ECE 445

Senior Design

Design Document

Interactive Chess Teaching Chessboard

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Group 49

Contents

1 Introduction

1.1 Problem

Chess is a widely recognized educational game that promotes critical thinking, pattern recognition, and strategic planning, making it a common activity in elementary and middle school enrichment programs. However, the game has a relatively high barrier to entry for beginners, particularly children, who often struggle with understanding how each piece moves, determining which moves are legal, and recognizing when they are in check or checkmate. These foundational difficulties can slow learning, reduce engagement, and discourage continued participation, especially in group settings such as school chess clubs where instructor attention is limited.

While electronic and “smart” chess boards exist that provide real-time feedback and move guidance, these systems are typically expensive and designed for individual consumers rather than classroom environments. Their cost and complexity make them impractical for deployment in school clubs or educational programs that operate under tight budget constraints. As a result, there is a gap between low-cost traditional chess boards, which offer no instructional feedback, and high-end smart boards that are inaccessible to most schools. This project seeks to address this gap by developing a low-cost smart chess board that provides immediate, visual guidance on legal moves, helping beginners learn the rules of chess more intuitively while remaining affordable and suitable for educational use.

1.2 Solution

The proposed solution is a low cost, embedded smart chess board that provides real time visual feedback to assist beginner players in learning legal piece movement and basic gameplay rules. When a player lifts a piece from the board, the system will detect the change in a board state and illuminate all legal destination squares using LED lighting beneath each square. This immediate visual guidance reduces the cognitive load associated with memorizing movement rules and allows players to focus on strategy. Additionally, the board can optionally display a recommended move generated by an onboard chess engine, which can be enabled or disabled through a simple user interface to support different learning goals.

The system will be implemented using a ESP32 microcontroller to manage board state tracking, move validation and engine computation. Each chess piece will contain a small neodymium magnet, and each square will contain a reed switch sensor to detect the presence or absence of a piece. By continuously maintaining an internal board representation in memory, the microcontroller can determine when a piece is lifted and calculate all legal moves according to chess rules. Addressable LED strips, segmented into eight rows and daisy-chained for control, will illuminate specific squares based on computed legal moves. A small OLED display and push button interface will allow users to toggle engine assistance, handle special cases such as a pawn promotion, and provide feedback for illegal moves or system status. Power will be supplied through a mobile battery pack, with appropriate current management to support the LED load.

1.3 Visual Aid

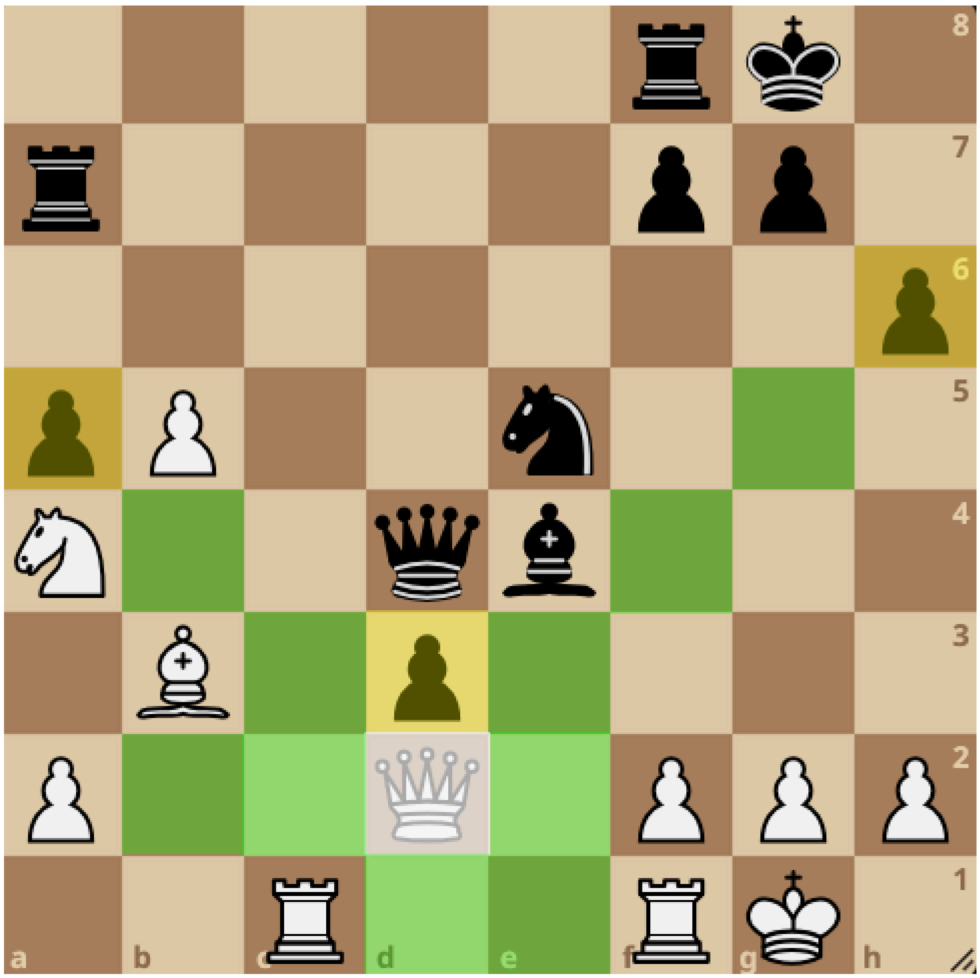

Figure 1: Visual Aid

The white queen is picked up, which will be indicated by a light underneath. The legal moves the queen can make are all lit up by LEDs but moves that result in a capture are indicated with a different color.

1.4 High Level Requirements List

1. Correctly display moves that are legal in chess at the current position and the best move (if turned on) within 5 seconds
2. Detect when board reaches an error state and execute subroutine to return to valid state
3. Whole system can run continuously for 1 hour without intervention

2 Design

2.1 Block Diagram

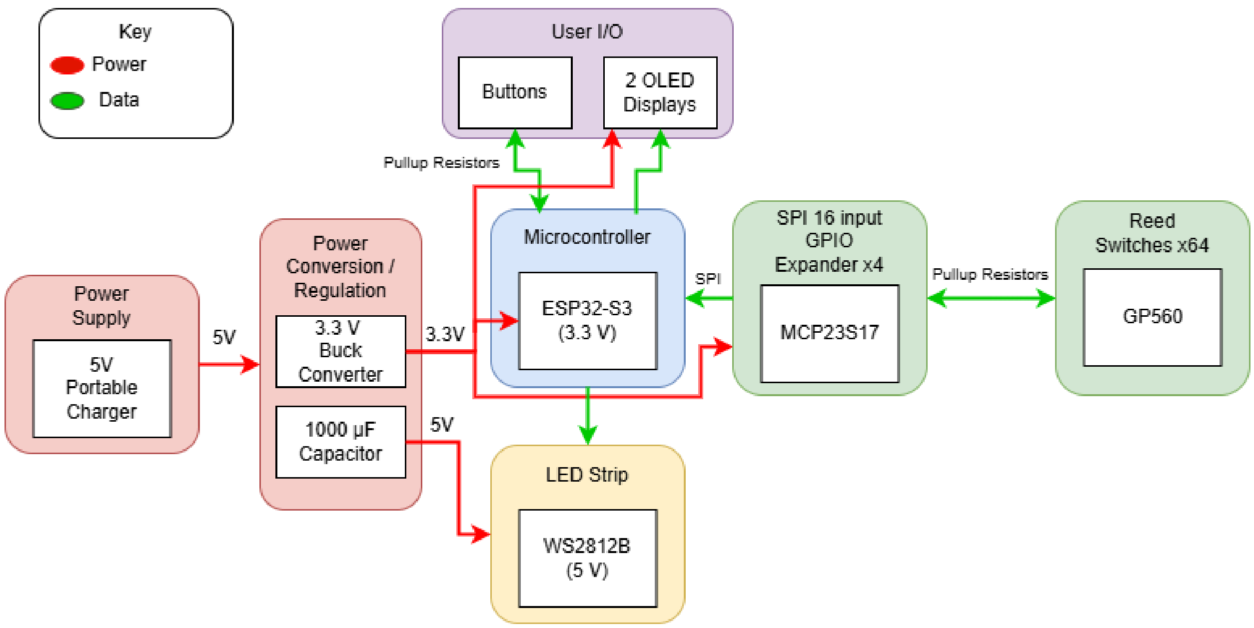

Figure 2: Block Diagram

2.2 Physical Design

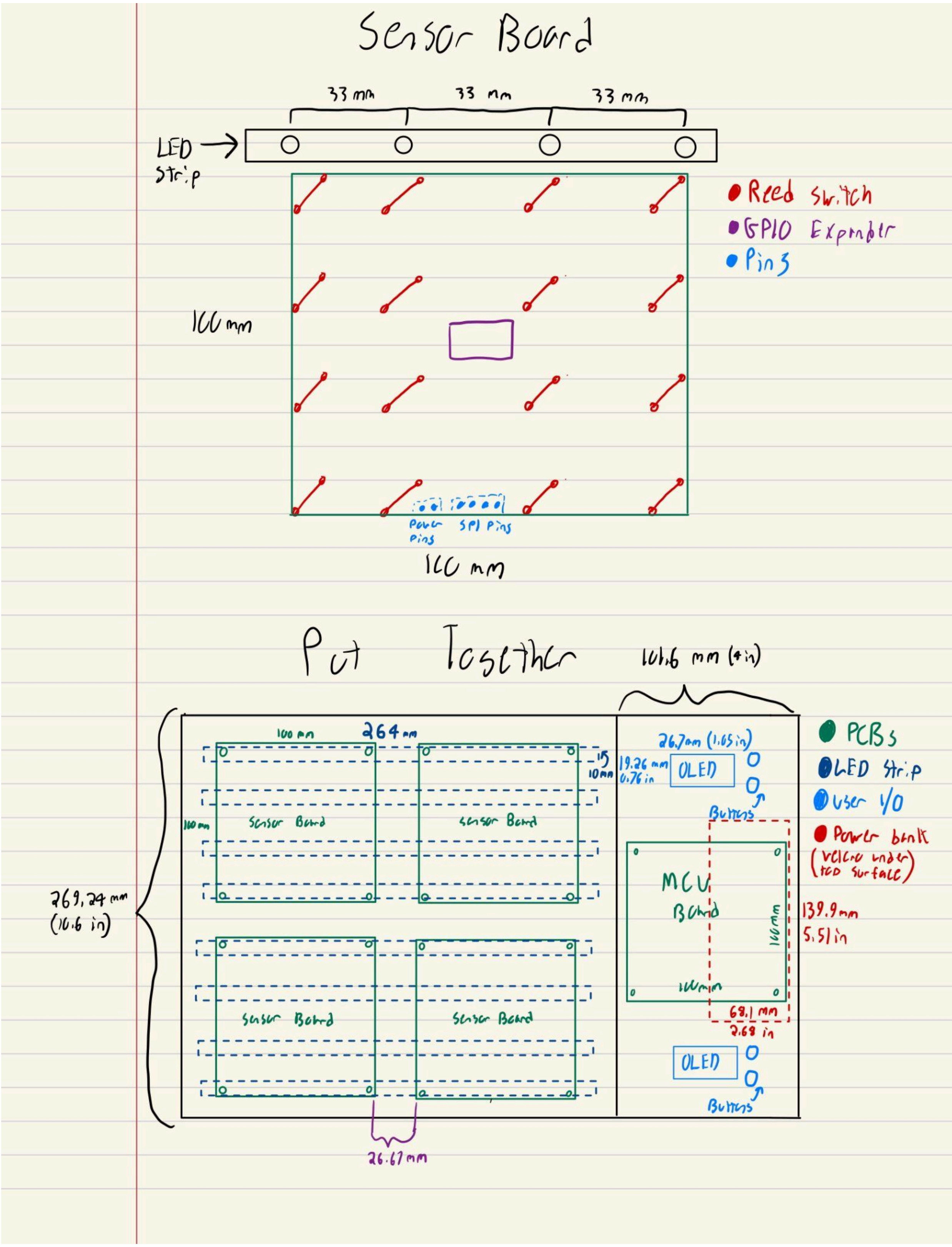

Figure 3: Physical Board Design

As shown in figure 3, the chess board is composed of two sections: the main board with the sensors and playable area and the additional section of the board containing the user IO and MCU board and power. The main board consists of four sensor PCB boards that each have a 4x4 grid of reed sensors (one per square) allowing for detection of a quarter of the chess board per PCB. The main board also includes the 8 strips of addressable LEDs (one per rank) daisy chained together. The second section of the whole board consists of the power bank, PCB board containing power regulation and MCU, and the user IO components of 2 OLED screens with buttons for input. Holes are drilled on a shell on top of all the electronics components to allow the LEDs to shine through. Alternatively, a semi transparent shell can be used.

2.3 Subsystems

2.3.1 Power Supply and Conversion/Regulation

A portable charger supplies 5V to the entire system. The portable charger that we intend to use is a power bank from VOLTME with a capacity of 10000 mAh. This should be able to supply 3A to our system for a little over three hours. Since we wish to target players who are at a beginner level, this should be sufficient. The power bank can also easily be swapped for one with full charge when the charge of one has been depleted.

A linear regulator receives 5V from the power supply and steps it down to 3.3V. This voltage level is required by the OLED display, microcontroller, and GPIO expanders. The power supply also directly charges a 1000 uF capacitor. This capacitor provides power to the LED strip. Providing power to the LED strip through a capacitor will protect the LEDs from being damaged by sudden surges or dips.

2.3.2 User I/O

Along with the physical chess pieces, users interact with the chess board through buttons and an OLED display. The OLED display communicates information about the overall system. The buttons allow the user to change the behavior of the system based on that information. For example, if there are issues with the function of the chess board, a recovery protocol can be initiated through this subsystem to address those issues. The user can also interact with this subsystem to select an option to show the best move that can be made based on the current board state. The best move is determined by the microcontroller using a chess engine and this information is conveyed through the LED strip.

2.3.3 Microcontroller

The microcontroller, an ESP32-S3, uses sensor data to determine the location of the chess pieces and outline the state of the board. The microcontroller also stores this information and uses that data to determine all of the possible moves for a specific piece. If requested, it will also determine the best move based on the current state of the board. The microcontroller polls the reed switches to receive data on the location of each piece on the board. The buttons on the board also send information to the microcontroller. It then controls the OLED display and the LEDs on the LED strip.

2.3.4 LED Strip

An addressable LED strip, divided into eight segments, is placed under the board. Each segment is divided further into eight smaller sections, one for each square in the rank. Each LED receives signals from the microcontroller that determine when the LED turns on and the color that the LED displays when it is on. The color of the LED will convey different kinds of information that are relevant to chess.

2.3.5 Sensor System

Reed switches will detect when a chess piece has been placed on or removed from a specific square by reacting to magnets embedded in the pieces. There will be 64 reed switches, one for each square on a chess board. Every reed switch will be connected to a GPIO expander. This will allow information about piece location to be sent from the reed switches to the microcontroller.

Four GPIO expanders are required because the chosen microcontroller cannot natively support receiving data from all 64 reed switches. One GPIO expander is connected to 16 reed switches. The GPIO expanders use I2C (Inter-Integrated Circuit) to send sensor data from the reed switches to the microcontroller.

2.4 Subsystem Requirements and Verification

Requirement	Verification
The power subsystem must reliably deliver stable 3.3V DC to the MCU and sensors.	**1. Connect a multimeter to the 3.3V output rail of the power subsystem. Ensure the board is in an idle state. Record the voltage reading. Confirm the voltage is 3.3V (±0.15V).** **2. While the system is idle, use an oscilloscope to measure the ripple on the 3.3V rail. Confirm the peak-to-peak voltage is less than 50mV.**
The power subsystem must reliably deliver stable 5V DC to the LED array.	**1. Connect a multimeter to the 5V output rail of the power subsystem. Ensure the board is in an idle state. Record the voltage reading. Confirm the voltage is 5.0V (±0.25V).** **2. Command half the LEDs to light up at maximum brightness. While the LEDs are active, measure the voltage at the 5V rail. Confirm the voltage remains above 4.75V.**
The power subsystem must reliably supply power to all components (sensors, LEDs, MCU, OLED) for at least 1 hour of continuous operation.	**1. Ensure the system is powered solely by the designed power source. Record the start time.** **2. Operate the board in a typical usage scenario (e.g., playing a game, requiring sensor scans and LED updates) for 60 minutes.** **3. After 60 minutes, verify all subsystems remain operational. Perform a sensor scan and test each LED. Confirm the MCU does not reset and the LEDs light up successfully.**
Each LED in the 64-LED array can be lit up individually without affecting adjacent LEDs.	**1. Ensure the board is powered and in an idle state.** **2. Using a test script on the MCU, command a single, specific LED to turn on. Visually confirm only the intended LED is lit.** **3. Repeat step 2 for at least seven other LEDs in different quadrants of the board and each LED strip per row. Visually confirm only the intended LED is lit each time.**

The LED array will light up with different colors to distinguish between legal moves, capture moves, and the best move.	**1. Set up a known chess position on the physical board. 2. Command the MCU to calculate and display legal moves for a selected piece. Record the color displayed. Confirm the color is distinct. 3. Command the MCU to calculate and display capture moves for a selected piece. Record the color displayed. Confirm the color is distinct from the legal move color. 4. Command the MCU to calculate and display the best move. Record the color displayed. Confirm the color is distinct from both legal and capture move colors.**
The MCU logic must find all legal moves for a given chess position within 5 seconds.	**1. Ensure the board is powered and the MCU is running the chess engine. 2. Achieve a standard mid game chess position on the board (via debug loading or playing on board). Start a timer. 3. Command the MCU to calculate legal moves for the side to move. 4. Record the time displayed when the MCU outputs "Calculation Complete." Confirm the elapsed time is less than 5 seconds. 5. Verify the list of legal moves against a known chess engine to ensure accuracy.**
The MCU logic must find the best move for a given chess position within 10 seconds.	**1. Ensure the board is powered and the MCU is running the chess engine. 2. Load/achieve a standard mid-game chess position onto the board. Start a timer. 3. Command the MCU to calculate the best move for the side to move (using its evaluation function). 4. Record the time displayed when the MCU outputs the move. Confirm the elapsed time is less than 5 seconds. 5. Verify the move is a reasonable candidate (no blunders) against a known chess engine.**
The MCU logic must determine an invalid board state (e.g., illegal position, missing piece) and attempt a recovery operation	**1. Ensure the board is powered and a valid game is in progress. 2. Simulate an invalid state by removing a**

within 5 seconds.	**piece from the board while it is the opponent's turn, creating an illegal position. Start a timer. 3. Observe the system response. Record the time when the MCU flags an "Invalid State" or initiates a recovery (prompt user to replace the piece via OLED). 4. Confirm the error is detected and the recovery prompt is displayed within 5 seconds of the piece being removed.**
Sensors must detect when a piece is on or off a particular square, accurately triggering only the sensor associated with that specific square.	**1. Ensure the board is powered and in an idle state with no pieces on the board. Record the 64-bit sensor state via serial debugging. Confirm all values read as "0" (no piece). 2. Place a piece with a magnet in the center of square e4. Record the sensor state via serial debugging. Confirm the bit for square e4 reads as "1" and all other 63 bits read as "0". 3. Repeat step 2 for squares on the edge (a1) and a corner (h8). Confirm only the intended sensor triggers each time. 4. Place pieces on two adjacent squares (d4 and d5) simultaneously. Record the sensor state. Confirm both corresponding bits read as "1" and that no other sensors are triggered by magnetic interference.**
User input buttons must detect only one action per single physical button press (debounced).	**1. Ensure the board is powered and the MCU is logging button presses to the serial console. 2. Press the "Select" button once firmly and release it within 0.5 seconds. 3. Observe the serial output. Confirm that only one button press event is registered. 4. Repeat steps 2-3 for the "Left," "Right," and "Back" buttons. Confirm each registers only one event per press.**
The user interface must reflect user actions on the OLED display within 0.2 seconds.	**1. Ensure the board is powered and the OLED is displaying the main menu. 2. Press a button to navigate the menu. Start a timer simultaneously. 3. Record the time when the OLED display**

	updates to highlight the next menu item. 4. Confirm the elapsed time between the button press and the display update is less than 0.2 seconds.

Table 1: Requirements and Verification of Subsystems

2.5 Tolerance Analysis

Reed Switches

One critical concern with the reed switches is how close the magnets under the chess pieces need to be to activate them, and if a magnet that is too strong will activate the reed switches on adjacent squares. The reed switches that we plan to use are the SW GP560/15-20 AT, which are activated by 15-20 Ampere-Turns. Calculating this exactly is very difficult so we will need to use some assumptions and approximations. First finding magnetic strength is usually in units of Gauss not Ampere-Turns, and there is no simple way to convert from Ampere-Turns to Gauss. According to an article about the problem of relating the Ampere-Turns units of a reed switch to Gauss, you can assume that about 1 Gauss per reed switch Ampere-Turn will activate the reed switch when both magnet poles are near the two ends of the switch [8]. This approximation assumes optimal magnet reed switch configuration where the magnet is sitting vertically positioned above a horizontally positioned reed switch. Using this, in a worst case scenario the reed switch must be activated by 20 Gauss. To get a good picture of what the magnetic field of our N42 magnets looks like, we used a website which uses collected measurements of real magnets to generate a plot of magnetic field versus distance for given magnet dimensions [10]. We plugged in the dimensions and grade of our magnets[9] and found that our worst case distance to get 20 Gauss is about 7mm. Since our sensors will be right under our chess surface, and the surface needs to be thin to let light through, this distance is achievable. For seeing if magnets will activate adjacent switches we will assume that it takes a worst case 15 Gauss. Assuming that the reed switches are only 3mm under the surface of the chess board, then a reed switch located a distance of 5.9 mm away would be at 15 Gauss. This means the space between our reed switches needs to be larger than ~6mm, which is totally doable as a chessboard with that spacing is incredibly small. Overall, getting our magnets close enough to activate the reed switches is a possible concern and pieces activating adjacent reed switches is extremely unlikely and not something we need to worry about.

Power Consumption

According to the WS2812B datasheet and component documentation from Cirkit Designer [3], each WS2812B LED can draw up to about 60 mA at full brightness when all three color channels are driven at maximum drive current (approximately 20 mA per channel). If we light only 1 LED per square, this means 64 LEDs total. In the worst case: I_max = 64 * 60mA =

3.84A. This would exceed our power bank max output of 3A from just the LEDs alone. However, based on the use case of lighting up legal moves, we would light up at most 28 LEDs at once if we placed a queen in the middle of the board. This results in a max current draw of 28 * 60mA = 1.68A. So in our worst case scenario, we would be well under the specifications of the power bank. Additionally, we will likely run the brightness at 50% or under further bringing down the current draw to 0.84A.

The power bank is specified at 10000mAh for the internal lithium battery at 3.6V. Actual power output is 10Ah * 3.6V = 36Wh (Energy = Capacity * Voltage). We can assume that the internal converter is not 100% efficient and assume a conversion efficiency of 80% based on estimates used by TexasInstruments [4], and take the usable power at 36Wh * 80% = 28.8Wh.

The LEDs will draw at max 840mA at 5V for 5V * 840mA = 4.2W. According to datasheets [6], the ESP32-s3 with Wi-Fi and Bluetooth disabled, actual active CPU current will be lower than the listed RF-receive current 91mA. This means for the MCU, power draw is 91mA * 3.3V (input voltage) = .3W. The 2 OLEDs draw just .08W during normal operations according to the datasheet [5]. The GPIO expanders datasheets show that they draw 1mA when active [7]. Multiply with the input voltage of 3.3V for 3.3mW of power draw. Added together, 4.2W + .3W + .08W + .0033W = 4.5833W. To get the operating time, we divide the watt hours by the watts used: 28.8Wh/4.5833W. = 6.28 hours of operation. This should be sufficient to reach our goal of one hour of continuous operation.

3 Cost and Schedule

3.1 Cost Analysis

Description	Manufacturer	Quantity	Price ($)	Link
SW GP560/15-20 AT Reed Switches	Standex-Meder Electronics	64	31.41	Link
MCP23S17-E/SP-ND I/O expander 16 inputs	Microchip Technology	4	7.12	Link
WS2812B ECO LED Strip Light 16.4 FT	SEZO	1	13.99	Link
FIT08613Pin LED Strip Connector	DFRobot	8	7.92	Link
ESP32-WROOM-32-N4 MCU	Espressif Systems	1	6.56	Link
HiLetgo 0.96" I2C 128X64 OLED Screen	HiLetgo	2	13.98	Link

N55P125062 Neodymium Magnets	Magnet Applications	32	8.96	Link
Portable charger, 10000mAh	Byobyc	1	9.99	Link
AEC1000M35V1320 1000 µF 35 V Aluminum Electrolytic Capacitor	Lumimax Optoelectronic Technology	1	0.33	Link
RNCP0805FTD10K0 10k ohm resistor	Stackpole Electronics Inc	8	0.80	Link
CRCW080550R0FKTA 50 ohm resistor	Vishay Dale	4	0.84	Link
1276-1066-2-ND 1uF capacitor	Samsung Electro-Mechanics	4	0.40	Link
WM4114-ND 5 pin header (2.54mm) 1x5	Molex	8	3.76	Link
A1921-ND 2 pin header (2.54mm)	TE Connectivity AMP Connectors	4	0.56	Link
5 pin wire (2.54mm) and 2 pin wire (2.54mm)	elechawk	1	15.99	Link
CL21A106KOQNNNE 10uF 16V capacitor 0805	Samsung Electro-Mechanics	2	0.20	Link
CL21B105KAFNNNE 1uF 25V capacitor 0805	Samsung Electro-Mechanics	2	0.20	Link
CL21A226MQQNNNE 22uF 6.3 V capacitor 0805	Samsung Electro-Mechanics	2	0.26	Link
KGM21NR71H104KT 0.1uF 50V capacitor 0805	KYOCERA AVX	1	0.08	Link
SP0503BAHTG 8.5V Tvs Diode	LittleFuse Inc.	1	0.53	Link
PR20B05VBDN 1.27mm pitch 2x5 pin header vertical through hole	METZ CONNECT USA Inc.	1	0.39	Link
USB4125-GF-A USB-C Receptacle Connector 24 (6+18 Dummy) - Power Only 6 Pin Position Surface Mount, Right Angle; Through Hole	GCT	1	0.59	Link
575-4 Banana Jack Connector	Keystone Electronics	4	3.76	Link
MLZ2012M3R3HT000 3.3 µH Inductor	TDK Corporation	2	0.20	Link

500 mA 200mOhm 0805				
10118194-0011LF USB - micro B USB 2.0 Receptacle Connector	Amphenol ICC (FCI)	1	0.49	Link
826658-5 Connector Header Through Hole 1x10 2.54mm	TE Connectivity AMP Connectors	1	1.81	Link
SS8050 BJT 25V 1.5A SOT-23	Shenzhen Slkormicro Semicon Co., Ltd.	2	0.20	Link
RC0805FR-071KL 1k Ohm resistor 0805	YAGEO	2	0.20	Link
RMCF0805JT5K10 5.1k Ohm resistor 0805	Stackpole Electronics Inc	2	0.20	Link
CRCW080510K0FKEA 10k Ohm resistor 0805	Vishay Dale	5	0.50	Link
CR0805-FX-3322ELF 33.2k Ohm resistor 0805	Bourns Inc.	1	0.10	Link
RC0805FR-07100KL 100k Ohm resistor 0805	YAGEO	2	0.20	Link
B3S-1000 Tactile Switch SPST-NO	Omron Electronics Inc-EMC Div	2	0.86	Link
36-5010-ND PC TEST POINT RED	Keystone Electronics	4	1.36	Link
AP62300TWU-7 Buck Switching Regulator IC 3A	Diodes Incorporated	1	0.30	Link

Table 2: Itemized list of parts

Cost Calculation

The total cost of the itemized list of parts above in Table 2 is $135.04.

According to the post graduation section of the Grainger college of engineering Electrical Engineering page [11], the average starting salary for a fresh graduate is $90,115. If we assume 50 working weeks at 40 hours per week, then that is 2000 hours for the whole year. This calculates out to an hourly rate of $45.06. I anticipate that every week, we will all work for 2.5 hours a week. We have about 10 weeks to work on the project. In total for the labor cost: 2.5hrs/week * 10 weeks * $45.06 per hour * 3 members = $3379.5.

For our board which is approximately 15in by 11in according to figure 3, we only need a base plate to hold electronic components and hooks for the led strip. This should take the machine shop about 5 hours.

The labor cost along with the total cost of everything in our itemized list is $3514.54.

3.2 Schedule

Week	Task	Person
6	Finish first design of main PCB	JJ
	Finish design of sensor PCB	Matthew
	Turn in Design Document	Tim, Matthew
	Source components and compile list	Tim, Matthew
7	Present Design Document	Tim, Matthew, JJ
	Finalize main PCB, optimizing size and adding all headers	JJ
	Put together breadboard demo of MCU + 16 reed switches	Tim, JJ
	Write software to run breadboard demo	Tim, Matthew
8	Breadboard Demo	Tim, Matthew, JJ
	Get final design and revisions to machine shop	Matthew Trela
	Based on functionality of breadboard make decisions and order components (magnet strength, reed switch viability, etc)	Tim, Matthew, JJ
	Teamwork Evaluation I (3/11)	Tim, Matthew, JJ
	If not yet finished, must finish and order main PCB 2	JJ
	If arrived, test sensor board	Tim, Matthew
	If needed, make changes and reorder sensor board	Matthew
9	Last week for PCB orders, so thoroughly test both boards	Tim, Matthew, JJ

	If there are any issues, make changes and reorder	Matthew, JJ
	Order any components that we don't have yet	Tim, Matthew, JJ
	Solder Components on boards	JJ, Tim
10	Individual Progress reports	Tim, Matthew, JJ
	Solder Components on boards	JJ, Tim
	Write software (chess engine, error detection, display)	Matthew, Tim
11	Solder Components on boards	JJ, Tim
	Write software (chess engine, error detection, display)	Matthew, Tim
	Progress Demo	Tim, Matthew, JJ
	Team Contract assessment	Tim, Matthew, JJ
12	Put project together and work on resolving bugs and errors	Tim, Matthew, JJ
13	Finishing touches	Tim, Matthew, JJ
	Mock Demo and Presentation	Tim, Matthew, JJ
14	Final Demo and Presentation	Tim, Matthew, JJ
15	Final Paper	Tim, Matthew, JJ

Table 3: Schedule for Project Timeline

4 Ethics and Safety

4.1 Ethical Considerations

This project involves the design and construction of a smart chess board using embedded electronics, sensors, and software to assist users during gameplay. While the system does not collect personal data, several ethical considerations are relevant during both development and potential use.
In accordance with the ACM Code of Ethics [2], computing professionals are obligated to avoid harm (ACM Section 1.2) and to be honest and trustworthy about system capabilities and limitations (ACM Section 1.3). In this project, the chess engine provides recommended moves based on algorithmic evaluation, which may be imperfect or constrained by computational limits. To comply with ACM Section 1.3, all documentation and user interfaces will clearly state that move recommendations are advisory and not guaranteed to be optimal or correct. No claims will be made that exceed the system's verified capabilities.

The ACM Code also emphasizes careful evaluation of risks associated with computing systems (ACM Section 2.5). During development, risks related to incorrect piece detection, sensor failure, or misleading visual feedback will be analyzed and documented. Design choices such as redundant sensing checks and clear error states will be used to reduce the likelihood of misleading outputs.

The IEEE Code of Ethics [1] places primary responsibility on engineers to protect the safety, health, and welfare of the public (IEEE Principle 1). Although this is a low-voltage, non-commercial system, the project will be designed conservatively to minimize electrical, thermal, and mechanical hazards. Additionally, IEEE Principle 3 requires engineers to be honest and realistic in stating claims or estimates based on available data. This principle directly informs how system accuracy, detection reliability, and limitations are described in the proposal and final documentation.

No personal data collection, surveillance, or user profiling is involved in this project, reducing concerns related to privacy or data misuse. All third-party software components, such as chess engines or embedded libraries, will be used in accordance with their licenses and properly cited, consistent with ACM Section 1.5 on respecting intellectual property.

4.2 Safety Considerations

Electrical and Power Safety:
The system is powered by a consumer-grade mobile power supply operating at low voltage (approximately 5 V), which significantly reduces shock risk. However, LED strips represent a relatively high current draw. To address this, current-limiting, appropriate wire gauge selection,

and capacitors rated well above operating voltage will be used. These measures align with IEEE Principle 1, which emphasizes responsibility for public safety.

Thermal Safety:
Sustained LED operation and voltage regulation may generate heat. Components will be operated within manufacturer-specified limits, and physical layout will allow for heat dissipation to prevent overheating or damage.

Magnetic Safety:
Neodymium magnets embedded in chess pieces pose a minor risk if exposed or removed. Magnets will be permanently enclosed within the pieces, and the system will be labeled as not intended for young children. This supports IEEE Principle 1 by mitigating foreseeable physical hazards.

Development and Mechanical Safety:
During construction, soldering, sharp leads, and exposed conductors present risks. These will be mitigated through proper lab practices, enclosure of electronics, and compliance with campus laboratory safety policies.

4.3 Regulatory and Standards Considerations

This project complies with applicable campus safety policies governing electronics prototyping, soldering, and battery usage. Because the system is not intended for commercial distribution, formal FCC certification is not required; however, reasonable electromagnetic interference mitigation practices will be followed due to the ESP32 MCU's wireless capabilities.

Overall, by adhering to the ACM Code of Ethics [2] (Sections 1.2, 1.3, 1.5, 2.5) and the IEEE Code of Ethics [1] (Principles 1 and 3), this project aims to demonstrate responsible, safe, and transparent engineering practice while minimizing the risk of harm or misuse.

5 References

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