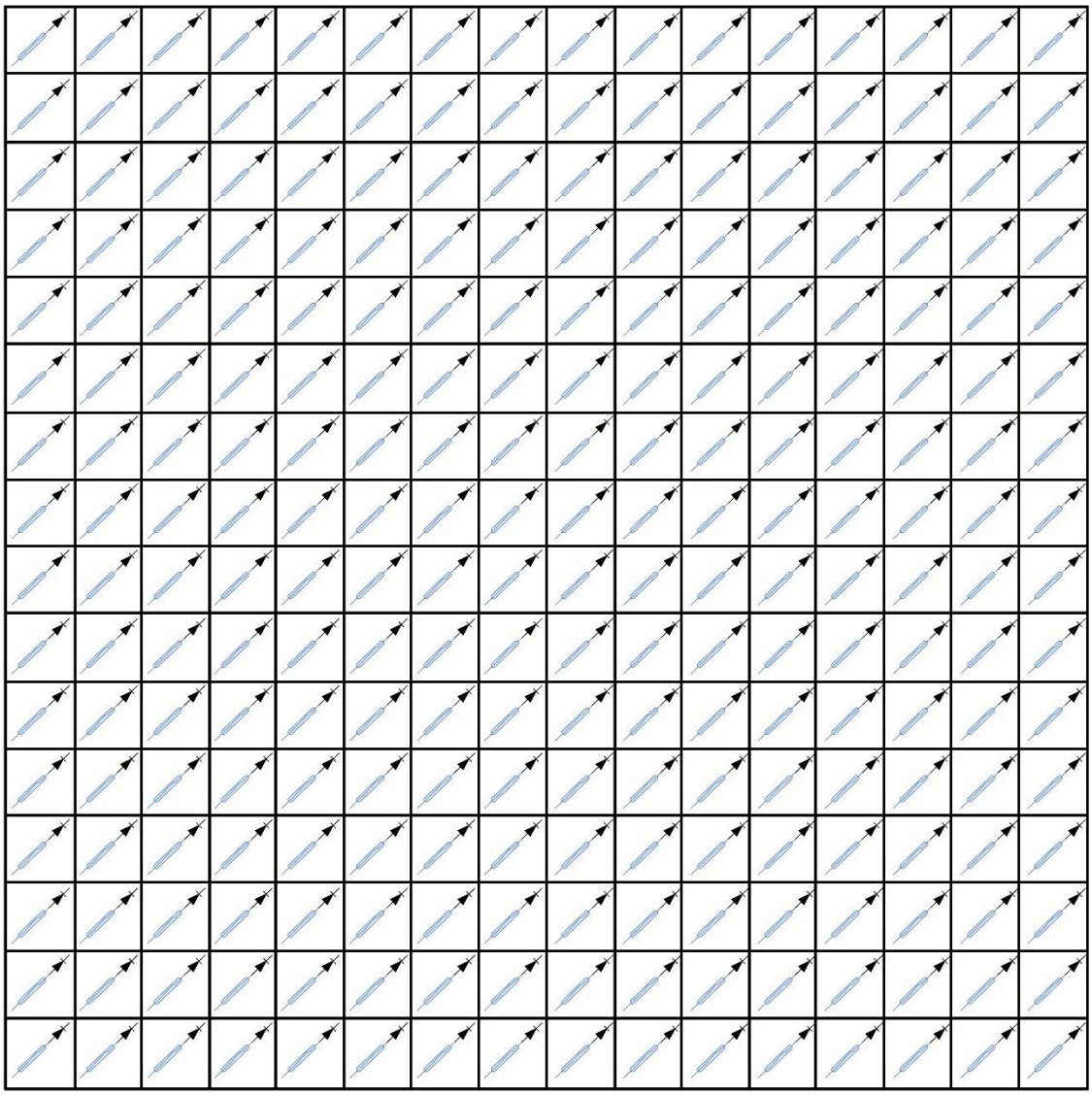

Figure 20: Reed Switch Matrix

As shown above within Figure 20, this is exactly how the reed switch matrix will look like once it's assembled. As noticed, there are a lot of reed switches and diodes in this matrix. It will take the electrical engineers a lot of time to be able to assemble this matrix and they may even need help from the computer engineers in the group to also help assemble it.

Connecting it to the resistors and then the Arduino Mega 2560 should not take to long in comparison to how long it will take to assemble the matrix. This will be the most efficient way to have the matrix set up and the reed switch matrix will still be easier to set up in comparison to the hall-effect sensor which is the alternative that will be discussed in the next paragraph.

An alternative to the reed switch matrix doesn't turn out to work well for the project would be to then make a hall-effect sensor matrix instead. It would take more

circuitry and wiring to make it work, but it is a very good alternative in case the reed switch matrix doesn't work or turns out to be more complicated than the group thought. As the comparison that was made before shows that hall-effect sensors are not as modern and efficient as reed switches, but in theory they are perfectly fine to work for the purpose of the project. Below is Table 45, which shows what components would be needed to make the hall effect matrix work.

Table 45: Hall-Effect Sensor Component Table

	Quantity	Component
Sensors	256	Hall-Effect Sensors
Resistors	64	10 kOhm resistors
Decoders	2	Multplexer/Demultiplexer
Microcontroller	1	Arduino Mega 2560

As shown above, there are less components needed to make a hall-effect sensor matrix, but there are more things needed to assemble it and put it together. For example, all the hall-effect sensors need wiring up to each other to make the matrix and they need additional circuitry, and an active voltage and current on always for it to work. In the end, the group will use hall-effect sensors only if it turns out that the reed switch matrix is more complicated and costly to setup than originally thought.

From the research found, the reed switch matrix should turn out to be easier to set up and less expensive to set up. The hall-effect sensor is strongly not recommended for the group to build because of how long it will take to build and because of all the wiring and circuitry that it would need. Below a diagram is shown on how the hall-effect sensor matrix would be set up in case it's needed, and it will more clearly show why it's not recommended and how it will be harder to set up than the reed switch matrix.

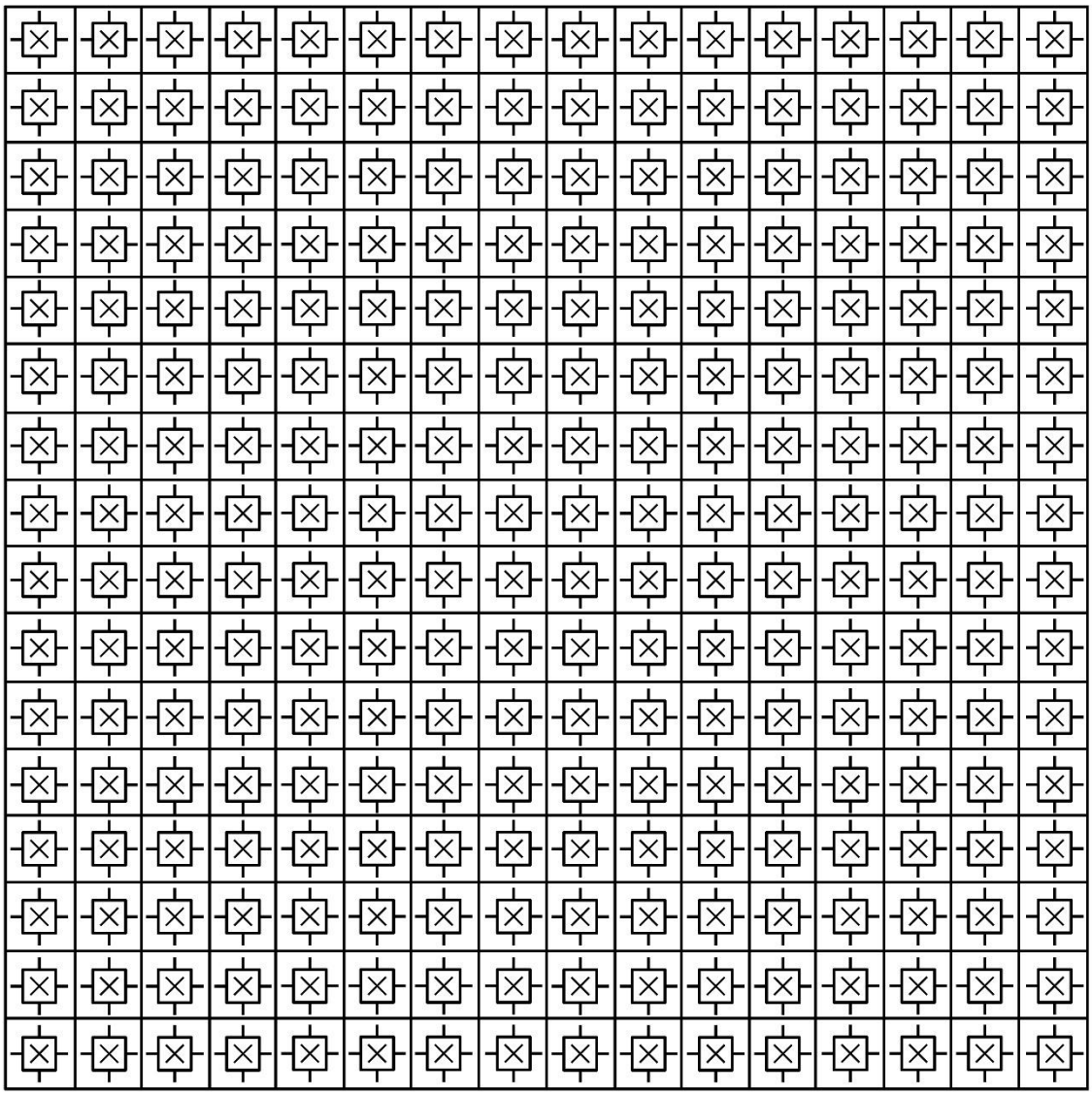

Figure 21: Hall-Effect Sensor Matrix

Shown above within Figure 21 is exactly how the Hall-Effect Sensor Matrix will look like when it's assembled. The only thing that is not shown in this matrix is all the wiring that will be needed to connect the hall-effect sensors in sequence to each other. The hall-effect sensor matrix would need more resistors to be able to connect to the power supply circuit, it will also need more than just one power supply to connect all the resistors needed to power all the hall-effect sensors. In previous projects, like this one it is not much of a hassle to use hall-effect sensors because these projects have only used and needed an 8x8 matrix.

That while still challenging is not too difficult or time consuming to set up because only 64 hall-effect sensors are needed to set it up. For this project 256 hall-effect sensors would be needed. It will already take a long time to set up the reed switch matrix which doesn't even require wiring or a power supply to work. It's obvious that a hall-effect sensor matrix is to be avoided if possible.

8.1.2 LED Setup

The way the LED's are going to be set up are by cutting the LED strips to the length as needed to match the dimensions of the board. Each individual LED is going to be placed under each individual square.

The LED's then will be set up in a matrix and then they will be connected to LED drivers that will supply power to them, then the LED's will also be connected to the microcontroller to be able to program each individual LED. In general, there is not much needed to set up and make the LED's work.

The challenge may come with programming it with the microcontroller and being able to connect all the LED's to the ports available in the Arduino Mega 2560. Table 46, which is shown below, lists everything that's needed to set up the LED's.

Table 46: LED Component Table

	Quantity	Component
LED Product	2	BTF-LIGHTING LED Strips
Power Supply	2	ALITOVE 5V 10A Power Supply
Microcontroller	1	Arduino Mega 2560

As shown on the table above there is not much needed to set up the LED matrix for the board. Two of the BTF-LIGHTING WS2812B 144 LEDs/Pixels/m Black PCB Individual Addressable Full Color led Pixel Strip Dream Color Non-Waterproof 3.2FT 1m should be more than enough for the matrix since only 256 are needed to go under each square on the board and it's great that it will bring 32 extra LED's in case it's necessary to have more.

It is important that the LED's can go under each square on the board to be able to illuminate the whole board. The purpose is for them to look nice and light up pathways that are taken in the game.

Two ALITOVE 5V 10A AC to DC Power Supply Adapter Converter Charger 5.5x2.1mm Plug for WS2811 2801 WS2812B LED Strip Pixel Light will also be more than enough for the project because the LED strips can only handle up to 5V, any more than that will burn out the LED strips. Then, to be able to program each individual LED it will be connected to an Arduino Mega 2560. The LED's will make the board really light up and look nice.

The LED's aren't really needed, but it is just for aesthetic purposes. They will also be programmed to light up the path of the game and where the characters are going. Below is a diagram showing how the LED matrix will be set up and look like.

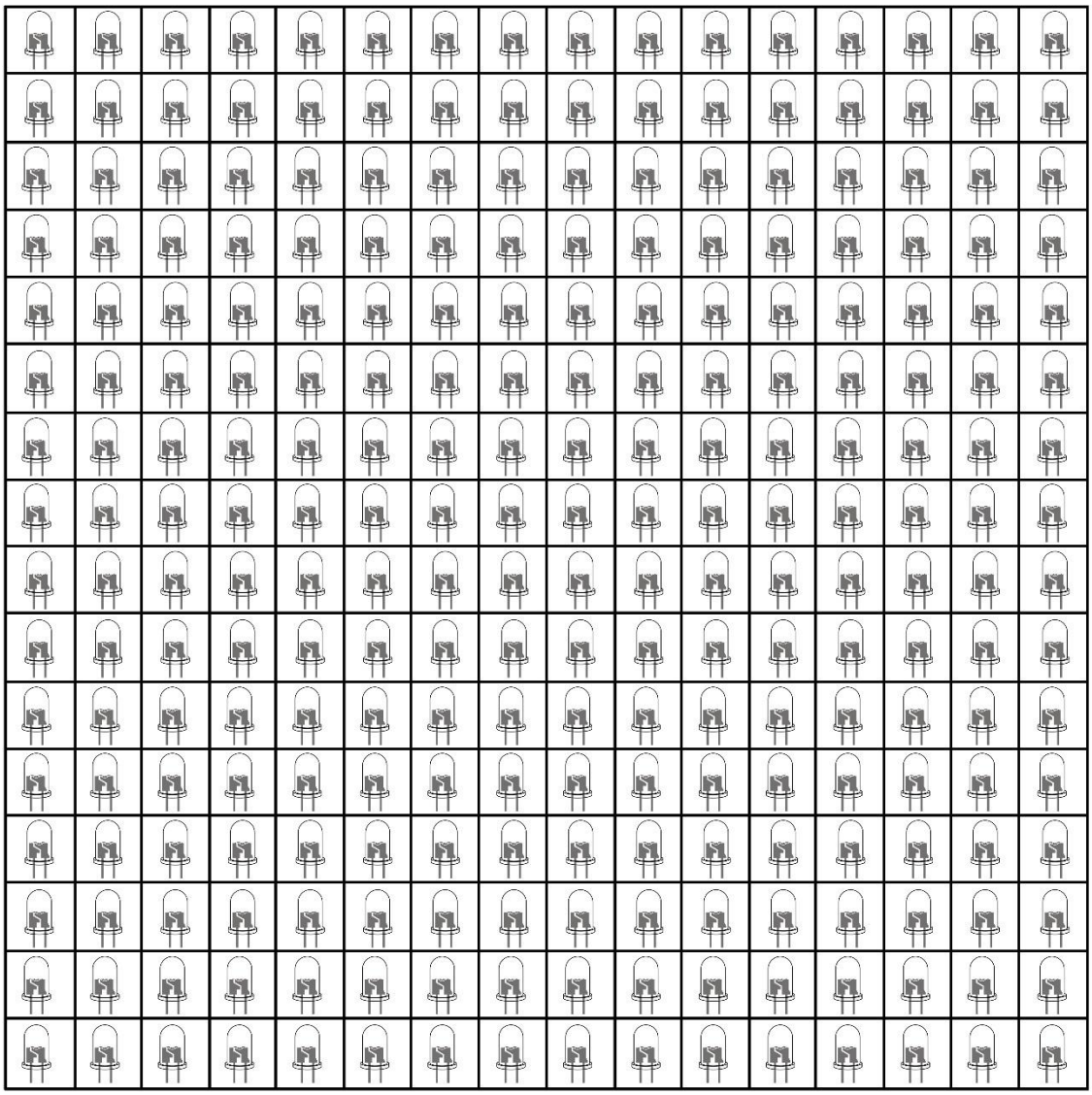

Figure 22: LED Matrix

As shown above within Figure 22, the LED matrix is very straightforward. There is not too much to it because all that is needed to assemble the matrix is the correct length cut since it's the BTF-LIGHTING WS2812B 144 LEDs/Pixels/m Black PCB Individual Addressable Full Color led Pixel Strip Dream Color Non-Waterproof 3.2FT 1m that will be used.

So, just having the strips spaced out enough from each other to fit under each of the squares and that the strip length matches with the board's dimensions will be all that is necessary to assemble the matrix. Then, to power the matrix it will just need to be connected to the LED drivers and as mentioned before two of the ALITOVE 5V 10A AC to DC Power Supply Adapter Converter Charger 5.5x2.1mm Plug for WS2811 2801 WS2812B LED Strip Pixel Light will be needed to power the LED strips without burning them out.

Then, finally, they will be connected to the Arduino Mega 2560 to be able to program each individual LED. Thankfully, it is not too complicated to set up and it's straightforward. The LED's can all be connected in a sequence and this is represented as follows within Figure 23.

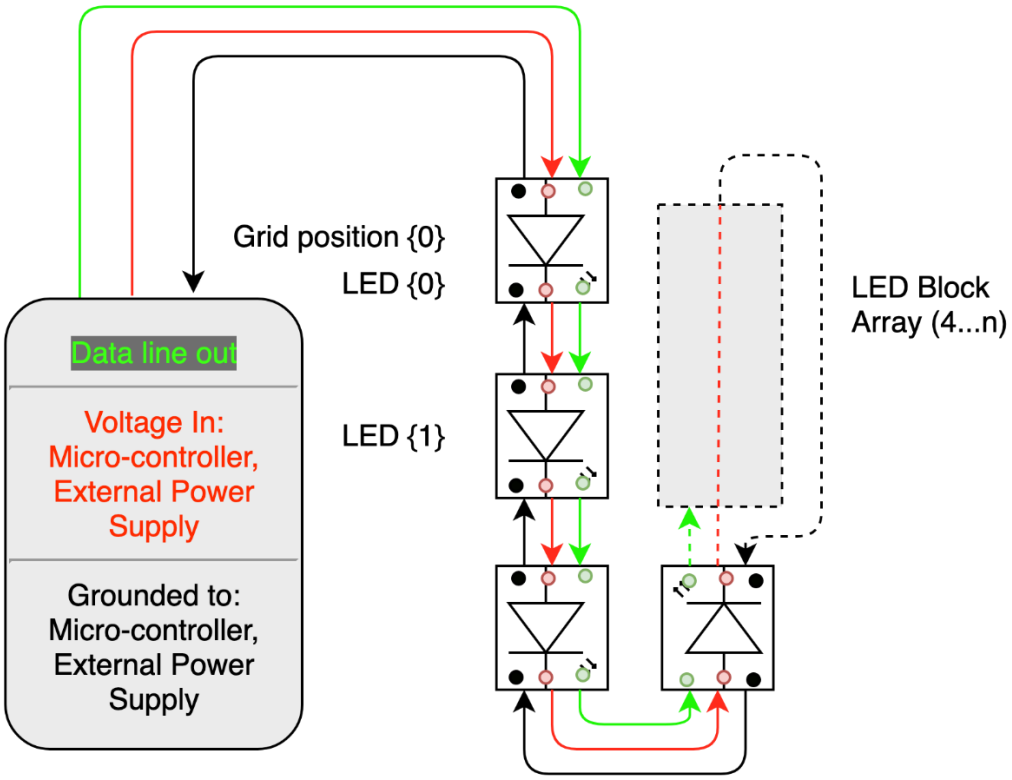

Figure 23: WS2812B LED Sequence

8.2 Hardware Test Plan

After connecting the system with the Arduino MEGA 2560 microcontroller, the most important aspect of the project that needs to be tested is the power supply of the stepper motors. It is crucial to observe how much current is the power supply drawing to the system when running a few scenarios of gameplay and mitigate the risk of being too hot on the stepper motors and the system itself.

The LEDs are going to be tested by building small prototype on the breadboard and using the Arduino MEGA 2560 again and connecting the LM3402 with some LEDs, and LED drivers in order to observe if the microcontroller can change the brightness of the LEDs.

A 'game time' run will be initiated and do multiple scenarios when LEDs will take part. In a case when the 'players' are getting ambushed or attacked by enemies, a reddish color will appear by the LEDs and will be controlled by the Dungeon

Master. The ‘Dungeon Master’ will be using an app for controlling the brightness and colors for the LEDs to perform.

If the LEDs don’t respond the commands from the application, then the connection between the Arduino MEGA 2560 and the LEDs must be checked. The Reed switches are to be tested as well. The magnetic holder in the XY plotter will use evasive maneuver to avoid certain Reed switches when holding magnetic game piece to the desired location.

Since the Reed switches do not require external source power, they are going to be tested individually when the XY plotter starts to move the game piece around. Another consideration is to avoid the Reed switches not to be so close to the LEDs during gameplay. They both need to work independently.

The ideal location of putting on these Reed switches are under the gameboard; however, the LEDs are also going to be there. Several test runs must be taken place and change locations of the LEDs and the Reed switches and then determine which ideal assembly will take part of this project afterwards. Table 47 showcases the procedures that the group will follow.

Table 47: Testing Procedure	
1	Check the functionality of the Stepper Motors and the Chopper Driver Controller for power supply
2	Check the connection between the Arduino MEGA 2560 and the LEDs
3	Run a few scenarios that require LED colors by the Dungeon Master
4	Check for XY plotter’s movement for the game piece
5	Check the functionality of the Reed Switches on the gameboard
6	Run a few scenarios when the game piece is required to move from one location to another location without any interference of the Reed Switches

8.2.1 Sensor Plan

For the Reed-Switch sensors, they are going to be tested for its strength and its functions for the project. In this case, the Reed-Switch sensor will be built on the breadboard and test the its strength with a game figure on the display. The game figures have a small mass and applying a magnetic piece on the bottom to test these types of sensors. The goal for this is to see how effective these sensors can respond with different types of Reed-Switch sensors.

To determine which product can be used in the project is to test the distance between the game figure and the sensor. The shorter the sensing distance, better results. The game figures should be affected on a larger distance as they are meant to be put in place.

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8.2.2 LED Plan

For the LEDs, they are going to be connected to the LM3402 along with the Arduino MEGA 2560 microcontroller. From there, the PWM signal will be used in this process to make sure that the LEDs have certain brightness levels for gameplay. In this case, the LEDs need to have passed certain requirements for the project. To do that, the LED product chosen for the project need to be tested before going large-scale. The best method is to put the circuit design of each distinct LED product all on the breadboard.

Also, the power system will be crucial for the connection of LED drivers which then determines which number of LEDs can be used on the 16 x 16 grid gaming surface. The distribution of power will be critical for those LEDs by verifying how much current can each LED can manage. To avoid any overheating and damage to the LEDs. On a breadboard, an LED driver will be connected to a set of LEDs and able to troubleshoot any connection errors.

8.2.3 XY Plotter Plan

The XY plotter will be bought assembled with a working area of 16 X 16 or greater and do slight configurations on the XY plotter which includes implanting a magnetic holder, motor controllers and changing the stepper motors as well. The XY plotter. As soon as these configurations are finished, the placement of the Reed switches and LEDs will be taken place.

Each LED will be placed on each square coordinate of the grid along with a Reed Switch. The connectivity for these components will be crucial during this process for every square coordinate. Testing will take place for the stepper motors with the connection for the motor controller and the Arduino MEGA 2560.

They will run a few gameplay scenarios when moving the game piece and purposely make a few errors do that the motor controller can detect those errors for its feedback functionality. That is the first stage of the plan is to make sure that the stepper motors, motor controller, and Arduino MEGA 2560 is satisfied.

The next stage is testing those components with the interference of the Reed Switches and the LEDs. Those LEDs will be connected to the LM3402 and the LM3402 will be connected to the one of the pins of the Arduino MEGA 2560. From there, few gameplay scenarios will be initiated and confirm that the LEDs and the Reed switches are functional.

Also, the magnetic holder will be configured in such a way so that the Reed switches avoid interference with each other during gameplay. This can be all summarized in within Table 48.

Table 48: Test Plan for the XY Plotter

Step 1	– Connect the motor controller, stepper motors with the Arduino MEGA 2560 – configure the magnetic holder to the right specifications
Step 2	– Connect the LEDs, and the Reed Switches on the 16x16 grid space with the LM3402 and LED drivers
Step 3	– Computer engineering students will test the XY plotter functionality with multiple scenarios and make finishing touches.

By following these main steps for the project, the specifications and standards will be met. However, the discrepancies of the project may arise such as coding malfunction, overheated and damaged stepper motors, and lack of connection between the microcontroller Arduino MEGA 2560.

8.3 Software Test Setup

When it comes to Software test set up, the group needs to check for potential bugs before it is made live or moved into production environment. During this stage many issues occur such as software security, the functioning of the site, its access to users and its ability to handle traffic.

The following testing types may be formed by using depending of the testing requirements

8.3.1 Functionality Testing

This test set up is used to check if their product works as per the specifications intended as well as the functional requirements the group designed in the developmental documentation. Functions are tested by feeding them input and then inspecting the output. The coding framework will be tested by running sample events and verifying that the output meets the project's expectations. The number of sample events must be higher.

This type of tests ensures their test setup is done right by checking that all the requirements are properly satisfied by the application.

8.4 Software Test Plan

The software test plan is set into place to make sure that the web application and tabletop software development procedure is done efficiently and to minimize debugging sessions. Errors that can occur along the way should be contained within their functionalities and not

8.4.1 U.I.S.A Testing

U.I.S.A Testing refers to the level of software testing the team can do in their project. The term U.I.S.A stands for Unit testing, Integration testing, Software (System) testing and Acceptance testing. In order to perform a high-quality testing plan for their project, the group need to follow each software testing in a specific format as showed in Figure 24 below.

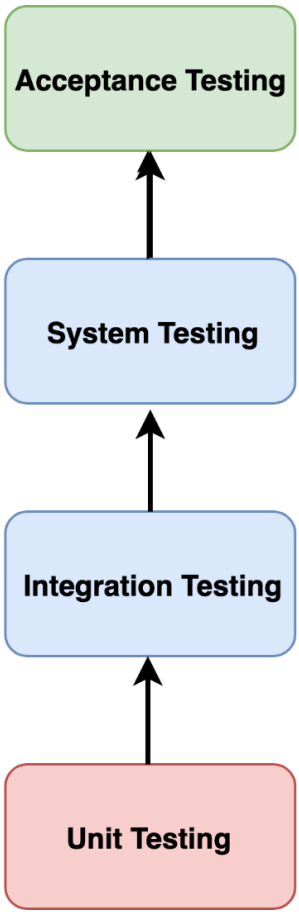

Figure 24: Software Level Testing

The first level of software testing the group need to proceed as explained in the graph above is Unit testing. The purpose of Unit testing for their project is to start off testing small pieces of code written, mainly individual functions or components. Once the group pick a function to test, it will give some inputs and then check for the function output. By doing so, it validates that each unit of the software performs as expected.

Proceeding with Unit testing will have some benefits in the long term such as increasing their confidence in changing and maintaining code, If the group can implement a good unit test where it runs every time their code is edited this will allow them to promptly catch any errors introduced due to the changes. Their code also needs to me modular in order to make unit testing possible, this will allow their code to be more reusable. A few popular tools the group are considering using are Jasmine, Mocha and tape

After setting up their Unit test, the next software test needed is the integration test. The purpose of this test is to expose faults in the interaction between integrated units. The group will be using the units previously tested and now combine them and test them as a group. After doing some research, the group may consider

implementing test drivers and test stubs to assist the team members during integration since they are effective and can potentially save time.

The group will also be implementing two types of integration tests which are component and system. Component integration tests are used to expose errors in the interaction and interface between integrated components and System integration tests are excellent for testing systems and packages as well as interfaces to external organizations.

Once the integration test is finished, the group will create a proper detail design document where it will define interactions between each unit. This is important so that anyone working on the code can see what functions were tested as well as the interaction between units that were defined.

The second to last test needed is the System testing, in this section the group will be testing the completed and integrated software. The purpose of this test is to evaluate the system's compliance with their specified requirements. One method the group may implement is called the black box testing, in which the internal design/implementation/structure of the item are testing is not known to the tester.

This method is great in finding incorrect or missing functions as well as interface errors, behavior or performance errors, initialization and termination errors. The only problem the group found for this method was that only a small number of possible inputs can be tested, this will leave many program paths untested.

The last phase of the software testing process the group will implement is called Acceptance testing, this test is done to evaluate their system's compliance with the business requirements and determine whether a finished product is ready acceptable for delivery. Then the customer can either accept or reject the product developed.

For their project,the type of Acceptance test the group will conduct is called operational Acceptance Testing (OAT). this is done to determine the operational readiness of their product. This includes testing of compatibility, recovery, technical support availability, maintainability, etc. This is all done to assure the stability of the product for their presentation and any potential customer who could be interested on it.

Applying U.I.S.A has also some potential costs or setbacks, the most noticeably the group found was that creating a high-quality acceptance tests requires significant effort and a good amount of time spent on it. Also, if the group encounters a "fragile" test issue, other teams have explained it can become burdensome for the maintenance part.

Although setting up these phases of software level tests seems like it will take a good amount of the given time available. The group has determined it is time necessary spent since we want to make sure the product that will be presented has no software connections errors.

8.4.2 Code Quality

Code quality defines code that is determined good (high quality) as well as code that is bad (low quality). This is all subjective as different teams could use different definitions, for example for an automotive developer good code quality may mean something different compared to a web application developer.

Code quality is important for the overall software quality, which impacts how secure, safe and reliable the codebase is. Today, high quality is critical for many teams and managers. Hence why their group will be focusing on some attributes to make sure the code written for their project is high quality.

When their code is being written, the first thing the group will look for when reviewing is the clarity of it, the team needs to ensure that their code is easy to read and oversee for anyone who has not created the code. The group needs to make sure it is easy to understand and therefore maintain and extend the code.

This is important for group projects since in their case, there will be mainly two people working on the code for their project. This is of great importance for either one of us to make changes. Once the code is clear, the group will then add comments to the code to explain its role and functions.

Once the code has been checked for clarity and comments were added, their next step is to check for any bugs, the less bugs the code has means the higher its quality is. These requirements are a priority that their code needs to follow. Their plan is to meet all the previously mentioned attributes to ensure the code written is high quality.

Besides following these requirements, the group will set up additional testing plan methods for code quality. Their first step is to set up a version control tool, after doing some research the group has determined that GIT would be preferred control tool. The reason being it provides a system that is easy to track which separates live product from less stable branches with unpublished features.

Once the feature is finished, a pull request is sent to GitHub. This will appear in a section that is ready to review waiting for a project member to review. Once it is reviewed by a team member and if it meets the requirements needed, it will then be merged to a development branch.

This Is a great system when it comes to controlling versions and shows every person’s code that has worked on it. Once the version control has been set up, their next step will be adding functional tests. Functional quality tests can show if the code is working fine or not. A pyramid-shape diagram shows the test process and where the group should be placing their efforts, the team should spend the most time doing unit tests, lesser integration tests and even lesser End-to-end tests as explained in the graph below in Figure 25.

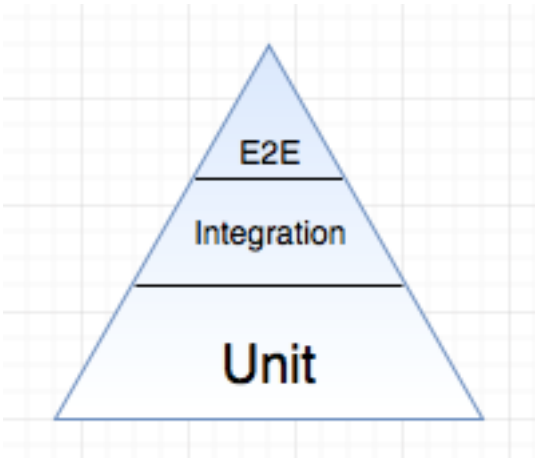

Figure 25: E2E/Integration/Unit Pyramid

8.4.3 Error Handling

The main objective of the Error Handling technique is the anticipation, detection and resolution of applications, programming and communications errors. There are specialized programs which are called error handlers that are available, and that the team could use. The best programs found forestall errors If possible, recover from then without closing/terminating the application. If the file fails, it will terminate an affected application and save the error information to a log file.

For their project, the error handling testing will be done by the computer engineer students working on it, the most experienced person will be the lead since he will have full knowledge of the code and database.

Their approach will be to generate improper transactions in-between the proper transactions and then check how the system behaved during the improper transaction and identify any given problem. Also, by using the improper master data and then check the application whether it can identify the problem and informed the users.

9.0 Project Management

Since the project consists four team members, it is important to manage tasks, scheduling, and distribute work effectively. The most important aspect of organization and management is scheduling. In this case, team members must be

aware of their availability to dedicate their contribution to the project. Frequent meetings are necessary to bring new ideas and solutions to mitigate risks in the future.

9.1 Version Control

To make sure that their project development is a smooth process, the group will be using a version control tool to distribute and manage their development pipeline. There are two different applications that need to be developed, which is the Web application for the removed users from the main group, and the controller application that monitors, controls and receives all changes that happen on the board and the database. Every iteration of various features will need be thoroughly bug tested and go through quality assurance to meet their defined feature set.

There are a variety of version control applications that can be used but the team will need the right application to meet their requirements to manage the project, as well as integrate nicely with their development tools and server environment.

9.1.1 Github

GitHub is an open-source software management when it comes to coding development. It features to become very effective when building and testing the codes seamlessly. Computer engineering students are going to be communicating not only to themselves, but to other experienced coders that may provide essential help. Any lines of code built by an experienced coder; this coder will be referenced to their contribution in the final documentation.

The most effective feature that is used in GitHub is the ability to add branches under a main branch called master. Unlike other centralized control system. GitHub branches are cheap and easy to merge., they will provide the group an isolated environment for every change to the codebase. When starting the project, the computer engineer students create a new branch which ensures the master branch always contains production-quality code.

9.1.2 Bitbucket

Bitbucket is another source like GitHub that is used to get source codes. It is used more for professional developers, but it’s another website that can be useful for the computer engineers in the group to find and reference codes that can be used to program the Arduino Mega 2560. Of course, any code that is referenced will be given credit to appropriately.

This software also has a free plan for groups up to five people and includes Jira software integration. It fits their group size and combines a task tracking system that can help with expediting their development and consolidates communication for across the project versioning and tasks. Jira is explained further on within

section 9.2.2. The feature set allows for all functionalities of using git, and different branches can be made on top of the master branch, such as the staging, dev, and hotfix branch.

The dev branch is where new features are “branched” out, finished, and merged back within the branch. This is where most of work on the software side will be done, and staging branch is where final integration testing is performed before pushing the master branch for production use.

Three projects will be created for their product. One being for the web application, another for the server and database communication/modeling, and the last for the Tabletop application. These separate the major tasks into these distinct categories so that the team can focus on one or the other without creating conflicts on other systems that might not be related.

9.2 Task management

This group consists of two computer engineering and the other two electrical engineering students. Therefore, the two electrical engineering students are responsible of implementing an XY plotter, connectivity of the LEDs, Reed-Switches, and the Stepper motors, and the Arduino MEGA 2560. The two other computer engineering students are responsible for web and application development. However, this type of task distribution can be changed ever so slightly due to limited time.

Depending on the code difficulty and the type of code used in this project, electrical engineering students can learn and help the computer engineering students if the code lines are too overwhelming. This can apply to the computer engineering students; they will contribute their help if the two electrical engineering students have difficulty. This process can be shown in Table 49.

Table 49: Task Distribution by Each Team Member

Team Member # 1 (CpE)	Developing a User Interface for Web application/Participate in using
Team Member # 2 (CpE)	U.I.S.A Testing / Web and application development
Team Member # 3 (EEE)	Configuration of the Magnetic Holder/Connection to the Stepper Motors and Motor Controller
Team Member # 4 (EEE)	Placement of LEDs, Reed Switches on the 16x16 grid connecting from that grid to the XY Plotter

This is the ideal distribution for all the students in their respective majors. However, this distribution table can be flexible to change if one of the team members may not accomplish their own individual tasks.

The group main task will be setting up reminders and assignments each week in order to accomplish all requirements set from the beginning and a fully working project towards the end of the semter.

9.2.1 Google Tasks

In the google calendar, there is a feature that can produce tasks for each team member, and they can evenly distribute during the week. In the task section, each team member will specify the content and estimate the page count for that content. As soon as that team member finishes writing those pages, they can mark that task “done” so that all the team member can see progression on the page count.

From there, they can police themselves and motivate others to write the page count needed for the project. This is a very flexible procedure since team members can contribute sources to others to finish their content and support them as much as they can. This could be used as well if the team members functions

9.2.2 JIRA

Another collaborative online platform, however, this online collaboration has multiple features in regards of software development. This online platform can

create consistent planning and have a visualization of the team members' progress when delivering codes. This can be beneficial to the team members that have a computer engineering background when sharing codes to each other and improvise their lines of codes in order to design a web application and interface.

The software also has benefits for tracking the hardware changes that need to be implemented. The way that Jira works is that you can separate their main objectives into multiple different projects. One project would be for the web application and one for the physical tabletop project. They will both have to integrate with each other through the internet, so when it comes to any parts that need the web component, an integration project can be utilized for the communication.

Once these projects are made, then Jira tickets can be generated by their team members on various tasks and set prioritizations and order for all the features that need to be made. The major requirements for their project will be at a high prioritization, while smaller features such as graphics improvements on the web application, will be at the lowest.

9.2.3 Microsoft SharePoint

Microsoft SharePoint is a collaborative online platform so that the team members can view their progression in terms of page count and what type of information can they contribute. After the writing their respective content done, they would notify other team members about their completion and give support to those in need in order to complete the project report. In this platform a folder was created so that they can link multiple source documents that can fulfill a great understanding necessary for the project. Since SharePoint is part of Office 365, it has become the nexus point on where we branch out to create all their documentation, graphs, and data sheets. Due to having an account through UCF, we are using Office 365's resources to its utmost potential in order to smooth out the processes of writing out documentation, and increasing the amount of time towards actual development.

The use of the Arduino MEGA 2560 will not only be simple, but rather require reading multiple documents and resources regarding of this microcontroller and learn the connectivity to the overall system of the project which is the XY plotter with the stepper motors and the motor controller. Essential coding references can be shared as well among the group so that they can learn to code and modify as much as they can to satisfy the requirements of the microcontroller and the implication of web and user application.

Also, it has feature of having a calendar that contains many functions which can be helpful for group communication. It can also integrate task tracking which can auto-email their progress on various documents that need more progress. The calendar can contain individual tasks that each team member needs to accomplish and will send an email notification if the task is not completed after the deadline. If

the share-cloud server is being used, the password can be created for team members for security reasons.

9.3 Scheduling

Scheduling is the most important step for a group-collaborative project. One team member was assigned to schedule either online meeting using a Discord platform, Zoom, or attending by person. Online meetings would be frequently be used due to distant homes or time constrained by work. Discord and Zoom meetings would be used regularly to discuss the project.

The main aspect of this process will be flexibility. If a team member is not able to attend the meeting due to family or work, the meeting continues, however, one of the team members will notify the absentee the contents of the meeting or send an email that summarizes the meeting during that time. This approach can be most effective.

9.3.1 Google Calendar

By using the Google Calendar, it provides a visualization of the working times and class times that each team members have. That way, the meetings are going to be made based off the google calendar. This a great tool for task management and providing a “check-list” feature for page count distribution. Each week, the page count would be roughly 6-7 pages which then the google calendar can alert the team member to write their own page count distribution in every week.

The Google Calendar have feature for the team members to post notes regarding on the specific work for the project. They can post notes to aid and give feedback when the content may be hard to comprehend. They can interact by creating attached meetings and applying on certain days for all the team members to know.

10.0 Works Cited

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11.0 Appendix A

From: Oguz Murtezaoglu <oguz@bipom.com>

Subject: Re: Requesting permission to use materials relation to senior design capstone project

Date: July 29, 2019 at 7:19:43 AM EDT

To: Hubert Barrantes <hubert.barrantes@Knights.ucf.edu>

Reply-To: Oguz Murtezaoglu <oguz@bipom.com>

Sure, no problem. Good luck with your project !

Best Regards

Oguz "Oz" Murtezaoglu

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On 7/28/2019 3:17 PM, Hubert Barrantes wrote:

To whom it may concern.

I would like to use a graph on your Analog/Digital Conversion with micro controllers document if possible for my capstone project. Is it ok to use the diagram below for documentation purposes?Below is the link
Please let me know.
Hubert Barrantes

https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.bipom.com%2Fdocuments%2Flectures%2FAnalog%2520To%2520Digital%2520Conversion%2520with%2520Microcontrollers.pdf&data=02%7C01%7Chubert.barrantes%40Knights.ucf.edu%7C96230bcd01664291321608d71416a949%7C5b16e18278b3412c919668342689eeb7%7C0%7C1%7C636999959874823817&sdata=SMGprugwo%2FyW2ufLM%2BF55tNLcN5DZQ50wDPiohO0UBI%3D&reserved=0