Seamless Autonotator

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***Abstract*—A system capable of automatically logging notation during a game of chess. This is an improvement on the state of the art since notation is still largely done by hand or not done at all by more casual players as well as tournament level players. The seamless notation will be done faster than human reaction speed, so much faster than a human could perform notation manually. It will also be 100% accurate, so it will be slightly more accurate than human notation which may have some errors.**

***Index Terms*—Chess, Hall Effect, Sensor, Move Generation, Multiplexing**

1 INTRODUCTION

Our use case is to serve as an all-in-one chess set (board and pieces) that automatically notates moves, which can be used by casual and professional chess players alike. It will also record the moves played in a database and send moves to a website where the games can be viewed.

For professional chess players, the system will be able to be used in a tournament setting. It has a 10 hour battery life, long enough for a day of tournament use. The board does not require externals such as a camera, so it can be easily transported and set up for play. It will remove the need for professional chess players to notate their games, freeing up some time during the game and removing the possibility of any notation errors due to poor handwriting or simple mistakes.

For casual players, the main benefit is providing the notation itself. Many casual players do not bother to notate their games, as it is an extra layer of work that is not enjoyable in and of itself. It also requires knowledge of algebraic notation, the standard method of recording chess moves, which beginners may have difficulty understanding. Automatically notating games and storing them in a database will provide casual players the opportunity to review games that they otherwise would have forgotten. If at the end of the game they think, "I wonder if I made the right move with my knight on turn 10," they can find the game in our database and export it to a chess engine or website, such as Chess.com, to analyze it. In this way, casual players using our system will be able to learn more and improve their understanding of chess.

A competing technology is the new product ChessUp. It is also a chess board that can detect moves on it, record games and store them in a database, and find legal moves for the current board state. It also has additional features, such as an automatic chess clock that switches when the board detects a piece has moved, and the ability to play online or against an AI by highlighting the opponent's moves on the board. The main advantage of our system over ChessUp is cost - ChessUp is $400, while our prototype alone will likely cost under $500. At scale, our system would be significantly less expensive. Another advantage of our system is that it aims to be usable for professional play in tournaments. The ChessUp board features lights under the squares and built-in AI assistance, which means it will not be approved for tournament use.

2 USE-CASE REQUIREMENTS

Our requirements are centered around the user experience while using the system:

- The system will record notation with 100% accuracy. If the system does not perfectly record notation, it will not be viewed as an improvement to the current standard of human notation in professional play. To accomplish this, the system will check the legality of each move to ensure that illegal moves are not recorded.
- The system will take 300ms or less from the time a move is made (signaled by a button pressed on the board) to the system's response of the move's legality (with red or green LEDs on the board). This is around human reaction time, so the system will not be so slow that it will noticeably impede the pace of the user's game.
- The system will provide 10 hours of battery life on a single charge. This is long enough for a full day of tournament use between charges.
- The system will store the most recent 10 games for each user. Users will be able to access these games with an account on the system's website.
- The system will translate completed games into exportable PGNs, which can be downloaded or copied from the website and imported into chess engines or websites such as Chess.com for analysis.

3 ARCHITECTURE AND PRINCIPLE OF OPERATION

3.1 Chess Board

We will have chess board style top layer for our design made from acrylic. This will have a chess board pattern engraved on it so the user can play a regular chess game on it. Underneath the top layer, we will have a printed circuit board that contains all of our in-board electronics. Fig. 1 demonstrates the layer stackup of our design.

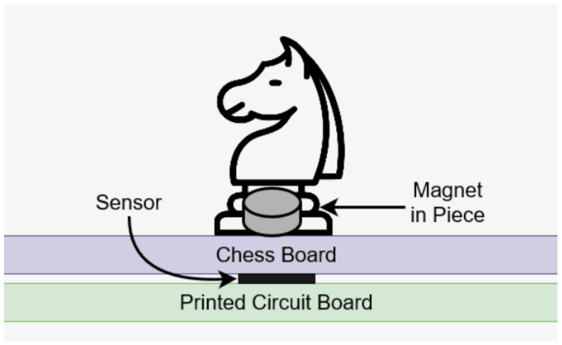


Figure 1: A cross section of the chess board, showing the PCB and sensor beneath the physical board.

3.2 Sensing

In order for our autonotation system to function, our chess board system will need to sense the color and location of every piece on the board. To accomplish this, all of our chess pieces will have magnets in the base. White pieces will have the magnet oriented in one direction while the black pieces will have the magnet flipped to create the opposite polarity of magnetic field. The difference in magnetic field will be sensed by hall effect sensors within the chess board.

3.3 Hardware

Fig. 2 demonstrates our hardware structure. Since the chess board must sense magnetic fields, there will be a printed circuit board underneath the top layer that houses hall effect sensors that can sense magnetic fields. This PCB will have one sensor per square, yielding 64 total sensors for the chess board. These sensors will be grouped in 8 sets of 8 to allow for convenient 8:1 multiplexing for each column of the board into an ADC. This ADC will communicate with an RPi so the RPi can gather the board state. In addition to the sensing, this PCB will also contain holders for batteries, power regulation, and the user interface. The power regulation and batteries will allow the board to not be tethered to an outlet as well as last a full day of tournament play per our requirements. The final aspect of the hardware is the user interface. This consists of a button and two LEDs for each player. These buttons and LEDs are connected to the RPi to allow the user to interact with the system.

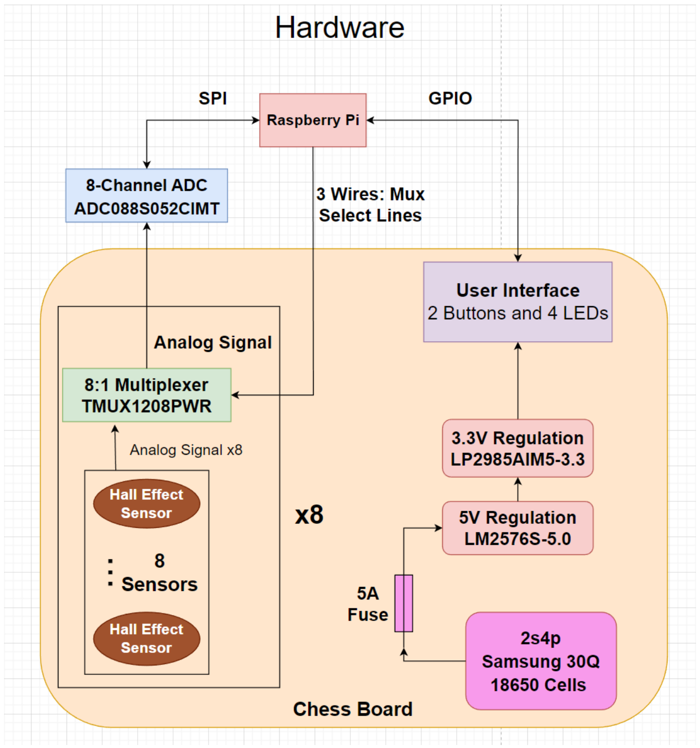

Hardware
SPI
Raspberry Pi
GPIO
8-Channel ADC ADC088S052CIMT
3 Wires: Mux Select Lines
User Interface 2 Buttons and 4 LEDs
Analog Signal
8:1 Multiplexer TMUX1208PWR
Analog Signal x8
Hall Effect Sensor
8 Sensors
Hall Effect Sensor
x8
3.3V Regulation LP2985AIM5-3.3
5V Regulation LM2576S-5.0
5A Fuse
2s4p Samsung 30Q 18650 Cells
Chess Board

Figure 2: This same figure is placed spanning both columns (actually spanning 0.75 of the two columns).

3.4 Legality Check

A legality check program will run on the RP. The program will keep track of the current board state, and when a player makes a move, it will check if the move is legal for the current board state. If the move is legal, a green LED will light up on the board to tell the players that the move is legal and it is the next player's turn. If the move is illegal, a red LED will light up to tell the players that the move is illegal so the same player must make a different move. Legal moves will be forwarded to the website and database backend program to record the game.

3.5 Server, Website, and Database

The website will have features such as individual user login (and registration), the ability to view current games, and the ability to view past games. Furthermore, users should be able to upload their past games to websites such as chess.com for further analysis. The website will store all data inside of the database, which will hold the user login data for each user and the notation of their previous games. Altogether, the website should consistently refresh to show the user notation updates that are occurring in their current chess game (which should send data to the website).

4 DESIGN REQUIREMENTS

The following design requirements are related to the use-case requirements that are outlined in Section 2. The system should record notation with 100% accuracy, so the sensors must be able to differentiate between the presence of a white piece, black piece, or no piece on each square with 100% accuracy. The software must be able to determine which piece was moved with 100% accuracy based on the sensor output. The software must also be able to determine the legality of the move played with 100% accuracy to ensure that illegal moves are not recorded.

The system must take 300ms or less from the time a move is made to the system's response of the move's legality. This process involves multiple subsystems and therefore the 300ms requirement is a limit on the sum of the latency of several steps in the process. To ensure that the entire process takes 300ms or less, we created latency requirements for each step. These steps and requirements are: receiving the user button press input in firmware (20ms), collecting the sensor data (30ms), translating the sensor data into a move in software (40ms), checking the legality of that move in software (30ms), and returning the result of that legality check by illuminating a green LED or a red LED (20ms). The latency requirements for each step are slightly pessimistic, and even then they only sum to 140ms in total. If the requirement for any individual step cannot be met due to some unforeseen factor that we failed to consider when creating these requirements, the process would still likely take under 300ms because there is 160ms of slack.

The system should have enough battery power to function for 10 hours on a single charge. We would like our system to be useful in a tournament setting in addition to a casual setting. A day of tournament play could consist of up to 10 hours of playing time, so our board would need to last at least this full 10 hours to be useful for a tournament.

Lastly, we want the system to provide opportunities for the user to replay past games in the future and will therefore need a database that allows each user to store and access at least 10 games worth of notation. Finally, since much of this tool should be used for analysis, the user should be able to export the games in a custom PGN format (the input format accepted by Chess.com) such that they can use the extensive analysis resources on Chess.com for analysis.

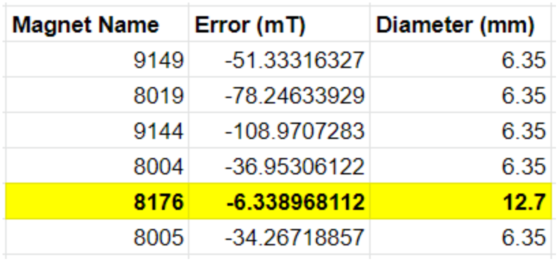
5 DESIGN TRADE STUDIES

5.1 Sensor Choice

We narrowed down our sensor choice to two sensors from Texas Instruments using the selection filters on Digikey. The main remaining design choice was to decide between a unipolar and a bipolar sensor. We decided on a bipolar sensor since it is a more robust sensing architecture. It is more robust because we can simply differentiate between piece color by flipping magnets rather than having to differentiate between two different magnet strengths. This robustness is crucial due to our 100 percent accuracy requirement.

5.2 Magnet Types

We tested several different strengths and sizes of magnets using a small test circuit board with our sensors and a 7mm spacer between the magnets and the sensors. Our findings were that the smaller magnets, regardless of strength, were not sensed accurately in that the sensor had trouble differentiating between them, while the larger magnets were sensed with reasonable accuracy. The larger diameter magnets also would lead to less sensitivity in piece placement on a chess board square compared to small magnets. This was verified in our testing as seen in Fig. 3. The chart lists the magnets we tested along with the error in mT from the expected magnetic field strength at 7mm away.



Magnet Name	Error (mT)	Diameter (mm)
9149	-51.33316327	6.35
8019	-78.24633929	6.35
9144	-108.9707283	6.35
8004	-36.95306122	6.35
8176	**-6.338968112**	**12.7**
8005	-34.26718857	6.35

Figure 3: Data showing that larger diameter magnets have a much smaller error in sensing.

5.3 ADC Choice

We chose our 8-bit, 8-channel ADC because we wanted a single ADC that would efficiently sample from all 8 multiplexers. We chose an 8-bit device because we don't need more resolution, and changing to fewer bits does not give us significant gains in cost.

5.4 PCB Sizing

We decided to fabricate the board in sections of two columns instead of one single circuit board due to cost. A full chess board for our specification is 18 in. in width and height, this made fabrication costs prohibitively high for our budget given the cost of our Bill of Materials. We also wanted to have some money left over to buy extra parts if needed towards the end. We also experimented with decreasing the board size, but even the minimum board size was at the limit of what could we afford given the 600 dollar budget.

5.5 Multiplexing Architecture

The multiplexing architecture was influenced by the PCB sizing. Since the board is being fabricated in columns, the board must be made of columns with a modular design such that each column can function alone as well as together. Having 8:1 multiplexing and an 8-channel ADC makes this easier to design from a circuits perspective. Having an 8:1 multiplexer was also optimal in terms of balancing cost with modularity.

5.6 Batteries

We are sizing our batteries to last a full 10 hours, so we want a compact solution that has a large capacity. Lithium-ion cells satisfy both of these requirements better than lead-acid, alkaline, or lithium-iron-phosphate. Using cylindrical cells over lithium polymer cells also is easier because we were able to find cell holders that are able to be soldered directly to the PCB. This takes care of the mounting and electrical connection aspects. Based on all of these factors and our previous experience using 18650 cells, we will be using these cells on our system.

5.7 Legality Check

The obvious way to check the legality of the most recently played move is to identify what piece was moved, check that the piece was moved to a position that its movement ability allows it to move to (Rooks only move in straight lines, King can only move one square, etc.), then check the positions of other pieces on the board to determine that the move doesn't break any other special rules. Another method is to generate all possible legal moves from the previous position, store them in a list, then check if the most recently played move is in that list. The second method clearly requires much more computation, as the program will have to determine the legality of many moves (typically 40-60 moves in complex positions) instead of just the most recent move. However, a key advantage of the second method is that the computation can begin before the move is played, as it only needs the previous position to start generating legal moves. After the move is played, the first method will need to compute its legality, while the second method only has to check it against a list. With our design requirement of 30ms to check the legality of the move in mind, we care much more about the latency of legality checking after the move is played than how much computation is done before, so we chose to implement in the second method.

5.8 Legal Move Generation

Many programs exist to generate a list of legal moves for a given chess position. One solution that was considered is Gigantua, the world's fastest legal move generator. Gigantua can generate over 500 thousand legal moves per second, meaning the 40-60 moves we would need to generate for a single position would take around 0.1ms [1]. As noted in the previous section, there is not a strict requirement on the latency for generating a list of legal moves, because it occurs before the user has made their move. The legal move list needs to be generated in the time between each player making their moves, which we can reasonably assume to be at least a second. In most games, players will take several seconds, if not minutes to decide on their next move, but it is possible to play very fast chess and we want our system to support those types of games. Even in very fast play, it should take at least a second for a player to physically move a piece and press their button to complete their move. Therefore, we do not need to select the fastest legal move generator, and can also consider other factors: memory usage and ease of implementation. Gigantua uses around 10MB of memory, as it achieves its impressive speed through the use of large look-up tables. We decided to use the legal move generation from Stockfish, a free and powerful chess engine. Stockfish generates legal moves using structures called bitboards, which use 1 bit for each of the 64 squares on a chessboard to represent piece positions, available moves, attacked squares and more [2]. It performs operations on bitboards to generate legal moves, which is slower than Gigantua, but still fast enough for our purposes with much less memory usage. Stockfish takes about 2ms to generate all the legal moves for a single position. Stockfish is also easy to implement, as it is well-documented and includes structs for positions and moves that are useful in the rest of the legality check program.

5.9 Server Backend

We chose to use Django to build the server back-end for the web application because it's built in the REST framework and because of its community support. REST framework support is important because a portion of our project, having data sent to a remote server, is done through a REST framework. While there are many solutions to sending notation from the chess board to the web server, since our goal is to send small packets of data at discrete times, a REST API was the least effort and most reliable to set up.

Other Python backend frameworks such as Flask fell short of the advantages that Django was able provide. In Flask, it is much harder to set up a basic data storage system to store moves. Furthermore, the documentation for Flask falls short in comparison to the Django documentation in both depth and access. Django also allows for an easily accessible upgrade from our initial SQLite database (our designated database in our MVP) to a larger, more flexible PostgreSQL database that is more suitable for production. Lastly, the Django framework is preferred due to the teams extensive background with the technology. Using a framework in which the team is already familiar is preferable as that allows us to build a cohesive website in a faster and more efficient manner (compared to learning a new framework that does not offer our use case any benefits).

6 SYSTEM IMPLEMENTATION

6.1 Mechanical Board

The chess board will be built from 2 layers as demonstrated in Fig. 1. The bottom layer is the printed circuit board that contains all of the sensing, power, and interface with the RPi. Sensors will be spaced every 2 inches as seen in Fig. 4 in order to create a normally-sized chess board. Above this will be an acrylic piece that is engraved with a chess board pattern. Below each engraved square will be a hall effect sensor to sense the pieces. The circuit board will have 3-D printed mounts to support itself and keep all of the individual column boards together.

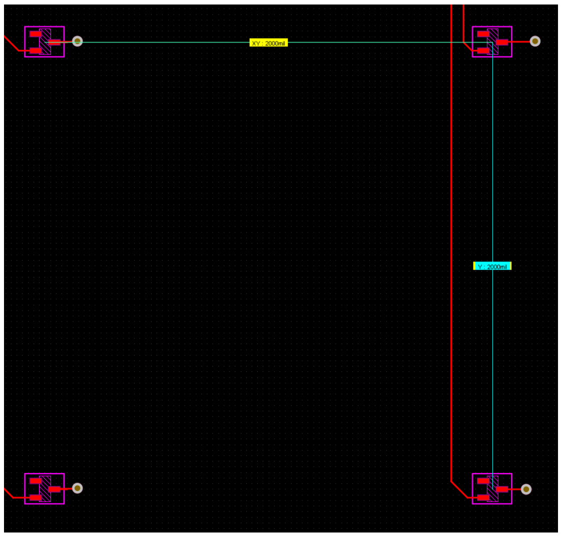


Figure 4: 2 Inch Spacing Between Sensors

6.2 Sensing Pathway

For our hall effect sensors, we will be using the DRV5055 from TI. The schematic for these sensors is seen in Fig. 5. These sensors are bipolar and have a sensitivity of 12.5 mV/mT, with an output voltage of 2.5V when no magnetic field is applied. Each column of 8 sensors has a dedicated 8:1 multiplexer. We chose the TMUX1208PWR. Since there are 8 columns in the chess board, there are 8 multiplexers.

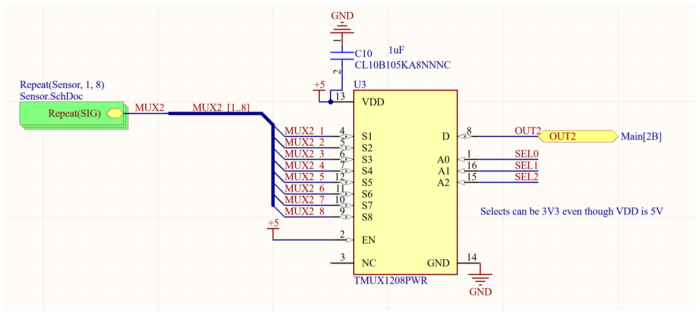


Figure 5: Multiplexer Schematic

These 8 multiplexers feed into an 8 channel ADC, the ADC088S052CIMT from TI. The schematic of all connections to the ADC are shown in Fig. 6. This ADC communicates to the Raspberry PI or SPI. The RPi then can process this sensor data to compute legality and respond to the user.

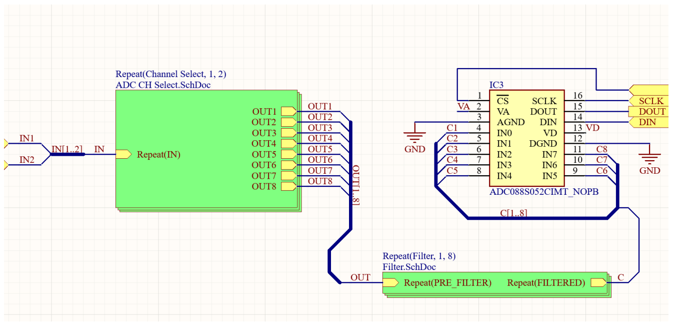


Figure 6: ADC Schematic

6.3 Power

Our battery will be a 2-series lithium ion battery. Our expected maximum power use is about 8.2W, of which the Raspberry Pi will use 5W. For 10 hours of play time, we will therefore need 82 Watt-hours of power. Given that the nominal voltage of our battery cells is 3.7V, we will need a maximum of 11.1 Amp-hours of capacity. The capacity of the Samsung 30Q is 3 A-h, so we will use 4 in parallel for a capacity of 12 Amp-hours. Therefore, our battery will be a 2-series, 4-parallel configuration.

6.4 Hardware User Interface

Our hardware user interface consists of one button and two LEDs per user. The buttons in Fig. 7 are tactile switches (TS15-1212-70-BK-160-SCR-D), and the LEDs in Fig. 8 are green (LTL2T3TGK6) and red (LTL2V3EV3JSR) to indicate legal and illegal moves. The sensors, multiplexer, and ADC all run at 5V. The RPi takes in 5V, but uses a 3.3V logic level. This means that all GPIO inputs and outputs to the RPi must not go above 3.3V. Therefore, the 3.3V regulator on the chess board PCB is used with the buttons to create a 0V or 3.3V input signal.

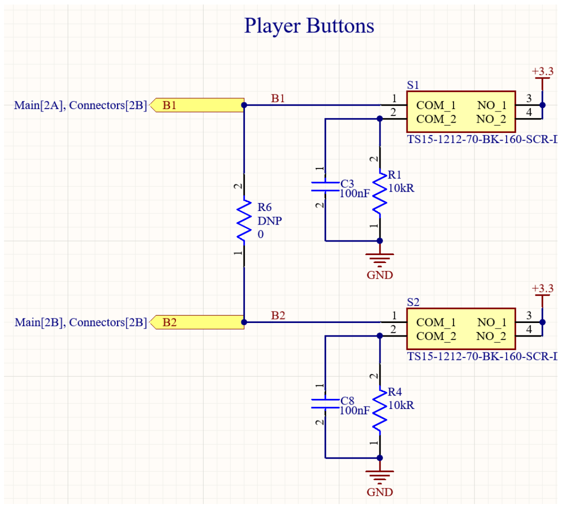


Figure 7: Tactile Switch Interface Schematic

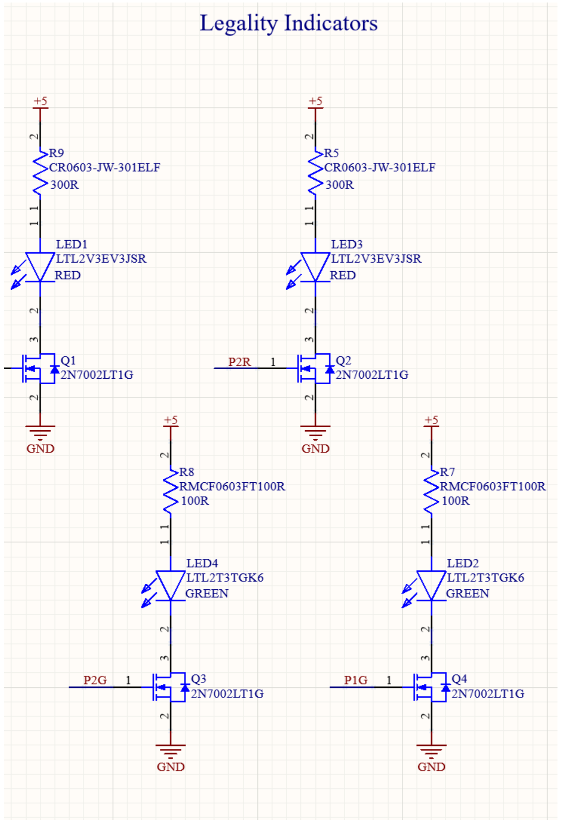


Figure 8: LED Control Schematic

For controlling illumination of the LEDs in Fig. 8, we also had to work with a logic level change from the 3.3V of the RPi to the 5V system on the board. This level change was necessary because the forward voltage of one of the LEDs is greater than 3.3V and the current limit of a RPi GPIO port is 16 mA. We may not need to deliver more current through an LED than 16 mA, but we did not want needlessly to restrict ourselves. To solve these issues, the outputs from the RPi control transistors (2N7002LT1G) that connect the LEDs from 5V to ground. There are current limiting resistors in series with the LEDs that can be changed if we desire increased or decreased brightness while testing the board.

6.5 PCB Interconnects

Since our circuit board is made from several identical PCBs, they all need to be connected in order to share common signals. At the edges of each board, there are large pads placed for all major power and signal nets. A subset of these nets are shown in Fig 9. Jumpers (0 Ohm Resistors) can be placed between all of these pads and the pads on the neighboring boards to connect them all. Having all of these boards connected means that power regulation and communication with the RPi only need to happen on one of the boards.

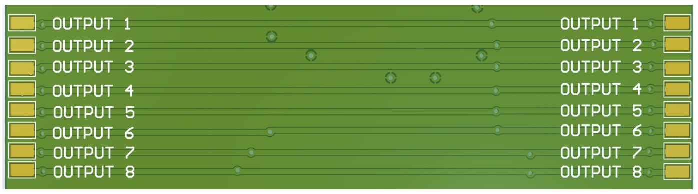


Figure 9: Inter-PCB Jumper Pad Locations

6.6 Firmware

The firmware is the interface between the sensors on the chess board and the software. The firmware will interface with the ADC on the PCB over SPI. Data will be received by the Raspberry Pi in a format designated by the ADC. The data will then be processed into a format that is convenient to use for the legality check.

6.7 Legality Check

The legality check program will be written in C++, as it is one of the fastest and most efficient programming languages. It will implement the legal move generation from the Stockfish chess engine. At the beginning of the game, and after each legal move is played, the program generates a list of every next legal move from the current position. Once a move is played and sensor data for the move is received, the program compares the new board state from the sensors with the previous board state to determine what piece was moved (source square and destination square). It also checks that only one piece was moved, and the correct color of piece was moved. Then, this new move is checked against the already-generated list of legal moves for the position. If the move is legal, the program will update the state of the board, light up a green LED on the board and begin generating the legal move list for the newly-updated position. If the move is illegal, the program will throw out the move, preserve the previous board state and already-generated legal move list, and light up a red LED on the board.

6.8 Server and Website

Our software infrastructure diagram is shown in Fig. 10. The website front end will use HTML and CSS to display the proper information, and use AJAX (asynchronous javascript) to handle the consistent update logic. We chose to use HTML and CSS for the front end visuals of the website because not only are they industry standard, but they also have a large existing infrastructure. Tools such as Bootstrap allow us to build a better, visually appealing, themed website without too much additional integration work.

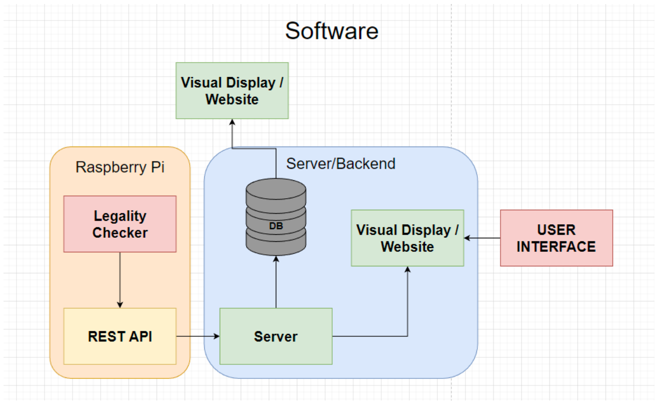


Figure 10: Software Design Flow

The backend of the server is written using the Django framework and will be modeled using the MVC design (the model, view, and controller) design. This separates the code that loads the HTML, the code that deals with the database, and the code that handles the back end of the server.

It should be noted that the Django framework is written in the Python language, which, due to being an interpreted language, is not the most latency conscious. However, the main goals in mind when building the website are to prioritize being robust and usable.

We can clearly see the MVC in play above as the server backend controls the Visual Display that the user is able to interact with. Furthermore, the database holds the chess notation information that allows for the user to upload their previous games to an external analysis source (Ex. Chess.com). Finally, the user can view the current game being played on the web application, which receives that information through the RPi (located on the chess board itself) which communicates to the backend of the server through the REST API.

6.9 Database

For the MVP, we will choose to use a local SQLlite database. While this initial database doesn't have great scalability, it works great for a few users and under <10000 total games stored. This is due to the built in nature of the SQLlite database into the Django framework: it takes little time to set up, and works well for a smaller production environment. Using a database with a SQL protocol allows for easy query access, which is a primary usage of our web application (say that a user wanted to query the database for all games which they played at the black position before 2022).

7 TEST & VALIDATION

7.1 Accuracy Tests

To test accuracy, we will first make sure that chess pieces that are placed off center (up to 37.5% or 3/8" off center) are still detectable with perfect accuracy. Next, we will play through a game of chess at varying speeds to make sure that the accuracy still holds when a faster game is played. If these tests fail, we will look at using larger or stronger magnets to make the sensing even more robust.

7.2 Latency Tests

To test the latency of the legality check, we will run the board through 3 games and use high frame rate video to time the latency from each move being made (user pushes button) to the legality output (LED on board lights up). Each game will be around 40 moves for both black and white, and the moves will be selected to create high-complexity positions, where the legality check will be slower due to a higher number of legal moves.

7.3 Power Tests

To test power usage, we will first measure power used at idle and and peak computation of the Raspberry Pi and sensors using a power supply in place of our batteries. We will then play a game of chess for at least 15 minutes and will compare the state of charge of the batteries before and after to see how much of the battery capacity had been used. This usage will be extrapolated to 10 hours. If more battery capacity is required, we have space on the bottom of the board to add it.

7.4 User Input Tests

To test the overall usability of the system, we will have a suite of user tests. Users will be asked to play a set of 3 games:

- One Blitz Game (with a time control between 3-5 minutes)
- One Rapid Game (with a time control between 10-15 minutes)
- One longer-paced game (with a time control between 30-60 minutes)

Between the second and third games, we will ask the users to attempt to register and login to the web application. They will then attempt to view their past games, and pull up a continuously updating view for their current game. Finally, after they finish playing the third (and longest game), we will ask a series of questions that measure various components of usability.

- Latency
  - "Did you feel any noticeable lag between pressing the clock and the legality checker?"
- Intuitiveness
  - "Did you find the website to be confusing or unintuitive to use?"
- Normality
  - "Did the experience feel irregular, or differ from a normal over-the-board chess game?"

The goal of the above set of questions is to measure whether the technology that we built into the chess board fundamentally changed the usability and playing experience that a normal player might have. We want to incentivize players to use our chess board because it reflects normal usability, but also has many of the initial features that we attempted to implement (automatic notation, chess database). Users will be periodically tested during the implementation phase of the project. Finally, a measure of success (after testing 6 different users) will be to receive less than 2 "No" responses on the total of 18 total questions asked (16/18).

8 PROJECT MANAGEMENT

8.1 Schedule

The schedule in Fig 11 is organized to accommodate the individual contributions of each teammate. Each teammate's role in the project is, for the most part, individual. The firmware, hardware, and software of the final chess board can be built in parallel, and there are multiple weeks allotted at the end of the schedule for integration among the three parts. Furthermore, there is a break week allotted for fall break to allow for flexibility: if team members feel that they are ahead of schedule, they can take the break accordingly, and if team members feel that they are behind schedule, they can use the week to catch up on remaining work. Lastly, proper time is allotted for tests and validation (most crucial for hardware), shipping, and the physical construction of the board.

8.2 Team Member Responsibilities

Vikram is responsible for the hardware portion of the project. This includes the mechanical chess board design and the circuits and PCB design. Patrick is responsible for the firmware interface with the hardware as well as the legality check and state machine logic of the system. Ryan is responsible for the software portion of the project that includes the the server, database, and web interface as well as the RPi's interface with the server. As individual portions of the project are completed, we begin the integration process. Integration will include making the hardware and RPi work together and then making the whole hardware and firmware system work with the software. The final step that will be done together is testing and validating our system and making any necessary revisions to any aspect of the design.

We ensure that all parts are as parallelizable as possible, by building interfaces that act between each individual part. Vikram's work will interact with Patrick's firmware, and Patrick's firmware will interact with Ryan's software. However, significant progress can be completed as the majority of the work can be done without extensive knowledge of the interfaces.

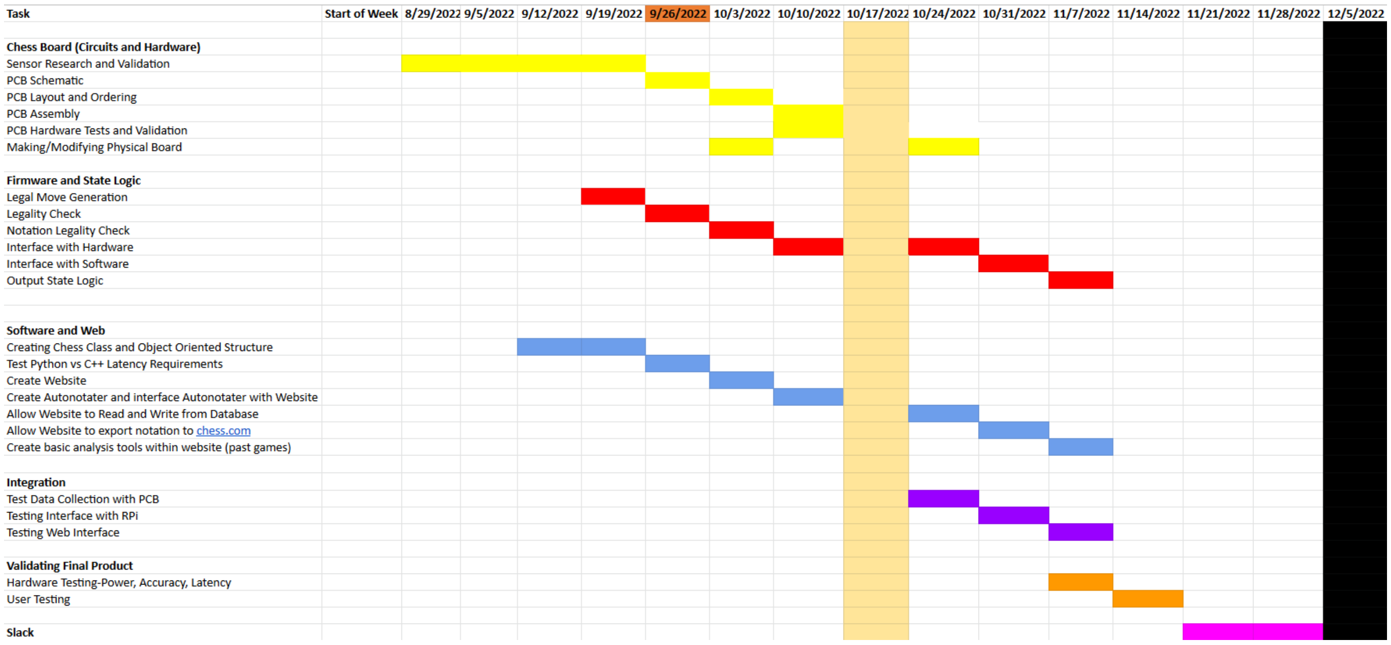
8.3 Bill of Materials and Budget

Our bill of materials in Fig. 12 consists of all of the PCB components, PCBs, acrylic sheets, and the chess pieces. The total cost comes out to $301.95. We are comfortably within the $600 budget, and we have enough money left to buy a second revision of the PCBs or more spare components if absolutely necessary. The breakdown of the BOM is in Fig. 12.

8.4 Risk Mitigation Plans

The largest risk from the hardware perspective is that the PCB does not work as expected. To mitigate some of this risk, the board is large enough and only 2 layers. This means manual alterations to the board are possible, but not necessarily easy. Another solution is that we could order a second revision of the PCB and reuse the existing bill of materials that we already bought. A benefit of the modular PCB design is that the cost allows for a second revision while staying under the 600 dollar budget. Stock is no longer a risk since we have purchased all of our PCB components and nothing was backordered.

The largest risks from software include packet loss. It is important to note that while the code can be tested, and the website can be made hard to bypass, it is possible that information from the RPi might be lost in transit or corrupted while being transferred to the website. We can manage this data loss by creating a checksum, or a secondary verification that the move sent did not corrupt in transit. This checksum works by checking to see whether the given information packet details a valid board state, and can be derived from a hash of the board. This creates a quick and reliable method of double checking the validity of an information packet sent from the RPi. In the case that an information packet sent from the RPi is valid, the website will send a confirmation to the RPi that the proper information is received. If the confirmation is not received within a given time period, the RPi will send the information once more.



Task	Start of Week	8/29/2022	9/5/2022	9/12/2022	9/19/2022	9/26/2022	10/3/2022	10/10/2022	10/17/2022	10/24/2022	10/31/2022	11/7/2022	11/14/2022	11/21/2022	11/28/2022	12/5/2022
Chess Board (Circuits and Hardware)																
Sensor Research and Validation		🟨	🟨	🟨	🟨											
PCB Schematic						🟨										
PCB Layout and Ordering							🟨									
PCB Assembly								🟨								
PCB Hardware Tests and Validation								🟨								
Making/Modifying Physical Board							🟨			🟨						
Firmware and State Logic																
Legal Move Generation					🟥											
Legality Check						🟥										
Notation Legality Check							🟥									
Interface with Hardware								🟥		🟥						
Interface with Software											🟥					
Output State Logic												🟥				
Software and Web																
Creating Chess Class and Object Oriented Structure				🟦	🟦											
Test Python vs C++ Latency Requirements						🟦										
Create Website							🟦									
Create Autonotater and interface Autonotater with Website								🟦								
Allow Website to Read and Write from Database										🟦						
Allow Website to export notation to chess.com											🟦					
Create basic analysis tools within website (past games)												🟦				
Integration																
Test Data Collection with PCB										🟪						
Testing Interface with RPi											🟪					
Testing Web Interface												🟪				
Validating Final Product																
Hardware Testing-Power, Accuracy, Latency												🟧				
User Testing													🟧			
Slack														🟪	🟪	

Figure 11: Gantt Chart

Description	Vendor Part Number	Manufacturer	Quantity	Unit Price	Item Total
MAGNET 0.5"DIA X 0.25"H CYL	469-1050-ND	Radial Magnets, Inc.	16	$ 1.58	$ 25.22
51Ω Resistor 0603	118-CR0603-FX-51R0ELFCT-ND	Bourns Inc.	1	$ 0.10	$ 0.10
Ratiometric Hall Effect Sesnsor	296-DRV5055Z4QDBZRCT-ND	Texas Instruments	67	$ 1.08	$ 72.31
10kΩ Resistor 0603	CRT0603-BY-1002ELFCT-ND	Bourns Inc.	2	$ 0.38	$ 0.76
0603 Jumper	RMCF0603ZT0R00CT-ND	Stackpole Electronics	11	$ 0.01	$ 0.14
Schottky Diode 20V 3A	B320A-FDICT-ND	Diodes Incorporated	2	$ 0.42	$ 0.84
75Ω Resistor 0603	RNCP0603FTD75R0CT-ND	Stackpole Electronics	2	$ 0.10	$ 0.20
300Ω Resistor 0603	CR0603-JW-301ELFCT-ND	Bourns Inc.	3	$ 0.10	$ 0.30
130Ω Resistor 0603	CR0603-FX-1300ELFCT-ND	Bourns Inc.	2	$ 0.10	$ 0.20
1kΩ Resistor 0603	CR0603-JW-102ELFCT-ND	Bourns Inc.	8	$ 0.10	$ 0.80
100Ω Resistor 0603	RMCF0603FT100RCT-ND	Stackpole Electronics	3	$ 0.10	$ 0.30
1206 Jumper	2019-RK73Z2BTTDCT-ND	KOA Speer	68	$ 0.05	$ 3.20
Tactile Switch	179-TS15121270160SCR	CUI Devices	2	$ 0.69	$ 1.38
Slide Switch	118-5MS1S102AM6QES	Dailywell	1	$ 3.17	$ 3.17
N-Channel MOSFET	863-2N7002LT1G	onsemi	6	$ 0.27	$ 1.62
10 nF Ceramic Capacitor 0603	810-C1608X7R2A103M	TDK	2	$ 0.10	$ 0.20
100 nF Ceramic Capacitor 0603	187-CL10B104KB8NNNC	Samsung Electro-Mechanics	14	$ 0.02	$ 0.21
Red Led Through-Hole	859-LTL2V3EV3JSR	Lite-On	2	$ 0.47	$ 0.94
Green Led Through-Hole	859-LTL2T3TGK6	Lite-On	2	$ 1.29	$ 2.58
3.3V 150 mA Linear Regulator	926-2985AIM53.3/NOPB	Texas Instruments	2	$ 1.14	$ 2.28
5V 3A Switching Regulator	926-LM2576S-50	Texas Instruments	1	$ 6.27	$ 6.27
8 Channel ADC	926-AD088S052CIMTNPB	Texas Instruments	2	$ 4.45	$ 8.90
8:1 Analog Multiplexer	595-TMUX1208PWR	Texas Instruments	10	$ 0.87	$ 8.68
Green SMD LED Indicator	859-LTST-C190GKT	Lite-On	1	$ 0.24	$ 0.24
2.2 uF Ceramic Capacitor 0603	187-CL10A225KO8NNNC	Samsung Electro-Mechanics	4	$ 0.10	$ 0.40
1 uF Ceramic Capacitor 0603	187-CL10B105KA8NNNC	Samsung Electro-Mechanics	12	$ 0.02	$ 0.28
68 uH Power Indudctor	810-CLF12577NIT680MD	TDK	1	$ 2.00	$ 2.00
Dual 18650 Battery Holder	534-1049	Keystone Electronics	2	$ 6.37	$ 12.74
Blue SMD LED Indicator	859-LTSTC193TBKT5A	Lite-On	1	$ 0.30	$ 0.30
6 position right-angle 100 mil header	575-8292200620	Mill-Max	3	$ 6.92	$ 20.76
32V 5A SMD Fuse	594-MFU0603FF05000P1	Vishay	4	$ 0.27	$ 1.08
100 uF Electrolytic Capacitor	647-UCQ1E101MCL1GS	Nichicon	4	$ 1.29	$ 5.16
Custom PCBs	N/A	PCBWay	5	$ 16.68	$ 83.40
16" by 16" 1/4' Acrylic	N/A	Professional Plastics	1	$ 25.00	$ 25.00
Chess Pieces	N/A	The Chess Store	1	$ 10.00	$ 10.00
				Total	$ 301.95

Figure 12: Bill of Materials

9 RELATED WORK

As mentioned in the Introduction, a similar product is ChessUp. It is also a custom chess board that can detect moves made on it. It includes a built-in chess engine, which finds possible moves and can recommend the strongest ones to the user. While it has some features that our product does not, the cost of our board is lower. Given the allocated time for this project, the scope of our design is more reasonable.

10 SUMMARY

The Chess Autonotator system is an all-in-one product that offers the familiar look and feel of a standard chess set with the conveniences of automatic game notation, legality checking, and a website to review past games and export them for analysis. The notation and legality checking will be too fast to even be noticeable by most players, and will be perfectly accurate. Foreseeable challenges in the remaining stages of the project are assembling and validating the PCB, writing the firmware to control the sensors, and machining the chess board and a set of pieces with our magnets securely held within them. We are confident that we will overcome these challenges, and that the final system will meet all of our use-case requirements.

Glossary of Acronyms

Include an alphabetized list of acronyms if you have lots of these included in your document. Otherwise define the acronyms inline.

- RPi – Raspberry Pi
- PCB - Printed Circuit Board
- HE - Hall Effect
- API - Application Programming Interface
- ADC - Analog to Digital Converter
- SPI - Serial Peripheral Interface
- GPIO - General Purpose Input Output

References

[1] Daniel Inführ. *Gigantua.* URL: `https://github.com/Gigantua/Gigantua`. (accessed: 10.14.2022).

[2] J. Kiiski T. Romstad M. Costalba and the Stockfish community (https://github.com/official stockfish/-Stockfish/blob/master/AUTHORS). *Stockfish.* URL: `https://github.com/official-stockfish/Stockfish/`. (accessed: 10.14.2022).