A Children's Game to Improve Spelling- SpellCheck

A Technical Report submitted to the Department of Electrical and Computer Engineering

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Shymbolat Tnaliyev
Spring, 2022
Technical Project Team Members
Noah Beamon
Justin Guo
Rachel Lew
Catlinh Nguyen

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Harry. C Powell, Department of Electrical Engineering

Statement of work:

Noah Beamon:

My main responsibility was LCD communication involving the transfer of words and images from the web application to the MSP432 itself for display on the LCD. This role consisted of two main parts: the first was writing Embedded C code for the reception of data over backchannel UART on the MSP432 and the second was the development of the web application functionality of sending multiple words and images from a dynamic user interface. For the Embedded C microcontroller code, I used an interrupt service routine (ISR), circular buffer, ACK, and memory allocation logic to receive and process the data from the PC host. For the web application code, I used Javascript with React library to develop a user interface that allows the user to enter and send custom words and images to the device in addition to default words and images. In addition to Javascript code written to control the UI, this process mainly involved using an image resizing library to dynamically resize the images to maintain aspect ratio and a standard of quality. My secondary responsibility was assisting in the development and analysis of the power supply and the barrel jack custom footprint.

Justin Guo:

My main responsibility was coding the software concerning the interaction between the LCD and the MSP432. I configured SPI communication between the two, allowing the MSP to send commands to the LCD. Using these commands, I was able to toggle the LCD’s power state, display pictures, toggle between different text, and draw buttons. I also made the decoding algorithm for the multiplexer inputs into the ADC of the MSP, which was then drawn onto the LCD as a string. I also saved the user inputted images in flash, allowing the system to continue playing. Finally, I also helped design the game of the project, which involved a touch button as verification and repeated checks on input.

My secondary responsibility was building the design for the letter verification system. I helped verify correct connections between the hall effect sensors and multiplexers, and I designed the software algorithm to read to the multiplexers using the ADCs.

Rachel Lew:

My primary responsibility was to design the mechanical aspect of the system. I chose the chassis and mounting appliances for the system and created the CAD designs for the 3D printed slot panel and letter blocks using Autodesk Fusion 360. I also assembled the system, which includes placing the magnets into the letter blocks in the correct combinations, mounting the PCB and slot panel, and mounting the LCD.

I had to closely work with Catlinh to ensure my 3D designs would sync with the letter identification system, so I was involved with the letter identification design. I helped with the magnet sensing testing to ensure my designs for the letter blocks and panel were workable. I also worked with Catlinh on the PCB to ensure that the PCB could align with the 3D printed panel. I determined the dimensions necessary for the PCB and the placement for certain components to work best with the chassis and helped route the board for manufacturing.

Catlinh Nguyen:

My primary responsibility was to design the letter identification system. I researched the components and determined the magnet strength and sensor sensitivity that would be sufficient for our system. I performed extensive testing to ensure that the Hall Effect sensor and magnet system would allow us to accurately identify which letters were placed in the slots. Furthermore, I had to work closely with Rachel to ensure that the letter identification system placement would match the dimensions for the enclosure and 3D printed panel.

My secondary responsibility was to work with Rachel to design the system schematic and board layout. I configured the letter identification system that I designed in Multisim and made the connections that would allow us to power our system using the power supply circuit and interface our system with the MSP432 microcontroller and the LCD connector. Once the schematic was completed, Rachel and I worked together to route the board for manufacturing and assemble the PCB within the system.

Shymbolat Tnaliyev:

My primary task was power supply involving the power requirements for our LCD display and researching the suitable voltage regulator for our system. After analysis and the professor's recommendation, the R-783.305 with 3.3V output voltage and 0.5A current output voltage regulator was chosen.Then I completed the task which required us to find the right wall transformer so that it would satisfy our given requirements using all components' current measurements for the system. Finally, the barrel jack component research was done, and it was chosen respectively.

My secondary task was to help Noah with LCD communication involving the user web site for downloading and sending words for the device. I worked and assisted with UI for clients of our website and making technical support pages. I created end-user documentation to guide the users on how to properly install and use the product.

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Abstract

SpellCheck is an educational device which facilitates learning in youth ages 5 to 7. Specifically, this interactive educational tool will help children practice how to spell the name of an object that appears on a screen. The device displays an image of an object on the LCD, the child places individual letters into their respective slots in the device, and the spelling is verified through the arrangement of letters in the slots. LCD will then verify the child's attempt to spell the word, by either highlighting the word in green and moving to the next word or highlighting the mistake and prompting the student to try again. This project seeks to apply computer engineering principles, including the use of an embedded system such as the MSP432, power supplies, and a limited mechanical interface, to demonstrate the effectiveness of interactive learning and instantaneous feedback in youth education.

Background

In recent years, there has been a growing influence of technology and gamification on education. Educational technology has supplemented classroom teaching by helping children learn easier, faster, and cheaper. Furthermore, research has demonstrated that the use of educational games significantly improved students' understanding and retention of classroom topics. A recent study found that learning English spelling through a game is more effective than learning English spelling from a traditional classroom setting, as students were able to remember the English spelling easier and found the gamified version very useful [1]. Other benefits to gamified learning include reducing student anxiety to learning new languages, providing immediate feedback, modifying a student's learning level, and creating a stress-free environment [2].

The purpose of this project is to design and implement a spelling game in order to facilitate spelling practice for children aged 5-7. To play this game, the device will show an object on the screen, as well as blank lines corresponding to how many letters are in the word. The user will have to find the correct letter blocks to spell the word and place the letter blocks onto the panel. When the user presses the "Check" button, the program will verify the spelling of the word and indicate whether the word is spelled correctly or not.

To our knowledge, this project is novel because it integrates physical letter blocks with gamification. Previous spelling games have existed fully in software as mobile or web applications, like the app "EDUBUZZ" kids spelling game app [1]. By incorporating physical letter blocks, this project also aids the development of fine motor skills and multisensory learning in children. Multisensory learning is a way for kids to engage multiple senses at once, thus improving the memory of the spelling. This method of learning is helpful for kids who learn differently. Children who struggle with visual processing would also struggle with a mobile app that teaches spelling visually. However, there have been some studies that compare multisensory approaches and conventional approaches for spelling that found there is not a significant difference in spelling performance but indicated more research had to be done to solidify this claim [3]. We aim to build SpellCheck to further such research by proposing another method to practice spelling. Our project will utilize hands-on learning and gamification to engage kids to practice spelling in a less conventional way.

In addition to performing an extensive literature review, our group also consulted with two professors from the UVA School of Education and Human Development who specialize in Elementary Education: Professor Lysandra Cook and Professor Tisha Hayes. With decades of experience working with our target age range, both professors noted that many current teaching tools are cost effective. However, all of these tools require some type of instructor intervention, which can be time consuming if there is a high student-to-teacher ratio. The professors emphasized that a teaching device that students can operate independently to reinforce previously learned topics, such as ours, would be especially valuable. Additionally, the ability for the teachers to input their own curriculum of words would greatly support their teaching.

We will be using our knowledge from our previous coursework to create SpellCheck. All team members have taken the ECE Fundamentals courses which will help in creating the power supply. Shymbolat, who is taking the primary task of designing the power supply, has also taken Electromagnetic Energy Conversion (ECE 3250). Justin, Catlinh, Noah, and Rachel have taken Advanced Software Development (CS 3240) which will help in developing the gamification and UI design. All team members have taken Introduction to Programming (CS1110) and other CS courses that will help with developing the code for identifying the letters and spelling verification. We will also use our knowledge from Introduction to Embedded Systems and Embedded Computing and Robotics (ECE 3430, ECE 3501/2) to work on the embedded systems and develop with the MSP432. Computer Networks (ECE 4457) is also a relevant class for uploading images to the microcontroller. For CAD design of the letters, Rachel and Justin will use their learnings from Introduction to Engineering (ENGR 1624) where they learned 3D printing techniques and CAD design.

Constraints

Design Constraints

Since the Banana Seals team is composed of both electrical and computer engineers, the project must include a team-designed custom Printed Circuit Board (PCB) and include either a microcontroller or National Instruments myRIO [4]. This constraint is a guideline imposed by the capstone course ECE 4440/4991.

CPU Limitations

The team selected the Texas Instruments MSP-EXP432P401R [5] for the CPU based on the large number of GPIO pins and multiple peripheral interfaces. The MSP432 allows for a maximum clock speed of up to 48MHZ, which was more than what was needed for the system, as the maximum clock speed utilized was 12MHZ.

Software Availability

UVA provides an active license for National Instruments Multisim [6] and National Instruments Ultiboard [7], which the team used for schematic and PCB design. In addition, Code Composer Studio [8] was utilized for writing the embedded software code due to its compatibility with the chosen microcontroller. Visual Studio Code [9] was used to program the UI interface, as it is a free IDE.

Manufacturing Limitations

The PCB manufacturer, Advanced Circuits, imposed manufacturing constraints for the printed circuit board. The 2-layer board was required to have a 62 mil thickness, along with specific requirements [10] to meet a student special criteria, with the most significant factors being:

- Maximum board size: 60 square inches
- Minimum 5 mil line/space
- Minimum 10 mil hole size
- Maximum 50 drilled holes per square inch

In addition to these constraints, the size of the enclosure that houses the system restricted the width and length of the PCB. The board needed to fit within the length and width of the enclosure's front panel in order to fit inside of the enclosure.

Economic and Cost Constraints

Because this project is meant for use in classroom environments, one goal was to minimize costs. This project was limited to a budget of $500. Many tools, such as the Virtual Bench, soldering irons, and microcontroller were available without any added cost. However, the majority of the components used to build this project had to be purchased. The greatest cost in this project was the letter identification system and the production of letter pieces. Only 30 letter blocks could be produced, and backup components could not be purchased on a large scale.

Environmental Impact

The project's letter panel and letter blocks were made using a 3D printer. The 3D printed materials emit toxic particles which are harmful for humans. Particles released during the printing process can affect indoor air quality and public health [11]. Printed circuit boards also can be concerned as harmful for the environment during manufacturing. Usage of recycled and environmentally friendly materials for the boards, letter blocks, and letter panel is recommended for future productions of SpellCheck. The PCBs used in SpellCheck should be recycled when the device is no longer being used.

Sustainability

The system presents sustainable design since the team rejected usage of the ion batteries for the power supply [12]. Instead, the team chose to power the system with a wall transformer which powers the system and can be for long term use. Since the D printed parts are made of ABS plastic, they can be recycled easily, and ABS is recycled plastic itself [13].

Health and Safety

One safety concern for the system is the design of the letter blocks. Since our primary users are elementary students, we had to consider the size and shape of the letter blocks to ensure that there are no choking hazards or potential sharp objects. The users should be able to engage with the system without constant adult supervision, as a teacher should not be expected to interfere while students are using the learning aid, so the system should be child-safe.

Additionally, since the system does not use reusable batteries for power, the device must be plugged into a wall outlet. This system can pose a risk of electrocution if handled improperly.

External Standards

1. *IPC Standards for PCB Design* - IPC standards outline the general requirements for the design of printed boards. IPC-2221A standardizes track and part spacings [14]. IPC-A-600J sets standards for acceptance criteria for the printed boards, including material, holes, plating, and more [15].
2. *SMD Component Packages* - Surface Mount Device (SMD) components conform to industry standards outlined by Surface Mount Technology (SMT) packages. JEDEC [16] is the leading standardization body for size specifications for SMT packages.
3. *STL (Standard Tessellation Language)* - The STL standard is a file format that stores only the surface geometry of 3D models [17]. The standard was used to communicate between the 3D printer hardware and the computer.
4. *UART (Universal Asynchronous Receiver-Transmitter* - UART is a circuitry block for implementing serial communication [18]. UART was to upload words and images from the web application to the MSP432.
5. *SPI (Serial Peripheral Interface) Communication Protocol* - SPI provides synchronous communication between a master device and peripheral device [19]. SPI was used to communicate between the microcontroller and the LCD display.
6. *Embedded C Coding Standard* - The Embedded C Coding Standard authored by Michael Barr was used to accelerate the software development process and avoid potential bugs [20]. Some standards set by Barr include comment rules, white space rules, and statement rules.
7. *U.S. Consumer Product Safety Standard* - Because our product is designed for children of ages 5-7, we must label our device to contain choking hazards not intended for children under the age of 3, as indicated by 16 C.F.R. Part 1501 [21] and 1500.50-53 [22] of the small parts regulation must meet standards from the U.S. Consumer Product Safety Commission. Our project must also meet the electrical standards as specified in 16 CFR § 1505.5 [23] of the U.S. Consumer Product Safety Commission. This includes:
    1. Switches must be rated at no less than the load they are intended for.
    2. The internal wiring must be fully insulated, and all electrical components must be strong enough to withstand voltages and currents specified for this project.
    3. Wires should be free of any sharp edges or corners, and wires should also be fully secure in their connections to provide reliable electrical contact.
    4. Soldered connections must be made secure before soldering.
    5. Current carrying components must be made of electrically conductive materials.

Tools Employed

Many tools were used to design, develop, assemble, and test our project. The tools for each category of our system are explained below.

Hardware

For board design and routing, National Instruments' simulation and design tools, Multisim and Ultiboard were utilized. Multisim was used to create board schematics and footprints for some components. Ultiboard was used for routing and designing the circuit board. Additionally, the FreeDFM service from Advanced Circuits [24] was used to check the PCB for any errors and ensure that the board was ready to be manufactured. 3W Electronics assembled the components onto the PCB [25].

Autodesk Fusion 360 [26] was used to design the components that were 3D printed. The MAE Rapid Prototyping and Machine Labs [27] was used to 3D print the STL files produced by Autodesk Fusion 360. The National Instruments Virtual Bench [28] was used for conducting our hardware test plan.

Firmware

The firmware was written in C using Texas Instruments' integrated development environment, Code Composer Studio (CCS). The testing of the project and firmware utilized existing libraries, including the driver library of MSP432 [29], and GitHub user RudolphRiedel's FT800-FT813 library adaptation [30] for the EVE TFT display. We determined this library adaptation was acceptable due to its MIT license.

Software

GitHub [31] and Git [32] were used for managing version control of the software and firmware. Github hosted our codebase and allowed for easy collaboration between software developers. The website application was written in JavaScript [33] and Cascading Style Sheets [34] using the React Native development framework [35], and deployed using Vercel App [36]. The application was written in the integrated development environment Visual Studio Code.

Ethical, Social, and Economic Concerns

The purpose of this project is to help students practice spelling, by verifying and correcting students' spelling of simple objects. However, with the advancement of educational technology comes the risk of displacing jobs in education. This project aims to create an inexpensive option for students to practice spelling, which will be cheaper than hiring an instructor. While this device can aid student learning, it is designed to be used in conjunction with classroom instruction as a reinforcement tool, rather than a replacement for traditional teaching methods. SpellCheck does not teach spelling, but rather helps students practice spelling words they have been taught in their classrooms. This concept is supplemented by our website that allows teachers to upload their own word lists from their lesson plans.

To ensure that our device can be accessible to all students, it is important that the cost of SpellCheck is low. If the device is too expensive to reproduce, some school communities may not be able to afford the device, and therefore our project would not be accessible to all students.

Another concern for our project is that the current version of the device is not fully usable by all students. Our device is currently not suited for those who are blind or visually impaired. Our device relies on the user to be able to view the LCD display and different colors. More accessible features such as sound and braille on the letter blocks are considered in the Future Works section later in the report.

Intellectual Property Issues

This project does not have the potential to be patented, because some prior inventions could be found that fundamentally encompass our project design. Three patents that encompass similar material are described below.

One patent presents a "Collective word building and spelling game" [37]. The main claim includes "A collective word building and spelling game comprising: multiple sets of the 26 letters of the English alphabets". While our project includes letter blocks that encompass the 26 letters of the alphabet, our project stretches beyond the scope of this patent to include electronic validation. In light of this claim, our project is still patentable.

One previous patent presents a "block-type board game using a word alphabet puzzle" that was developed for educational purposes [38]. This patent's main independent claim includes "A printed portion .. with one of alphabets, Korean consonant / vowel, numerals and symbols on the upper end of a hexahedron body", "A word block board … having a structure including an attachment plate … made of an iron plate or a magnet", and "constructing a maze through a process of learning the spelling and arithmetic of the word, thereby performing a maze game." Some components of the patent are similar to our project, including the letter blocks and magnetic slots. However, the fundamental difference compared to our project is that this patent does not use electronic verification. Therefore, our project is still patentable in light of these claims.

Another previous patent presents an "English word spelling game" [39]. The main independent claim states that the device "is characterized in that, comprise housing, is arranged on the primary controller of enclosure interior, accumulator, display screen, pilot lamp, loudspeaker, control panel, spelling plate and 52 letter cards". This patent is very similar to our project in that the user must spell out a word using letter cards and displays a verification of the spelling. The differences between this patent and our project is that the patent device says the word to spell using a loudspeaker while our project displays the object on a display, and the patent device verifies the spelling using the color of a pilot lamp, while our project displays verification on the screen. Additionally, the letter cards in the patented device are bonded to the receptacle using a magnet, while the blocks on our project are stuck onto pegs. While there are some differences between the two projects, our project is fundamentally similar to the patented device, and therefore cannot be patented.

Detailed Technical Description of Project

The goal of our project was to build an educational tool that helps children practice spelling. The user must use the letter blocks to spell the image displayed on an LCD display. Each of the letter blocks are encoded with unique binary codes using different magnet formations. The letter blocks are placed in slots where magnetic hall effect sensors will detect the magnet formations. Our microcontroller will then decode the formation and verify the spelling of the input detected. If the entered word is correct, the microcontroller will send a new image to the LCD to display. The system design was broken down into the following sections:

1. Hardware
    1. Power Supply
    2. Letter Sensing System
    3. Connection to MSP432
    4. Connection to LCD
    5. Board Layout
2. Firmware
    1. Letter Detection
    2. Verifying User Input
    3. LCD
3. Software
    1. User Interface
4. Mechanical
    1. CAD Design
    2. Assembly

Block Diagram

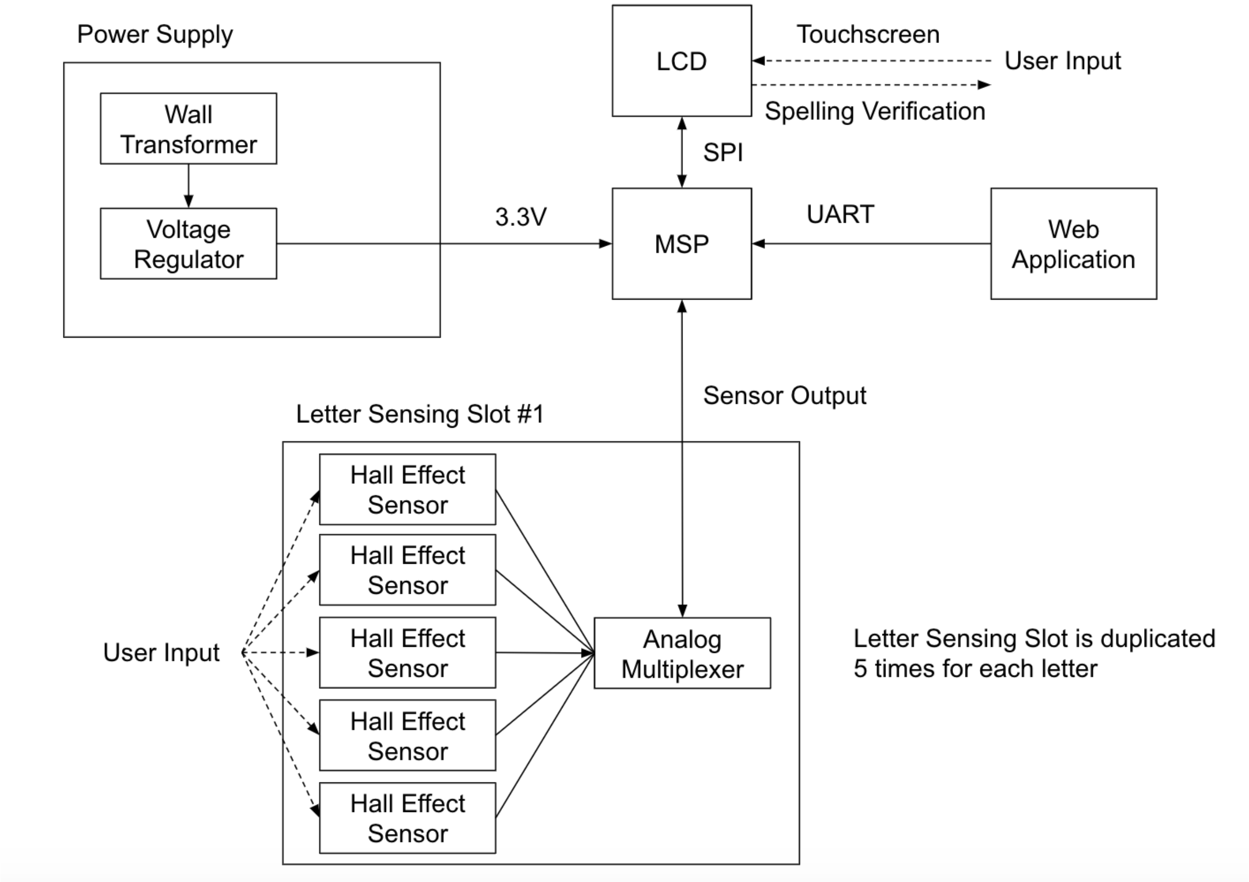


Figure 1: Fully System Block Diagram

Figure 1 displays the full system block diagram of the SpellCheck system. The power supply plugs the device into a wall socket and regulates the voltage to supply the MSP432 with 3.3V. The MSP controls the logic and interfacing with the other components of the system. The MSP first displays an object on the LCD using SPI. The user then puts letter blocks into the slots and the MSP reads and decodes the user's input. The MSP then uses SPI to display a verification of the spelling guess onto the LCD. Additionally, the user may upload their own list of words and images from the web application via UART.

Hardware

The hardware system is a PCB, designed as a booster pack that attaches onto the MSP432. This PCB comprises a power supply, connection to an LCD display, connection to an MSP432 microcontroller, and 5 letter sensing slots. The power supply powers the entire system via connection to a wall transformer. The LCD display interacts with the user by displaying images, reading user touch input, and displaying spelling verification. The MSP432 controls the logic for the system. The letter sensing slots detect which letter blocks were placed into each of the five slots. The schematic was designed using Multisim and is shown in Figure 2. Each subsystem is described in detail in the following sections.

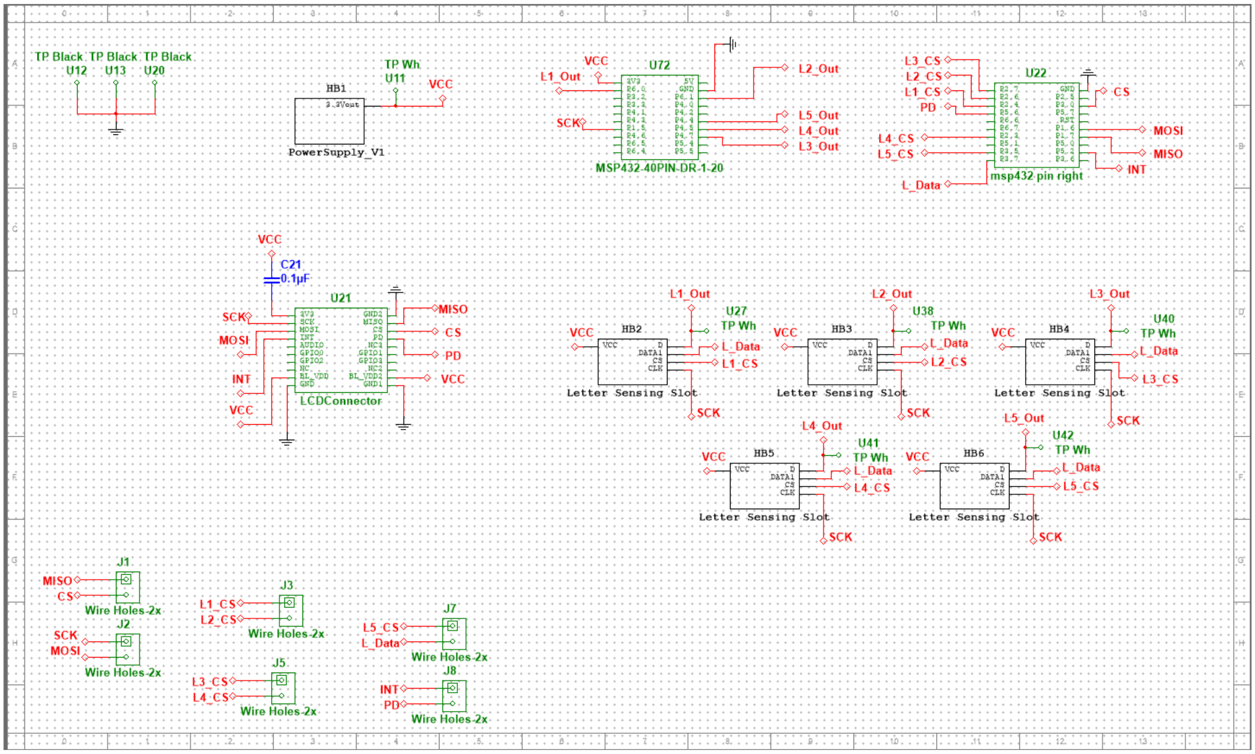


Figure 2: Overall Schematic of SpellCheck System

Power Supply

The SpellCheck system is powered by a wall transformer that connects to a barrel jack connector on the PCB. Figures 3 and 4 display the power supply block and the hierarchical subsystem of the power supply.

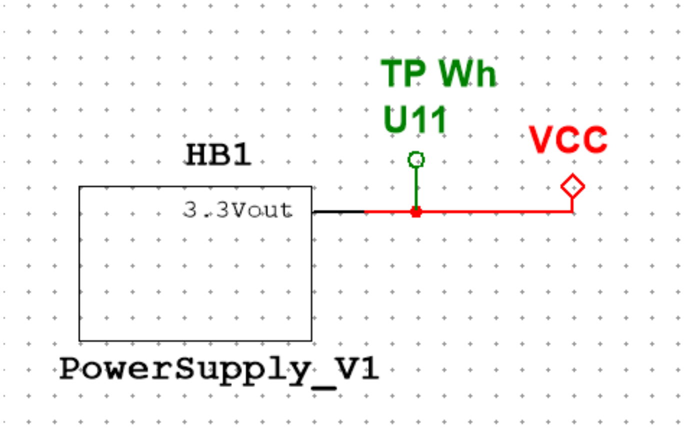


Figure 3: Power Supply Block

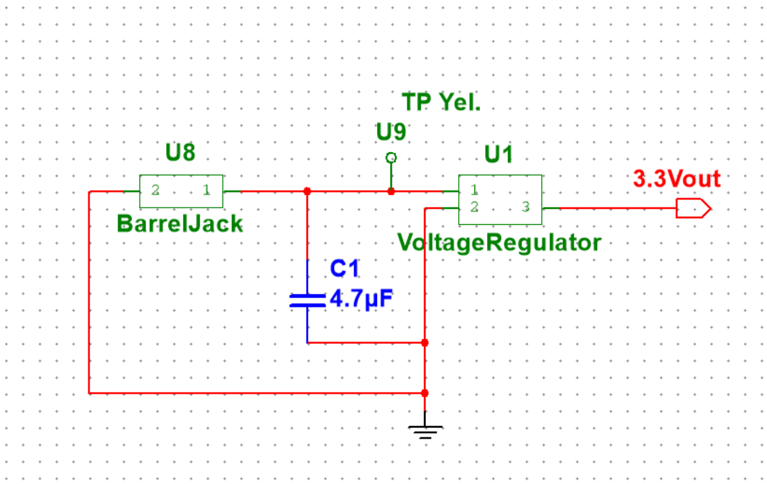


Figure 4: Power Supply Schematic

Component	**Current (mA)**
LCD	280
Hall Effect Sensor (25)	82.5
MSP	100
LTC MUX (5)	10
Total Consumption	**472.5**

Table 1: Current Consumption of Components

Table 1 illustrates the current analysis of the system required for the voltage regulator R-783.305 where output is 500mA. The maximum current consumption of the whole system devices is 472.5mA. Our device requires 1.6W (3.3V*472.5mA) of power. The regulator delivers 1.8W at 81% efficiency. Therefore, the R-783.305 voltage regulator characteristics are enough for the system.

Letter Sensing System

Letter Slots

In order to determine which letter block was placed into each slot, each letter block is configured with a different combination of magnets. Because there are 26 letters, 5 binary values is sufficient to represent all letters. By placing Hall Effect (magnetic) sensors in each letter slot, reading the combination of magnets, and decoding this combination, we can determine the letter block that was placed in the slot and check this letter against the correct answer. The encoding scheme of magnets is displayed in Appendix A Figure 27 and the method of reading a binary value from a letter block is shown in Figure 5.

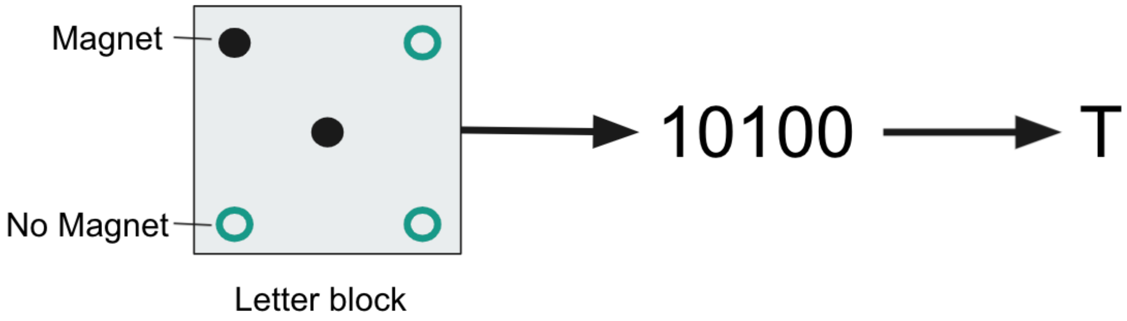


Figure 5: Letter Decoding Example

Hall Effect Sensing

Hall Effect sensors were used to detect different magnet combinations. These sensors have three pins: VCC, Ground, and Vout. Based on the range ($-B_{SAT} < B < +B_{SAT}$) of the strength of the detected magnetic field, the Hall Effect sensor will output a voltage that is linearly proportional to the strength of the field. Beyond the linear range, the voltage output stays at a constant level. The DRV5053 Analog-Bipolar Hall Effect Sensor [40] was selected because it supported a 3.3V input without requiring a voltage regulator, had high temperature stability, had sufficient sensitivity, and produced an output voltage that was detectable by the MSP432 analog I/O pins.

The greatest source of uncertainty revolved around the strength of the magnets. While the magnets had to be strong enough to be detected by the Hall Effect sensors through the plastic slot, the magnets also had to be weak enough to not interfere with the readings of other magnets within the same block. If a magnet was too weak, it would not be detected at all by the sensor. On the other hand, if a magnet is too strong, nearby sensors corresponding to other magnet holes would detect the signal and show that there was a magnet in place, even if there was not. Both of these scenarios would result in inaccurate readings.

In order to mitigate this issue, magnets were specifically chosen such that they were strong enough to put the sensor in saturation range. In other words, any magnetic field stronger than the saturation value would generate a steady voltage reading from the sensor (1.8V for the positive polarity or 0.2V for the reverse polarity) rather than varying proportional to field strength. If there is no field detected, the voltage output will be 1V. According to the datasheet for the Hall Effect Sensor, the magnetic field strength to put the sensor in saturation is 73mT, or 730 Gauss. However, this is assuming that the magnet is placed right over the sensor. Because the magnets will need to be sensed from a distance through a thin layer of plastic. We opted to test magnets of two different strengths: 6619 Gauss and 7179 Gauss. Based on the results of testing, we decided that the 7179 Gauss magnets would be best suited for our application, providing significant strength that can be detected by the sensors, without interfering with neighboring sensors.

Hall Effect Sensor System

Each letter block was placed into a letter slot on the PCB that sensed and decoded the letter block magnet configuration. The schematic for one letter slot is shown in Figure 6. Each slot had four inputs and one output, which are explained in Table 2.

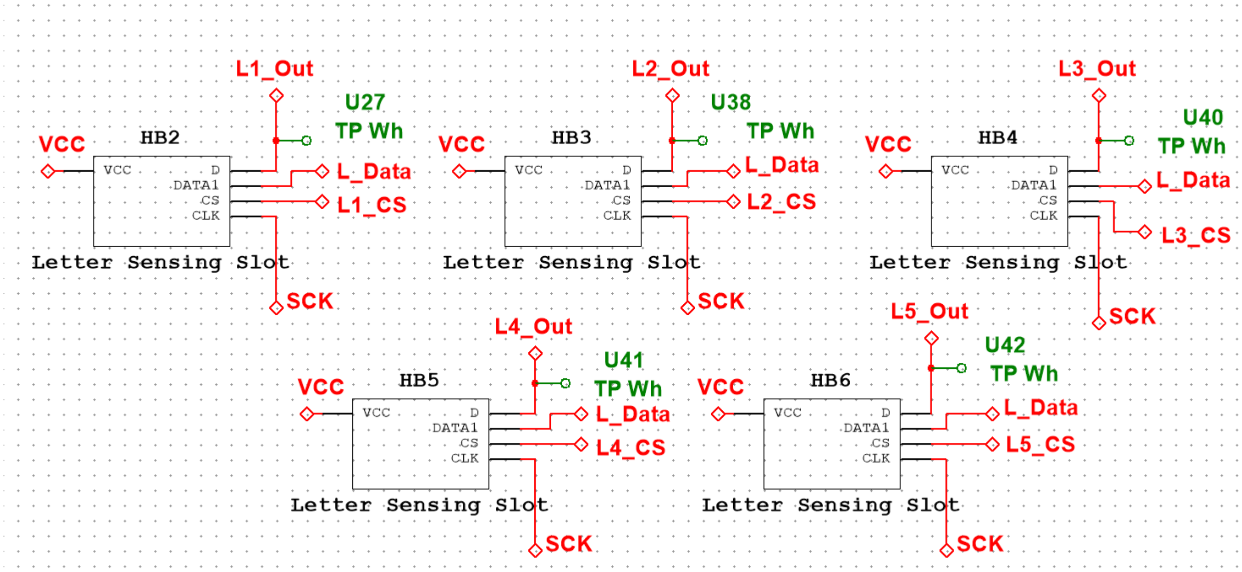


Figure 6: Schematic for One Letter Sensing Slot

Connection	**Connection Type**	**Purpose**
VCC	Analog Input	Voltage input
D	Analog Output	Hall Effect sensor voltage output
Data 1	Digital Input	Select line for multiplexer
CS	Digital Input	Chip select to enable multiplexer
CLK	Digital Input	Clock Line

Table 2: Letter Sensing Slot Connections

The letter sensing slot subsystem consisted of a multiplexer and five Hall Effect sensors, as shown in Figure 7. As previously mentioned, each letter block had a different combination of magnets that was read and decoded, with five different potential locations for magnets. Therefore, each letter sensing slot had five Hall Effect sensors that were constantly outputting voltages that are proportional to their detected magnetic fields. However, because the MSP432 has a limited number of analog I/O pins, the voltage outputs from the Hall Effect sensors were connected to different data input lines to an 8:1 analog multiplexer [41]. Based on what value was passed into the multiplexer Data 1 select line, the multiplexer passes the voltage value of a different data input line to its singular output. Therefore, we used software to loop through each of the multiplexer inputs and read each sensor voltage output. If the voltage reading of a sensor exceeded the threshold that determines the presence of a magnet, this value was decoded as a 1. Otherwise, the value was recorded as a 0. Thus, for each letter sensing slot, we read a 5-bit binary value that could then be decoded as a letter according to the encoding scheme displayed in Appendix A Figure 27.

This subsystem was repeated four additional times to create five total letter sensing slots. The schematic for all five slots is shown in Figure 8.

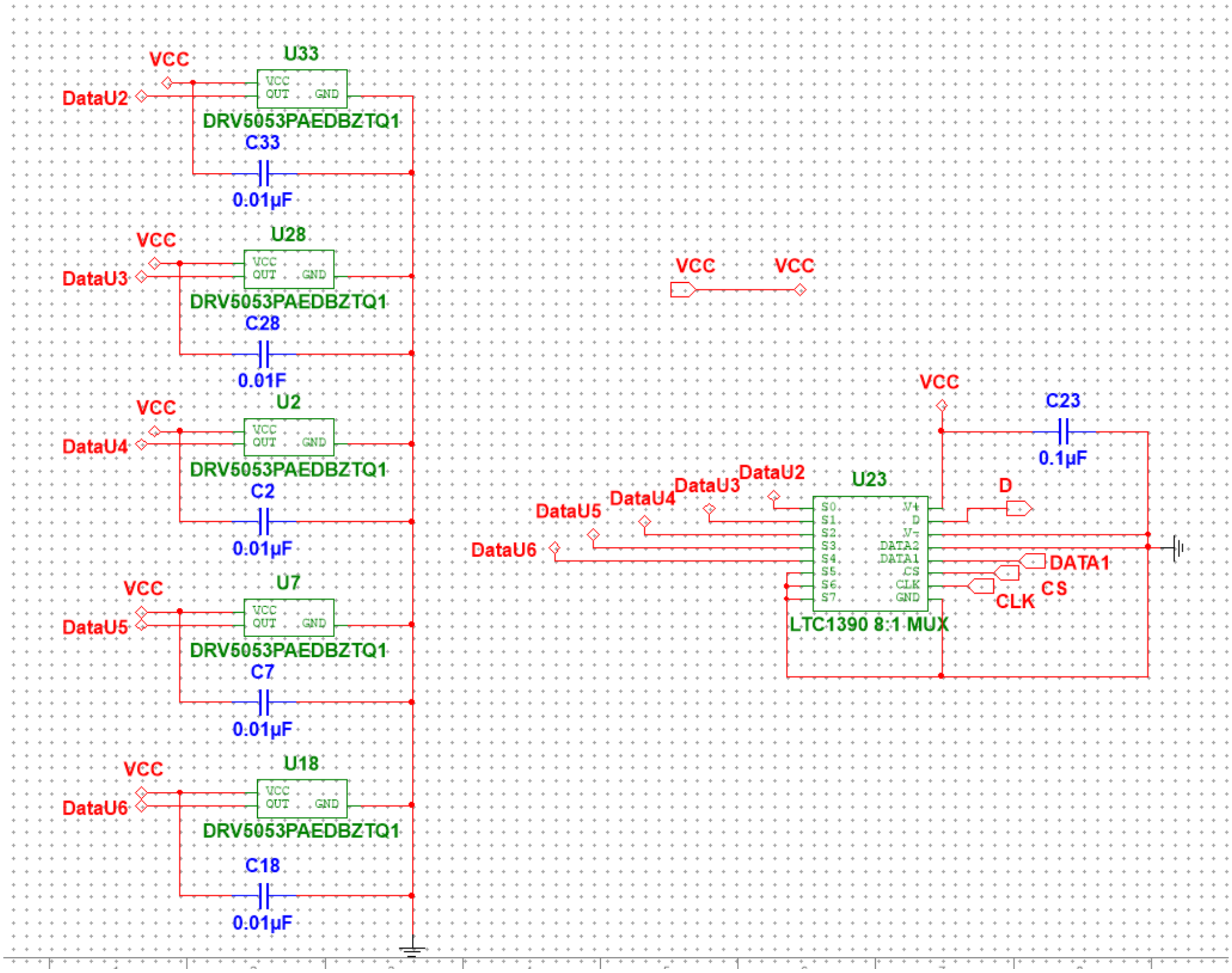


Figure 7: Hierarchical Subsytem Schematic of One Letter Sensing Slot

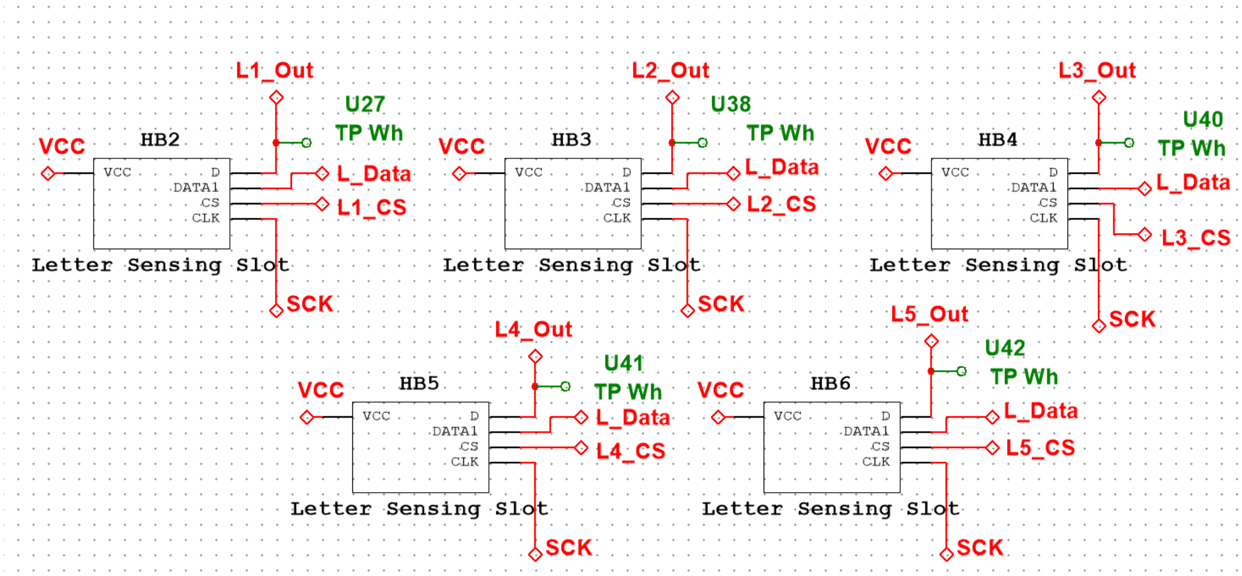


Figure 8: Schematic for All Five Letter Sensing Slots

Connection to MSP432

As previously mentioned, the MSP432 controlled the logic for the entire system. This microcontroller interfaced with the LCD display, as well as the multiplexers and sensors. Figure 9 displays the schematic for the header box connections to the MSP432 header pins. Each of the sensing slot outputs (LX_Out) was connected to an analog I/O pin. The other letter sensing slot lines (SCK, L_Data, LX_CS) were connected to GPIO pins suited for digital I/O. Additionally, because the MSP interfaced with the LCD using SPI, the designated SPI pins on the MSP were connected to the corresponding pins on the LCD connector.

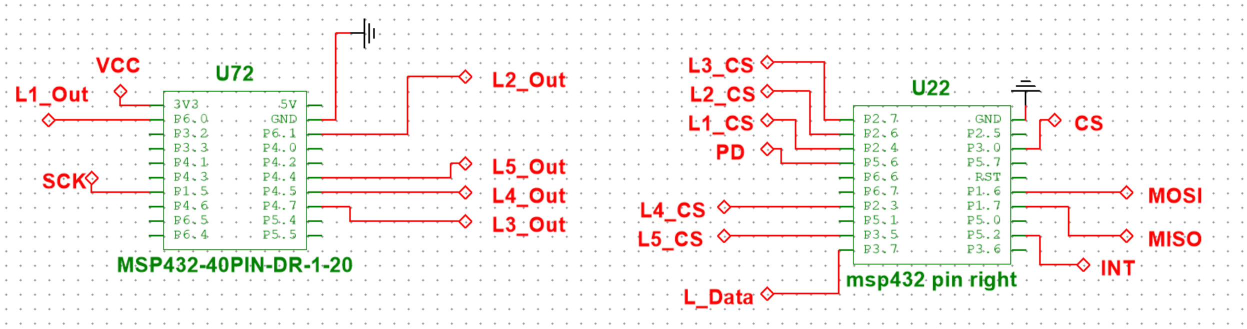


Figure 9: Header Pin Connections to the MSP432

Connection to LCD

As previously mentioned, the LCD communicates with the microcontroller via SPI and the connections are shown in Figure 10. Additionally, the voltage input VCC was connected at 3 points: 3V3, BL_VDD, and BL_VDD2. These connections power the LCD display and the LCD backlight, respectively.

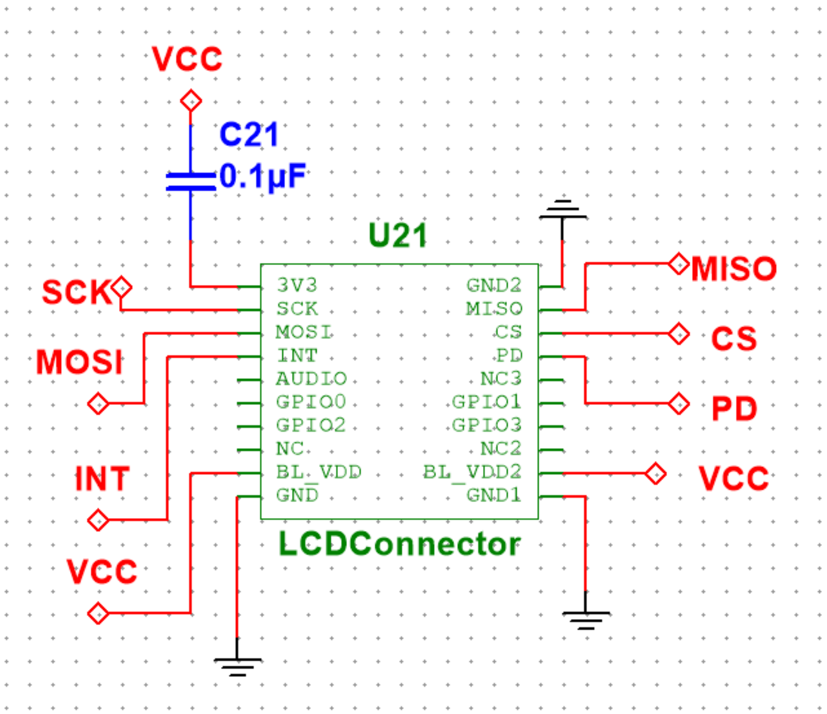


Figure 10: Connections to the LCD TFT Display

Board Layout

The PCB was designed to attach directly onto the MSP432 header pins on one side and sense the letter blocks on the other side. Additionally, the board size was constrained to the size of the enclosure that houses the device. Figure 11 displays the board layout of the PCB. Along the middle row of the board were the Hall Effect sensors, which were placed specifically to line up with the 3D printed letters slots and blocks. It was important that these sensors were perfectly aligned in order to accurately read the magnets through the 3D printed slot panel. Additionally, the board was laid out such that the sensors were the only components mounted to the bottom of the board to minimize the distance between the magnets and sensors. All other components were mounted to the top of the board. Lastly, the footprints for the barrel jack and LCD connectors were strategically placed on the left side of the board to allow cables to feed through the opening in the enclosure.

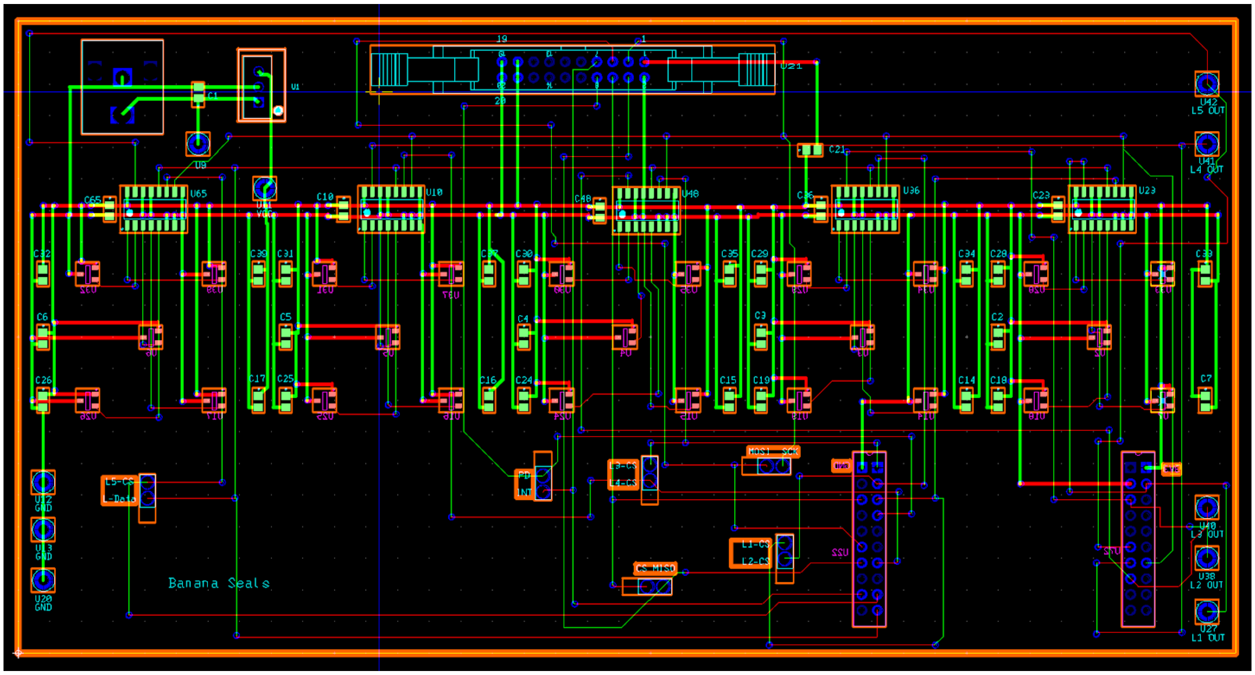


Figure 11: PCB Board Layout

Firmware

Letter Detection

As previously mentioned, each letter was encoded as a different combination of five possible magnet locations. Therefore, in order to determine what letter block had been placed in each slot, each Hall Effect sensor had to be read, and the combination of readings had to be decoded. The first step of this process was to determine whether or not a magnet was detected above a given sensor. The Hall Effect sensor generated a voltage output proportional to the detected magnetic field that was sent to an analog input pin on the microcontroller. This analog value was passed through analog-to-digital conversion (ADC) to convert the voltage to a digital value. This digital value for the Hall Effect sensor output was checked against a threshold value that was determined via testing, to determine whether or not a magnet was detected or not. Because each magnet had both a positive and negative polarity, a magnet was marked as detected if the voltage output was below the negative polarity voltage threshold or above the positive polarity threshold. Any voltages measured that fell in between the two threshold values were marked as having no magnet.

Each of the Hall Effect sensors corresponding to one letter sensing slot were connected to different data lines of an 8:1 analog multiplexer. The purpose of the analog multiplexer was to gain the ability to read five different sensors only using one pin on the microcontroller. By iterating through each of the multiplexer select lines, each data line could be read, allowing us to record the readings of each Hall Effect sensor in a slot. This multiplexer and sensor configuration was replicated five times to represent five total letter slots.

Verifying user input

Figure 12 displays a software flow diagram for how the system verifies the user's input from the letter blocks. First, the system polls the Check button on the LCD to monitor when it has been pressed. Next, we iterate through each multiplexer select line and iterate through every letter slot to read each Hall Sensor voltage through the ADC. If the ADC value is greater than THRESHOLD_HIGH or less than THRESHOLD_LOW, the binary value for that slot and line is recorded as a 1, indicating that the sensor detected a magnet. Otherwise, we store the value 0 into the respective slot and line. This process is repeated for all select lines and letter slots. Once the 5-bit binary value is stored for every single letter slot, each 5-bit value is decoded as a letter. If the binary value is 00000, the letter is decoded as an empty slot. The letters for all five slots are concatenated to form a word. The word is then compared against the correct answer. If the guess is correct, we highlight the user's guess on the LCD in green and display the next image for the user to spell. If the guess is incorrect, we highlight the incorrect letters in red and prompt the user to guess again. This process repeats every time the user presses the Check button on the LCD.

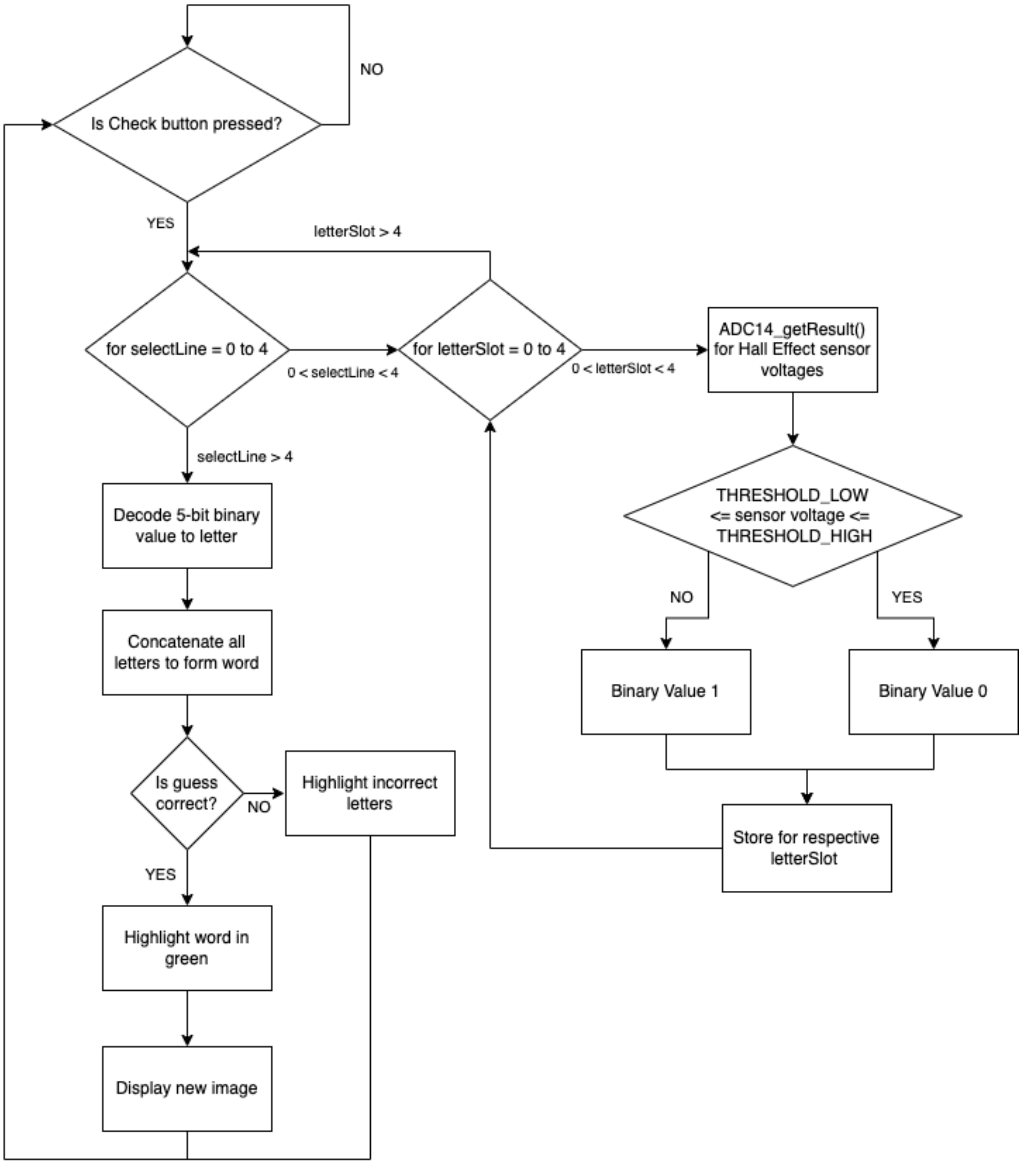


Figure 12: Software Flow Diagram for Letter Verification

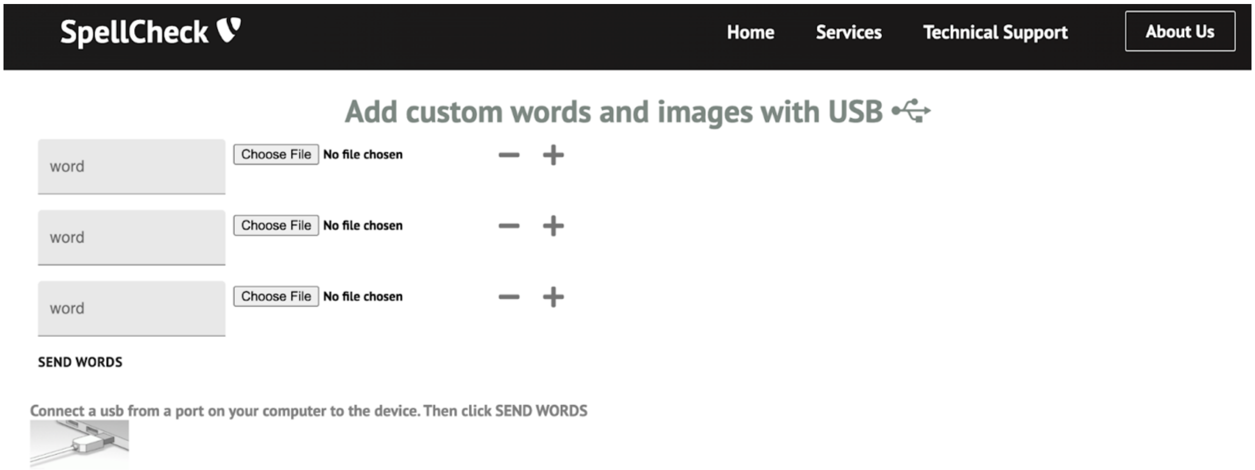
LCD

The TFT LCD display interfaced with the MSP432 microcontroller using the serial-peripheral interface (SPI). SPI communicates using four data lines: CLK, MOSI, MISO, and CS. The CLK serial clock line synchronizes communication, MOSI sends data from the MSP to the LCD, MISO sends data from the LCD to the MSP, and CS chip select determines which direction the data is being sent. The microcontroller uses SPI to write commands to the EVE display engine on the LCD. Images are downloaded from the web application and stored in the MSP's flash memory. Then, the MSP writes the images to the LCD and these images are loaded into the LCD's RAM memory. Then, the LCD loads the image bitmap from RAM to display the image when needed.

Software

User Interface - Front End

The SpellCheck website is deployed on Vercel App and can be found at https://spellcheck-client.vercel.app/. The website uses an open source template from GitHub user briancodex for the user interface design [42]. The website's main purpose is to provide an interface for teachers to easily upload word sets from their lesson plans to be used on the SpellCheck device. Figure 13 shows how a user can upload images to the device.



Add custom words and images with USB

Connect a usb from a port on your computer to the device. Then click SEND WORDS

Figure 13: SpellCheck Website Custom Words Form

From a user perspective, the user will navigate from the home page of the website to the services tab and select either "Custom Words & Images" or "Default Words & Images" to upload words onto the device. To enter their own images, the word/image pair must follow the following constraints:

- Image files must be .png or .jpg/.jpeg
- Word can be no more than five lowercase letters
- Word and image fields must be filled

If any of the constraints are violated, an alert message will be displayed to the user. Once the user submits the words (their own custom words or the default words), the user will be prompted to select a COM port for the device (the device must be plugged in for the ports to appear). A loading icon will appear on the screen until the words are successfully uploaded and a success alert will appear to the user.

The website also provides a technical support page if users need to resolve common problems and are unfamiliar with the device. The following section will explain in further detail how the system receives the images and their corresponding information.

Uploading Images to the MSP432

Once the user uploads their image and word onto the web application, the application must load the information onto our device. Figure 14 displays a software flow diagram of the image uploading process. First, the web application checks that the text is valid (5 letters or less) and that the image is either a .png or .jpeg/.jpg file format. When an image is selected, the react-image-file-resizer module dynamically resizes the image and optimizes them for picture quality. Next, an object is created containing the image and its properties, including file size, height, width, type (jpeg or png), and a unique identifier matching the unique identifier of the image's respective word. If the user would like to upload a new image and word pair, the new input is mapped to a new unique identifier. The user may also remove previously uploaded words.

Once the user presses the "Send Words" button, the program searches for all of the words and image objects with the same unique identifier and stores the information into a new processed array containing an object. The object has the following field: word, file, image size, height, width, and file type. Any items with a unique id that does not appear in both arrays are not added to the processed array. In order to communicate all of this information to the MSP over UART, all fields are concatenated into a string. In this string, each field is followed by a specific delimiting character to indicate what the field represented: '|' for word; '/' for file; '$' for file type; '*' for file size; '#' for image width; '!' for image height. Additionally, '%' is added at the end of each word/image pair to indicate the end of data being sent for a segment , '.' is added once at the end to indicated the end of the data stream, '+' is added as a dummy/buffer character to resolve timing issues encountered by the microcontroller. Finally, this concatenated string is passed into the TalkToMSP(string) function that converts the string to a javascript array which is sent over the COM port that has been selected by the user. This function also listens for an ACK signal from the microcontroller. If the ACK was successfully received, the image was successfully transmitted and the stored array is cleared. If not, the image transmission failed.

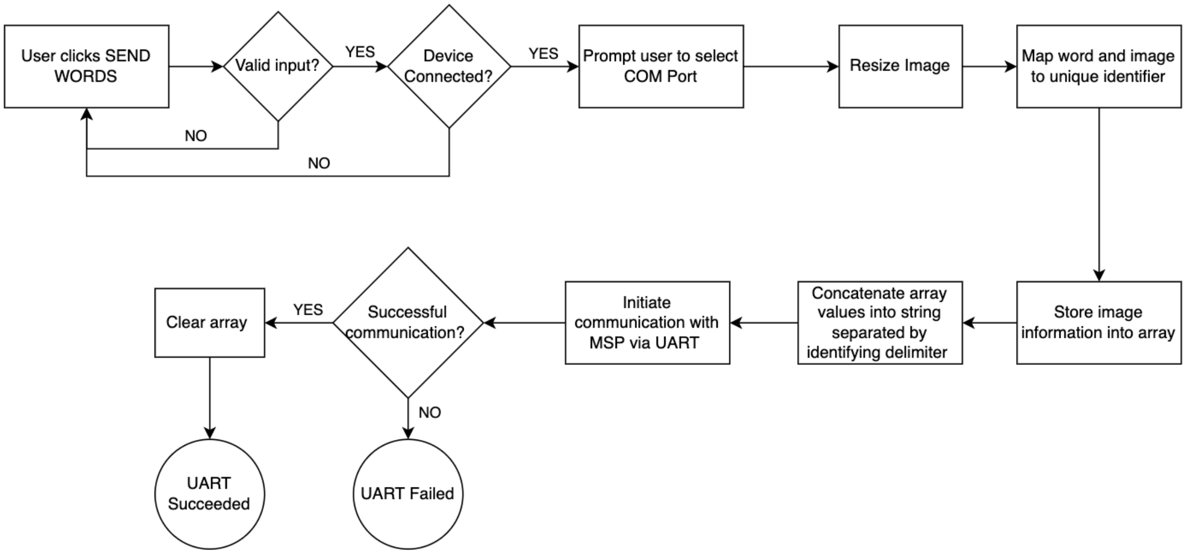


Figure 14: Software Flow Diagram for Uploading Images to MSP432 from Web Application

Mechanical

CAD Design

There were two components of our system that were 3D printed. First, the letter blocks had to be designed to interface with the magnet identification system. Second, the slot panel for the attempted word had to be designed to fit onto the chosen enclosure and ensure letters were placed in a certain orientation.

For the letter blocks, the size of the letter block was chosen based on the size of a standard toy letter block [43]. Holes for the magnets were put in the four corners and middle of one side of the block to maximize the spacing between the magnets to decrease any interference between magnetic fields. Since the orientation of the letter block is critical for correctly identifying the letter, an indentation was placed onto the bottom of the letter block that would make the letter block fit onto the panel in one way. Finally, the bottom of the letter block was shelled to minimize the cost of 3D printing each letter block. It should be noted that the block should be filled in the areas that were shelled to ensure the singular block orientation. Due to cost constraints, our project's letter blocks are not filled. The final CAD design for the letter block can be seen in Figure 15.

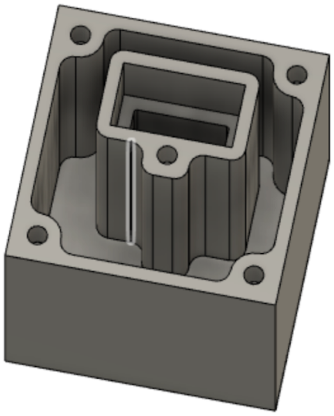


Figure 15: Letter Block CAD Design - Bottom of Block

For the slot panel, the height, length, and width of the panel reflected the measurements of the given panel from the chosen enclosure. Five indentations were placed onto the panel to indicate where the letter blocks should be placed, along with the peg shape that would fit inside the indentation designed on the letter block. Four holes were placed on the corners of the panel so it could be properly mounted onto the enclosure and secured in place. The final CAD design for the panel can be seen in Figure 16.

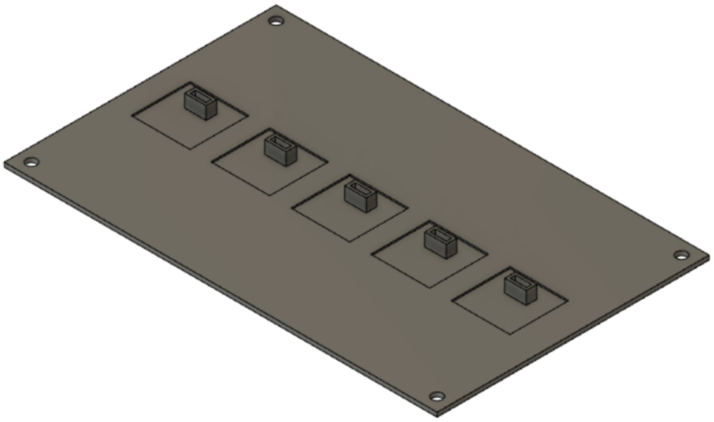


Figure 16: Slot Panel CAD Design

Assembly

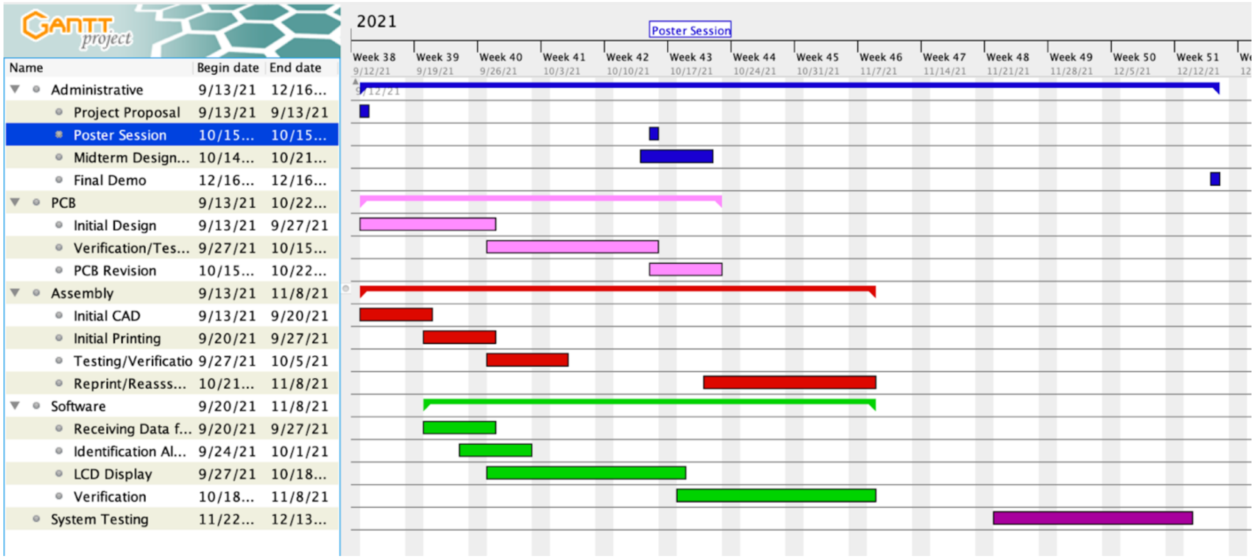
Once the letter blocks and slot panel were 3D printed, the magnets had to be placed into each letter block in accordance with the letter identification scheme seen in Appendix A and B. Even though we are able to identify if a magnet was present regardless of the polarity of the magnet, we decided to put the magnets into the blocks with the positive polarity being read by the sensors to keep the blocks consistent. With this design choice, we increased the number of identification combinations for future blocks.

For the slot panel, the PCB had to be assembled right underneath the panel and the sensors had to be aligned with the block indentations. If the PCB was not aligned with the slot panel accurately, the sensors would not be able to read the magnetic field with the accuracy that we need to decode the letters. Letter identification on the panel with the PCB underneath was tested to find an accurate position for the PCB. The measurements for the PCB were used to then match drill four holes into the panel and PCB, which could then be mounted together using screws.

A phone tripod mount was used to mount the LCD display [44]. The mount was chosen since it could securely hold the LCD and could be attached onto the enclosure using a screw. The mount was within our budget constraints and gave the cleanest look compared to other suggestions.

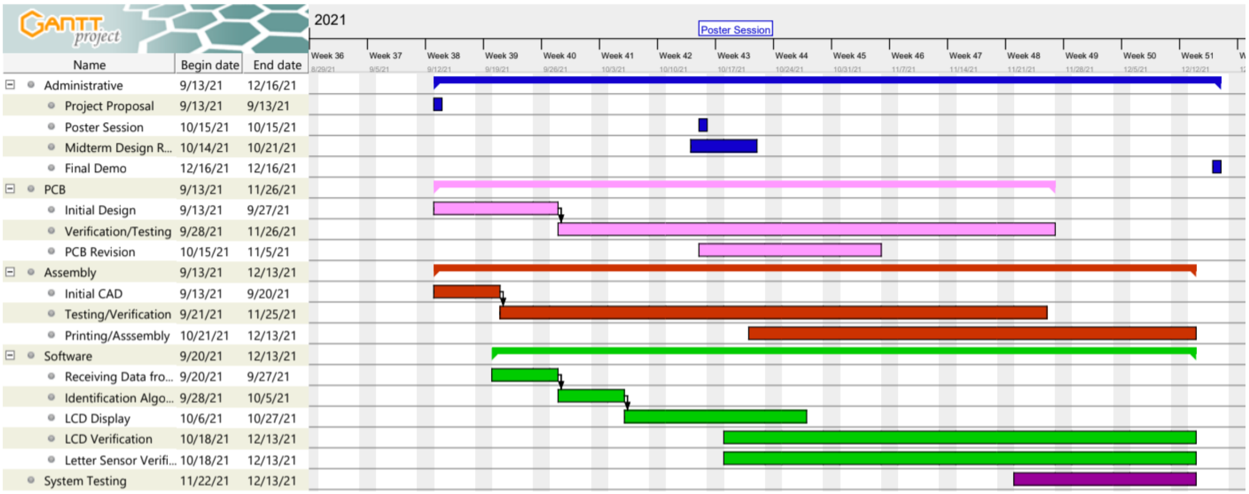
Project Timeline

The first proposed project timeline can be seen in the Gannt chart in Figure 17. The Gannt chart is categorized in the following subjects: Administrative (blue), PCB (pink), Assembly (red), Software (green), and System Testing (purple). Originally, we expected to simultaneously work on the PCB design, 3D printing designs, and firmware, with most development being completed by the middle of the term. Most of the work was frontloaded, especially the PCB, as we wanted to give our team enough time to order and wait for components. Figure 18 represents an updated Gantt chart that more accurately represents the project's timeline. The team realized that the majority of testing was reliant on component ordering, which was delayed. Software development also took longer than expected and the PCB design was prolonged since the team decided to participate in the first and last PCB orders for the course. LCD related tasks were pushed back due to the LCD Display taking longer than expected to arrive. However, all tasks were still able to be parallelized and towards the end of our timeline the system could be tested as a whole. The team aimed to have a final working system by December 15th.



Name	Begin date	End date
Administrative	9/13/21	12/16...
Project Proposal	9/13/21	9/13/21
Poster Session	10/15...	10/15...
Midterm Design...	10/14...	10/21...
Final Demo	12/16...	12/16...
PCB	9/13/21	10/22...
Initial Design	9/13/21	9/27/21
Verification/Tes...	9/27/21	10/15...
PCB Revision	10/15...	10/22...
Assembly	9/13/21	11/8/21
Initial CAD	9/13/21	9/20/21
Initial Printing	9/20/21	9/27/21
Testing/Verificatio	9/27/21	10/5/21
Reprint/Reasss...	10/21...	11/8/21
Software	9/20/21	11/8/21
Receiving Data f...	9/20/21	9/27/21
Identification Al...	9/24/21	10/1/21
LCD Display	9/27/21	10/18...
Verification	10/18...	11/8/21
System Testing	11/22...	12/13...

Figure 17: Proposed Gantt Chart



Name	Begin date	End date
Administrative	9/13/21	12/16/21
Project Proposal	9/13/21	9/13/21
Poster Session	10/15/21	10/15/21
Midterm Design R...	10/14/21	10/21/21
Final Demo	12/16/21	12/16/21
PCB	9/13/21	11/26/21
Initial Design	9/13/21	9/27/21
Verification/Testing	9/28/21	11/26/21
PCB Revision	10/15/21	11/5/21
Assembly	9/13/21	12/13/21
Initial CAD	9/13/21	9/20/21
Testing/Verification	9/21/21	11/25/21
Printing/Asssembly	10/21/21	12/13/21
Software	9/20/21	12/13/21
Receiving Data fro...	9/20/21	9/27/21
Identification Algo...	9/28/21	10/5/21
LCD Display	10/6/21	10/27/21
LCD Verification	10/18/21	12/13/21
Letter Sensor Verifi...	10/18/21	12/13/21
System Testing	11/22/21	12/13/21

Figure 18: Updated Gantt Chart

The primary tasks of the project have been split among the five team members into primary and secondary roles. Noah's primary focus was hardware communication (mainly the LCD), and assisting the development of the microcontroller software and power supply. Justin's primary focus was developing the microcontroller software application, as well as helping with the letter identification system connections. Rachel's primary focus was the CAD design for the letter blocks and slot panel, and assisting Catlinh with the letter identification system and PCB design. Catlinh focused on designing on the letter identification system, with secondary focuses on letter design and PCB design. Shymbolat focused on designing and developing the power supply, and helped with the hardware communication.

Test Plan

Hardware

Magnets and Sensing

The magnets and sensors were tested in 3 capacities: for interference, for critical distance from the sensor that can produce a reading, and in the device enclosure. Initially, all testing was done with the 6619 Gauss magnet.

Interference Measurements:

As previously mentioned, the greatest concern was whether or not the magnetic field from one magnet could interfere with the sensor that is designated to another magnet. In order to test for interference, different combinations of magnets were tested. For example, one sensor was tested with no magnet in its slot, but with 1, 2, 3, and 4 neighboring magnets. If there was interference with other magnets, the sensor would show a change in its voltage output.

The results of this testing are displayed in Appendix C Table 7. While there was a slight interference in sensor readings in the presence of neighboring magnets, this difference was not statistically significant. Therefore, the presence of each individual magnet is still distinguishable and sufficient to create different detectable magnet combinations.

Critical Distance:

To find the critical distance between the magnet and the sensor to produce a reading, the magnet was tested at different distances from the sensor as the sensor voltage output was recorded. These readings were graphed against the baseline sensor reading of 1.0282V that was measured with no magnet present. The results are displayed in Figure 19.

Note: This graph displays the magnet from the reverse polarity. The results are similar, except the range is from 1V – 1.8V in the positive polarity.

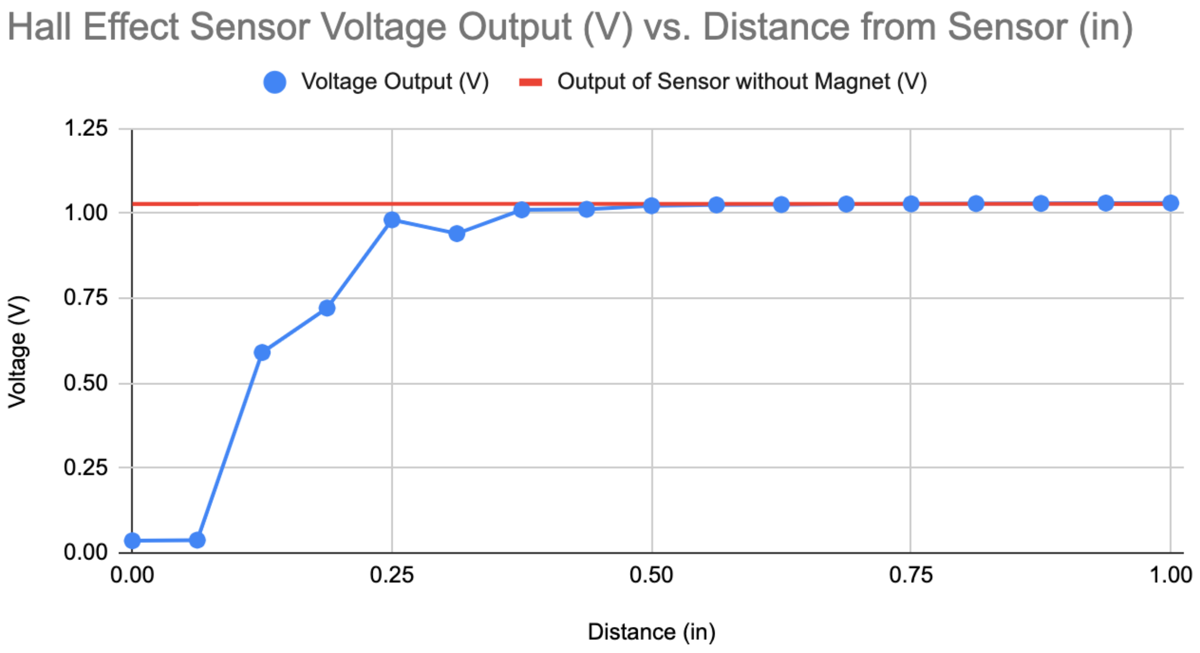


Figure 19: Hall Effect Sensor Voltage Output vs. Distance from Sensor

As shown in the graph, the critical distance between which the sensor can still detect the magnet is 0.19 in. Therefore, as long as the magnet is placed between 0.00-0.19 in, it will be detectable.

Enclosure Measurements:

Both strengths of magnets were inserted into blocks and measured through the slot from the sensors mounted onto the PCB. The voltage output results for each magnet are displayed in Table 3. As expected, both magnets place the sensor in saturation and can be detected by the sensor.

Baseline Voltage Output: 1.0282V

	6619 Gauss Magnet	**7179 Gauss Magnet**
Negative Polarity	0.4814	0.0426
Positive Polarity	1.9995	2.0303

Table 3: Voltage Output from Hall Effect Sensors for Different Magnet Strengths

Preliminary PCB Testing

Before creating a full PCB for our entire system, we manufactured a tester PCB with only the MSP connections, LCD connector, and power supply so that we could start working with the

LCD as soon as possible. Figure 20 shows the schematic for the tester PCB and Figure 21 shows the board layout of the tester PCB.

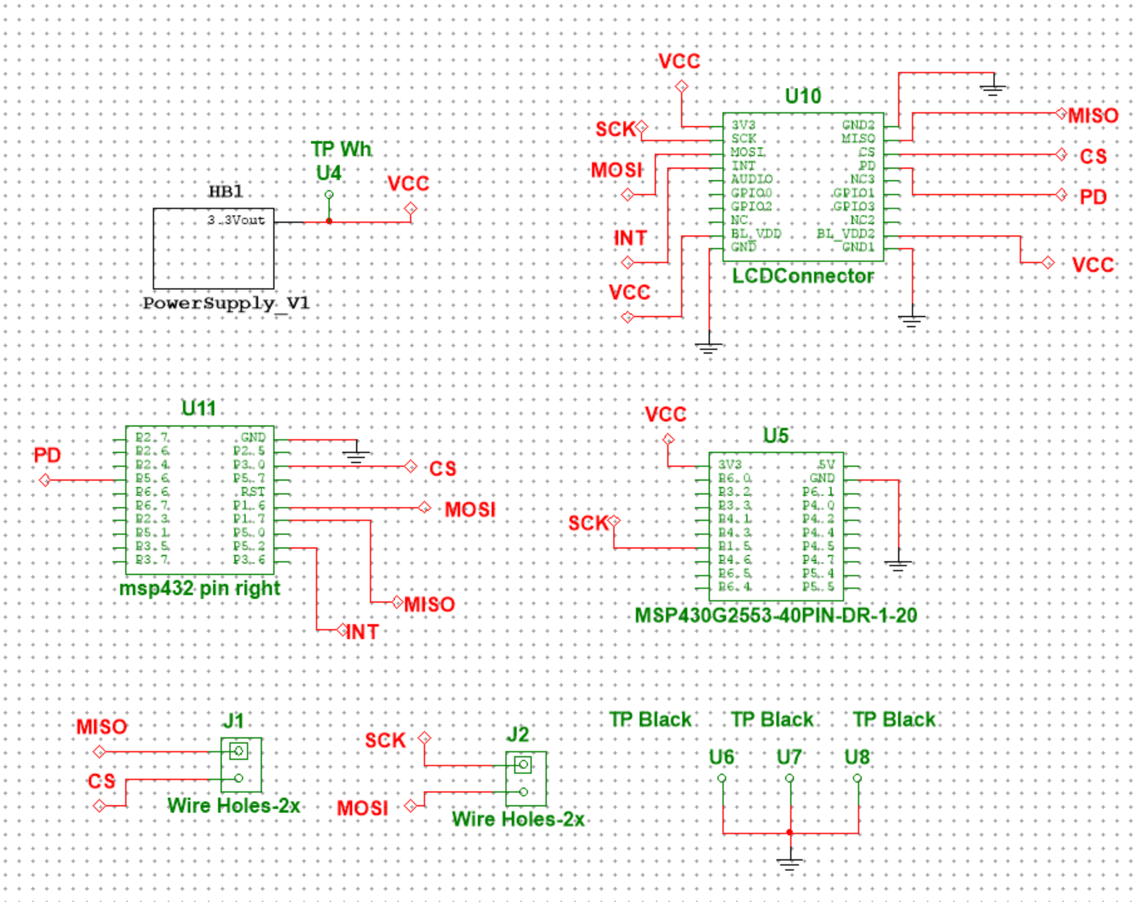


Figure 20: Schematic Drawing of Tester PCB

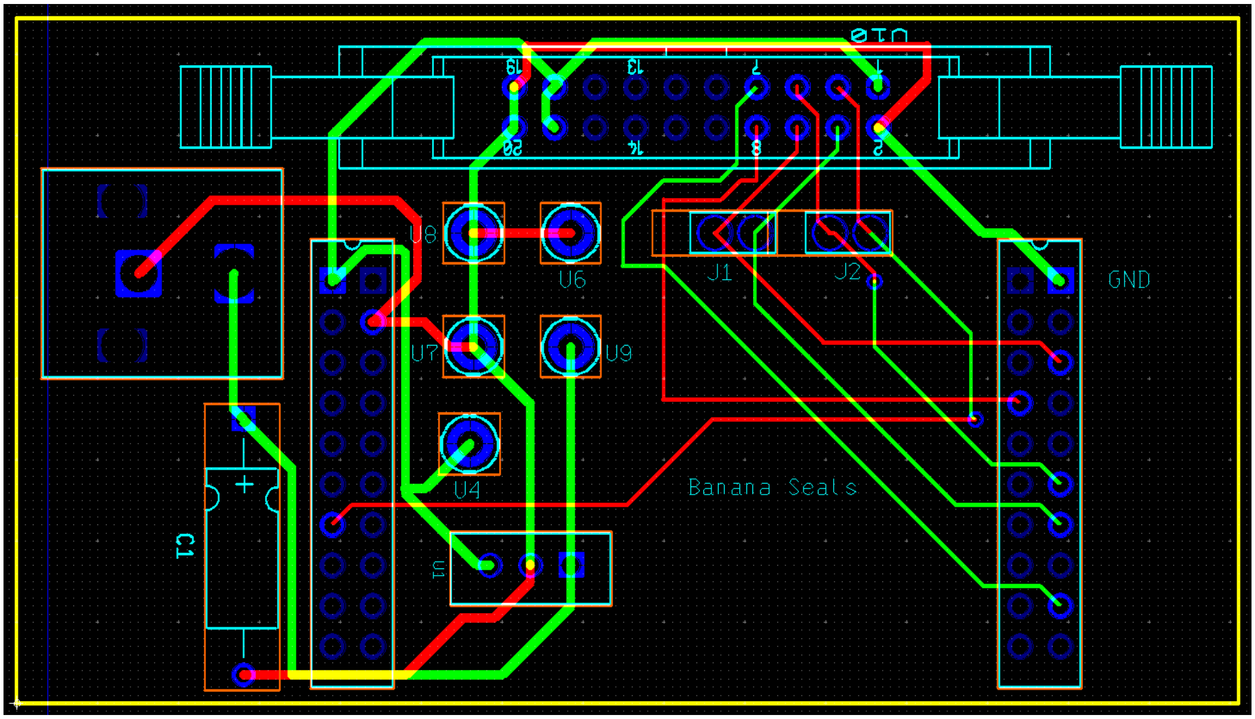
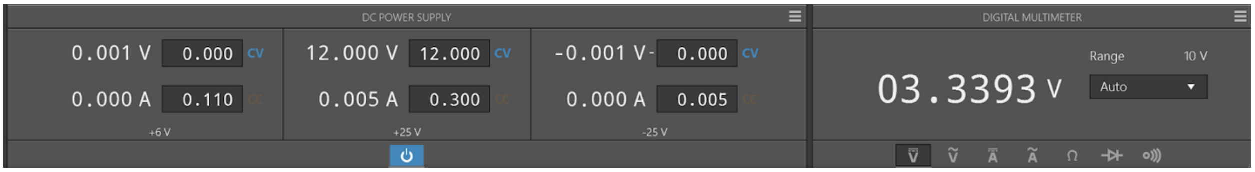


Figure 21: Board Layout for Tester PCB

The power supply had to be verified that it could regulate the voltage from a wall transformer and step the value down to 3.3V, which is the required voltage to power the PCB. In order to do this, test point U9 was connected to the output of the voltage regulator. After the PCB was plugged in, the voltage at this point was measured and found to be 3.3393V, which is similar to the expected voltage of 3.3V. The measurement from Virtual Bench can be seen in Figure 22. Therefore, the power supply operated as expected.



0.001 V 0.000
0.000 A 0.110
12.000 V 12.000
0.005 A 0.300
-0.001 V 0.000
0.000 A 0.005
03.3393 V
Range 10 V
Auto

Figure 22: Measured Voltage at U9 for Power Supply Verification

The LCD system was tested so that it could accurately load and display images. After connecting the tester PCB to power and the MSP, we tested that the SPI communication between the MSP and LCD was working as expected. We debugged the system until the LCD could display images and accurately process touch.

Full PCB Testing

The PCB with the full schematic was tested to ensure that all electrical connections were sound and functioning as expected. Because the power supply and LCD connector had already been tested in the tester PCB, which had a nearly identical circuit, much of this process focused on the sensor functionality and letter identification.

In order to test the sensors, the PCB was plugged in and a voltmeter probe was placed on each of the sensor output lines. A block with an attached magnet was placed on each sensor. Each sensor was verified that it could produce a sufficient voltage output in the presence of a magnetic field.

Next, we had to verify that the LCD could be properly powered by the PCB. If the LCD only had power to its backlight, it would display a bright white screen. If the LCD was properly receiving power to its 3V3 pin and its backlight pins, the screen should turn off. However, when we first plugged the LCD into the PCB, only the backlight turned on, indicating that there was a problem with powering the 3V3 pin. After further inspection, we found that we had improperly connected the bypass capacitor for the LCD in series, rather than in parallel. The incorrect connection can be seen in Figure 23. This was the only change that we had made to the LCD circuit between the tester PCB and the final PCB. To fix this, the capacitor was shorted as seen in Figure 24. This solution solved the LCD powering problem.

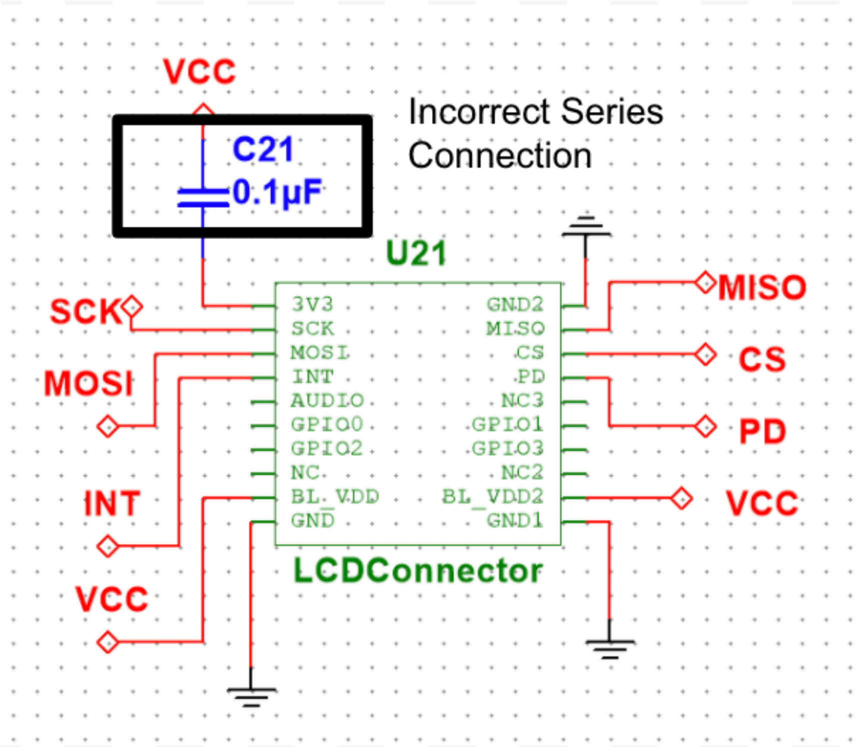


Figure 23: Incorrect Circuit for LCD Connector

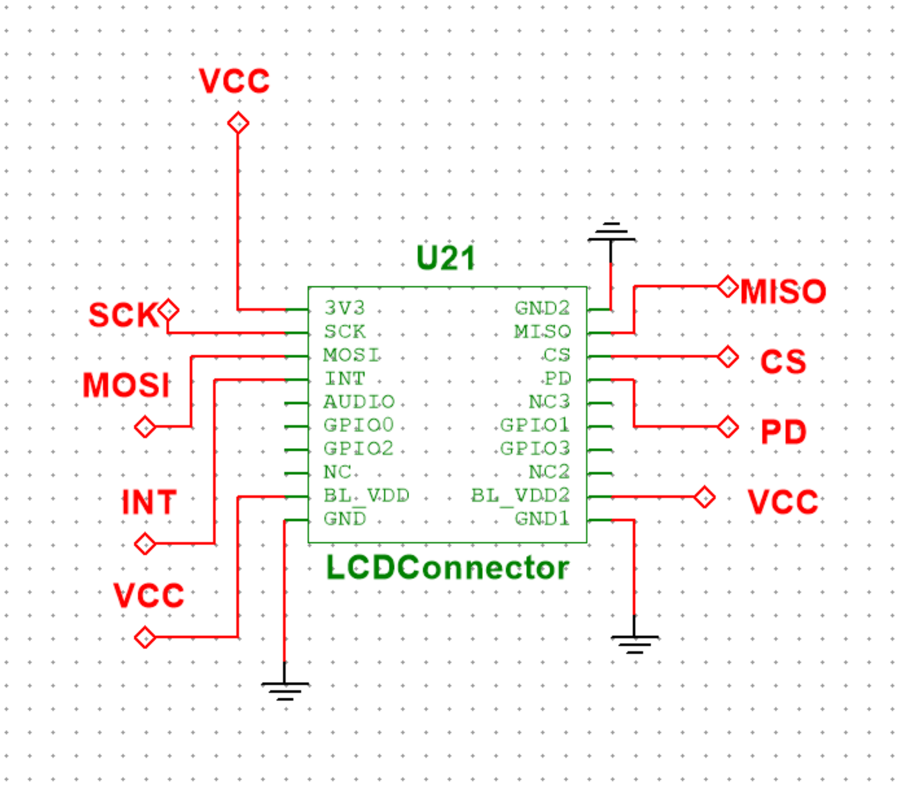


Figure 24: Resolved Circuit for LCD Connector

Software

Figure 25 displays the test plan for the process of uploading images from the web application onto our device. First, we checked that the web application can differentiate between valid and invalid user input. Next, we tested that the web application can detect that the MSP is connected via USB. Next, we tested that UART communication is working between the web application and the MSP. Lastly, we tested that the image and text that were uploaded by the user on the web interface was stored onto the MSP and could be loaded properly on the LCD display. Once all of these points were verified, we had a functioning image uploading system. Furthermore, we tested the web application for seamless user interaction and that the site would not break or crash.

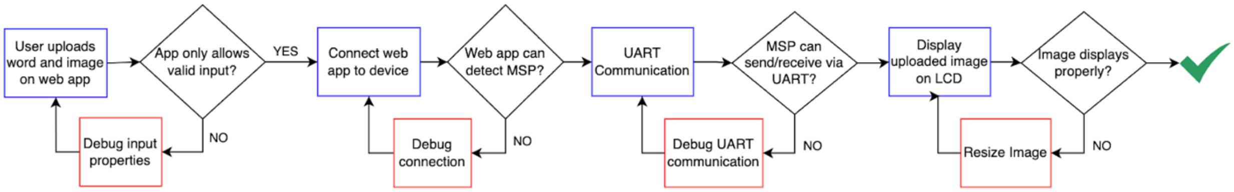


Figure 25: Test Plan for Uploading Images from Web Application

To test the LCD display, the power connections were first verified. The backlight pins, pins 17 and 18, were connected to power. We expected the backlight of the LCD display to turn on. When the final power port, pin 1, was connected to power, we expected the LCD display to turn off. We verified these actions occurred. Once the power was verified, we checked the SPI connections by connecting the LCD and MSP according to the port mapping we specified in our PCB layout. After sending commands to turn on the LCD and configure its clock, we read the chip identification register. By confirming that the register read 0x7C, which is the value given in the LCD's datasheet, we were able to confirm that the LCD was able to transmit and receive data to the MSP using SPI.

Full System Testing

Figure 26 displays the test plan for the spelling verification aspect of our project, using our full PCB. As shown in Figure 26, the testing was broken up into 3 main sections: LCD display, letter identification, and spelling verification. The LCD system was tested so that it could accurately load and display images. Because we previously verified LCD functionality on the tester board, this part of the process did not require significant debugging, as the full PCB had the same circuitry as the tester PCB. Next, we verified that the letter identification system was functioning correctly. Because we had previously verified that the sensors could produce an expected voltage output in the presence of our magnets and blocks and that the neighboring magnets did not pose any interference, this part of the testing process focused on how to decode the voltage readings into letters. We debugged the multiplexing process, encoding scheme, and decoding process in order to fix the letter identification system. Lastly, we tested the spelling verification flow that is detailed in Figure 12. Because we previously verified that the letter identification process was working and could accurately identify all 26 letters, this segment of the test plan involved debugging software logic. Once this functionality was implemented, we had a basic functioning system.

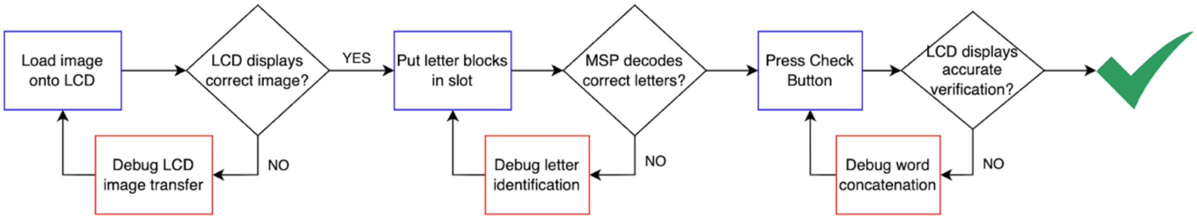


Figure 26: Spelling Verification Test Plan

Final Results

We successfully built a device that helps students practice how to spell. The system contains all of the key components, including an interactive LCD display, letter blocks, child-safe enclosure, and a user-friendly interface for teachers to upload their own word lists. Furthermore, our final project meets all of the key criteria that was specified in our proposal. Tables 4 and 5 show the expectations that we set for SpellCheck in the project proposal. First, letter detection is fully functional and can correctly identify all 26 letter blocks. Second, spelling verification was implemented and can determine if a user's spelling guess is correct. Next, the LCD display shows the pictures, the user's guess, the spelling verification, and highlights the letters that were spelled incorrectly. However, the LCD display does not implement a user specific game interface. Next, the letter board makes it easy for the user to place letters and has slots for all five letters. Lastly, the Check button on the LCD effectively initiates spelling verification when pressed. However, we did not implement a power button because this can be done by plugging the device into a wall socket. Therefore, the requirements that we satisfy places our project in the A range as defined by Table 5.

	Letter Detection	**Spelling Verification**	**LCD Display Communication**	**Letter Board Placement**	**Button Functionality**
2	Can accurately identify all letters produced	Can determine if target word is spelled correctly or not	LCD display can show not only pictures, but also components of the software game	Letters can be placed and read easily, and fit only in one orientation onto the board. Must have 5 letters onto board.	Accurately initiates spelling verification when pressed. Other button turns on power.
1	Can somewhat identify the letters produced	Can determine if target word is spelled correctly most of the time OR determines correct spelling for wrong target word	LCD display shows only pictures, but not components of the game	Letters can be placed and read easily, but orientation to place in board is not straight forward	One of the functions are correct.
0	Can not accurately identify letters	Cannot determine if target word is spelled correctly	LCD does not show pictures OR does not turn on.	Letters do not fit into the system	Does not work

Table 4: Rubric for SpellCheck Expectations

Points	**Grade**
8-10	A
5-7	B
2-4	C

0-2	D

Table 5: Grading Rubric Key

In addition to the requirements that we set in the beginning of the semester, our team implemented extra functionality that makes the device easier to use and more effective. In our conversations with Professor Cook and Professor Hayes from the UVA School of Education, both teachers conveyed that the ability for teachers to personalize the word lists and images was important. In order to incorporate this feedback into our project, we built a web application that allows teachers to either select a premade list of words, or to upload their own words and images. Additionally, the website has instructions about how to operate the device and information about our team. This additional functionality makes our device more applicable in a classroom setting.

Costs

The cost to produce SpellCheck this semester was lower than the cost of one production model, as our team members already owned a MSP432 microcontroller. Table 6 shows a high-level breakdown of the total costs if SpellCheck was made in limited and large quantities.

	Cost for 1 unit	Cost per unit for 10,000 units
MSP432	$23.99	$4.26
PCB	$33	$5.75
PCB Components	$101.40	$58.24
LCD Display	$86.79	$34.20
Mounting Components	$19.40	$12.90
3D Printing Components	$35.96	$10
Magnets	$4.20	$3.30
Total	$304.74	$128.65

Table 6: SpellCheck Costs

The most expensive part of the system is the PCB and its components. If the project was scaled for mass production of 10,000 units, the total cost for one unit would decrease by 57.78%, from $304.74 to $128.65. To decrease costs in mass production, the 3D printed components could be manufactured with automated equipment instead of using 3D printers, which would significantly decrease the cost for the letter block pieces. Choosing a less expensive LCD display can also decrease costs for production. A detailed breakdown of all costs spent for SpellCheck, including testing materials, can be seen in Appendix D Figure 29.

Future Work

The team sought advice from professors from the UVA School of Education and Human Development in order to garner feedback and improvements of our system for practical use in the classroom environment. To improve upon the current version of SpellCheck, the team suggests that the project can be expanded in the following ways.

Dictation

Due to cost and timing constraints, we were not able to connect a speaker and dictate the objects for users to spell. This addition would eliminate any ambiguity of the objects displayed on the screen and help students connect the spoken word to its spelling. Professor Lysandra Cook and Professor Tisha Hayes emphasized the importance of phonics in spelling practice. Thus, incorporating a speaker that can sound out each letter as it is placed will help correlate the letters with their sounds. Sound would also be helpful for students who are visually impaired that want to use our system.

Advanced Blocks

Initially, the team believed that the number of unique combinations for identifying blocks was 31. After testing the magnets and assembling the letter blocks, we learned the polarity of the magnets mattered in the voltage reading from the sensor. Thus, the number of unique combinations for the blocks has increased to 242 (3^5) combinations. With these extra identifying combinations, blocks can be used to represent prefixes, suffixes, and digraphs. Blocks can also be used for shapes, numbers, and colors if teachers wanted to use the system's application for practice in another subject. In general, future teams should consider the variety of directions the system can be used in accordance with the different blocks that can now be produced.

Some modifications should also be made to the letter blocks. Professor Cook suggested the letter blocks have the letters in lowercase, as this would be of higher utility since platforms teachers use now are also in lowercase letters [45]. The current version of our system has uppercase letters due to cost and time restraints. The letter blocks could also incorporate the braille alphabet onto the blocks. This would make the system more inclusive for students who are visually impaired.

Gamification and Login

One aspect of our project that could be improved is the gamification and personalization of the system. Due to time constraints, the gamification on the LCD's interface was not as engaging as we had first expected. To improve the user experience, future teams should consider the time needed to develop the gamified user interface. In addition, future teams can also incorporate a user login for the device, so each student can have a personalized account where the teacher can then keep track of how the student is performing. Statistics each account could hold include the number of attempts per word and how many words were spelled correctly on the first try. According to Professor Tisha Hayes, this feature would be extremely useful for teachers to understand which areas their students need more help with.

Mounting Considerations

Future teams should be cognizant of assembly while developing designs for the system. For example, we match-drilled the PCB and slot panel in spaces available with no tracing, but the placement of the drilling could have been planned while designing the PCB beforehand. Planning for the holes would have resulted in a cleaner final look on the panel.

Incorporating Wifi Modules

One central feature of our device is the user interface that allows teachers to customize their own word lists and images. Currently, this uploading process requires a teacher to connect their laptop to the device via USB. However, this process is more involved and requires the teacher to be within a few feet of the device in order to upload new words. For ease of use, future teams may implement WiFi modules to allow teachers to interact with the device wirelessly. This feature would be much easier for teachers to use the SpellCheck device.

Collaboration with UVA School of Education and Human Development

In our meeting with Professor Lysandra Cook, we discussed putting our device in practice in a classroom environment. Professor Cook teaches reading and writing intervention, which is a course that examines reading and writing research and its implications for teaching students for disabilities, and offered an avenue to test our project in her class. Future teams may look into collaborating more closely with the UVA School of Education and Human Development and quantifying the true impact of the device in children aged 5-7.

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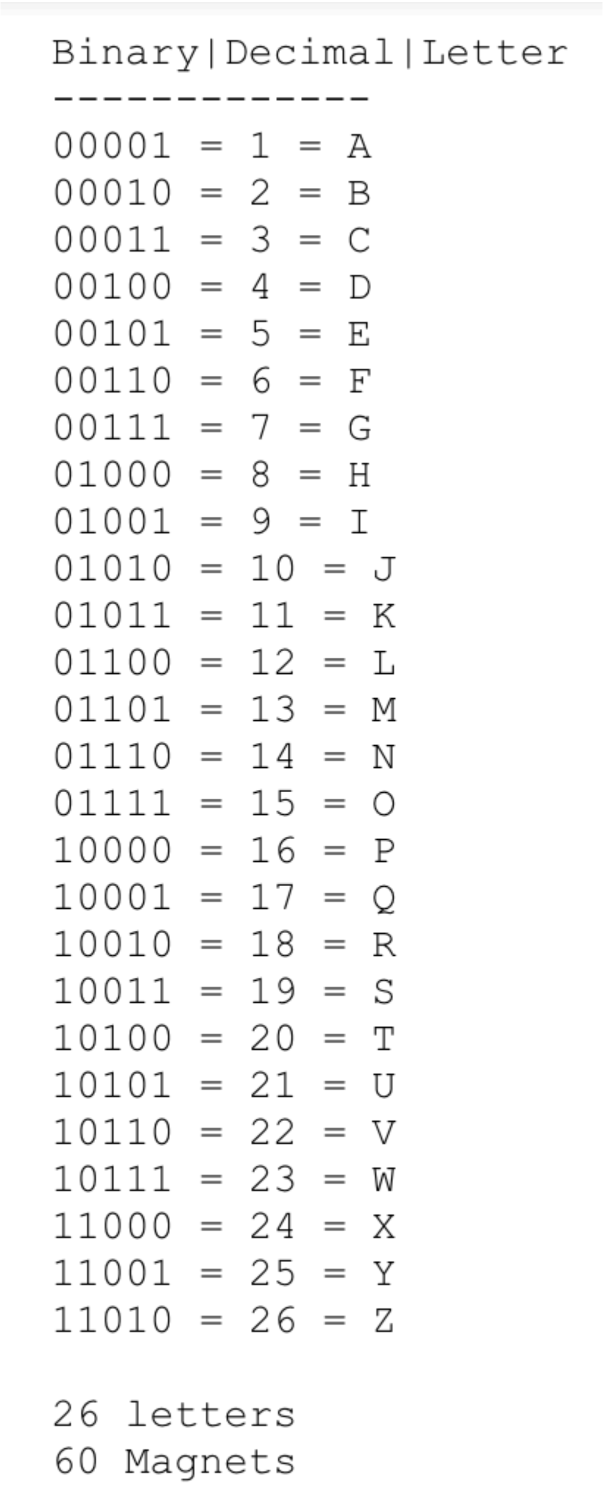
Appendix

Appendix A



```
Binary|Decimal|Letter
-------------
00001 = 1 = A
00010 = 2 = B
00011 = 3 = C
00100 = 4 = D
00101 = 5 = E
00110 = 6 = F
00111 = 7 = G
01000 = 8 = H
01001 = 9 = I
01010 = 10 = J
01011 = 11 = K
01100 = 12 = L
01101 = 13 = M
01110 = 14 = N
01111 = 15 = O
10000 = 16 = P
10001 = 17 = Q
10010 = 18 = R
10011 = 19 = S
10100 = 20 = T
10101 = 21 = U
10110 = 22 = V
10111 = 23 = W
11000 = 24 = X
11001 = 25 = Y
11010 = 26 = Z

26 letters
60 Magnets
```

Figure 27: Letter Encoding Scheme

Appendix B

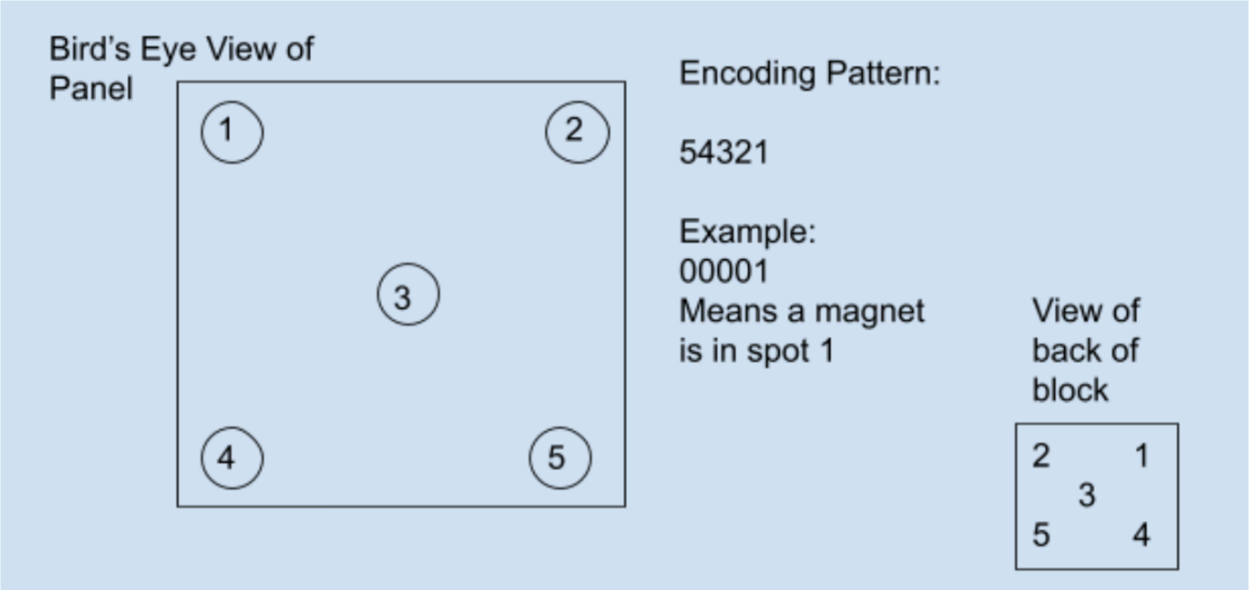


Figure 28: Magnet Assembly Reference

Appendix C

Status	Voltage Output #1	Voltage Output #2	Voltage Output #3	Average
No Magnet to Sensor	1.028	1.028	1.028	**1.028**
Magnet to Sensor (0 distance)	0.036	0.037	0.036	**0.036**
Magnet to Sensor + 1 Other Magnet (0.8in distance)	0.038	0.038	0.382	**0.153**
No Magnet to Sensor + 1 Other Magnet	1.031	1.031	1.030	**1.031**
No Magnet to Sensor + 2 Other Magnet	1.034	1.034	1.034	**1.034**
No Magnet to Sensor + 3 Other Magnet	1.028	1.032	1.029	**1.030**
No Magnet to Sensor + 4 Other Magnet	1.022	1.023	1.031	**1.025**
Magnet to Sensor + 1 Other Magnet	0.036	0.037	0.036	**0.036**
Magnet to Sensor + 2 Other Magnet	0.037	0.037	0.037	**0.037**
Magnet to Sensor + 3 Other Magnet	0.362	0.038	0.039	**0.146**

Table 7: Magnet Interference Testing

Appendix D

A	B	C	D	E	F
Item	Quantity	Unit Price	Total Cost	Remaining Budget	
				$500.00	Starting Budget
8x1 Multiplexer	10	5.752	$57.52	$442.48	
Hall Effect Sensors	5	1.732	$8.66	$433.82	
LCD Display	1	86.79	$86.79	$347.03	
Connection Header	1	5.48	$5.48	$341.55	
AC/DC WALL MNT ADAPTER 12V 3.6W	1	9.84	$9.84	$331.71	
CONN PWR JACK 2X5.5MM SOLDER	1	1.37	$1.37	$330.34	
DC DC CONVERTER 3.3V 2W	1	7.83	$7.83	$322.51	
IDC CABLE - MKR20A/MC20G/MKR20A	1	4.91	$4.91	$317.60	
SWITCH PUSH SPST-NO 0.1A 32V	1	1.12	$1.12	$316.48	
Enclosure	1	18.71	$18.71	$297.77	
KJ Magnetics (Pack of 10)	3	1.1	$3.30	$294.47	
Female Connection Header	2	1.26	$2.52	$291.95	
				$291.95	Budget After Order#1
Hall Effect Sensors	25	1.22	$30.50	$261.45	
Board SendOut #1	1	33	$33.00	$228.45	
				$228.45	Budget After Order#2
PC TEST POINT	25	0.3408	$8.52	$219.93	
CONN HEADER VERT 6POS 2.54MM	10	0.227	$2.27	$217.66	
CAP ALUM 4.7UF 20% 50V RADIAL	10	0.138	$1.38	$216.28	
CAP CER 0.015UF 50V X7R RADIAL	50	0.0832	$4.16	$212.12	
CAP CER 0.1UF 50V X7R RADIAL	10	0.165	$1.65	$210.47	
CONN HEADER VERT 20POS 2.54MM	1	5.48	$5.48	$204.99	
CONN PWR JACK 2X5.5MM SOLDER	1	1.37	$1.37	$203.62	
DC DC CONVERTER 3.3V 2W	1	7.83	$7.83	$195.79	
CONN HDR 20POS 0.1 GOLD PCB	2	1.26	$2.52	$193.27	
				$193.27	Budget after Order#3
KJ Magnetics (Pack of 10) 1/16x1/16	3	1.1	$3.30	$189.97	
KJ Magnetics (Pack of 10) 1/16 by 1/8	3	1.4	$4.20	$185.77	
PROTOBOARD 14/16 SOIC SMT SIP	2	5.62	$11.24	$174.53	
SENSOR HALL ANALOG SOT23-3	30	1.3944	$41.83	$132.70	
IC MULTIPLEXER 8X1 16SOIC	3	6.4	$19.20	$113.50	
CAP CER 10000PF 10V X7R 0805	30	0.133	$3.99	$109.51	
CAP CER 0.1UF 6.3V X7R 0805	10	0.151	$1.51	$108.00	
CAP CER 4.7UF 16V X7R 0805	3	0.64	$1.92	$106.08	
CABLE ASSEM 20POS	1	13.78	$13.78	$92.30	Budget after Order#4
Board SendOut #2	1	33	$33.00	$59.30	
3D Printing - Letter Blocks	30	0.95	$28.50	$30.80	
3D Printing - Panel	1	7.46	$7.46	$23.34	
Miscellaneous for Assembly	N/A	N/A	$18.83	$4.51	
			Budget Remaining = $4.51		

Figure 29: SpellCheck Budget Breakdown