

ECE 445 Senior Design Laboratory
Design Document

Blitz Board

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1 Introduction

1.1 Problem

When one plays chess against a remote player or bot on chess.com, there is no physical component- the board is replaced with a display and mouse. A good solution is a two-axis motor system to move pieces from beneath the board on behalf of a remote or virtual opponent, but this method is slow, especially for “takes”, where a piece must be taken off the playing field. One existing product on the market, Square Off, does this by taking a piece off the board and then moving another into its place. This requires up to twice this distance traveled compared to taking a piece off the board as the second movement. This lack of speed from the computer side restricts the variety of game modes that can be played on the board. Additionally, most players punctuate their moves by pressing the switch on a chess clock, which is not featured as part of the existing solutions.

1.2 Solution

Our solution to this problem is to expand upon the capabilities of the two-axis motor system by implementing faster movements on the computer side. More efficient pathfinding for a given move will allow for faster games of chess, such as blitz. Additionally, we wish to create space for a digital chess clock that both the player and the computer will be able to control via electromechanics. This will further replicate the experience of an in-person game of chess with physical pieces and a chess clock with a mechanical switch. Additionally, we wish to expand upon the ability of the board to communicate with the player via lights within the board that can communicate illegal moves, the last move made, or even suggestions for the player if time allows us this semester.

1.3 Visual Aid



Figure 1: A common chess table with large margins around the edges of the board

Most robotic chess boards on the market feature a single, bulky slab that comes with the necessary game pieces. Within the board, stepper motors fixed onto two sets of perpendicular rails will move an electromagnet around the board with a motor-and-belt system. External control allows for the activation of the electromagnet when needed in order to move pieces. Additionally, we will use hall effect sensors to detect magnetic fields produced by permanent magnets placed inside the chess pieces and relay the position of different pieces on the board. These are typical mechanical elements we wish to emulate in our design. Each of these can be seen in the figure below.



Figure 2: A player using the prototype of the Blitz Board

We hope to expand past other robotic chess boards on the market by developing the system to be built on an entire table. This will allow us more space for the stepper motors and rails to maneuver pieces, as well as space for a functioning digital chess clock that faces the human user. The addition of the digital chess clock, and further optimization of the motors to move pieces faster than others on the market will allow for more in-depth gameplay and a wider variety of game modes such as blitz chess.

1.4 High-Level Requirements

- The stepper motors and electromagnets should be able to perform movement of and discard of taken pieces faster than other boards on the market
- The stepper motors and electromagnet will be able to perform moves in a precise manner
- The chess board will have a working chess-clock that can be utilized by both the player and computer

2 Design

2.1 Physical Design

To save time and cost of labor on behalf of the ECE Machine Shop, we have elected to use a previous semester project that was never finished. It only provides us with the mechanical construction of the board which is entirely composed of the piece movement unit. FIGURES below depict the construction of the stepper motor and rail system. The motors control the rotational movement of small sprockets that align “teethwise” with long belts. As the motors turn, the sprockets turn and actuate linear movement with the belts.

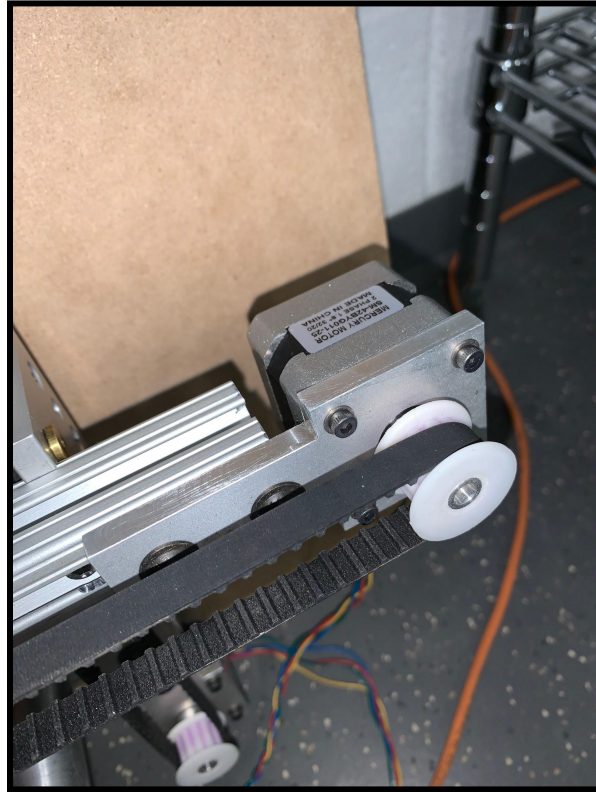


Figure 3: A Stepper Motor with White Sprocket and Black Belt Attached



Figure 4: The Intersection of Two Perpendicular Motor Rails

FIGURE depicts the electromagnet fixated atop a small section of rail. This small piece of rail is secured to one of the belts controlled by one of the stepper motors and controls the movement of the electromagnet from side to side while being guided by a full, board-spanning section of rail. The long rail that the electromagnet slides along for side to side movement is attached to a second belt that controls movement up and down the board. With both of these, the electromagnet is able to move in any direction on the board.



Figure 5: The Electromagnet Secured to a Small Piece of Rail

The next step in the basic design of this board is to keep all the electronics and mechanical aspects underneath the board. This makes for challenging space management to keep the whole product small enough to fit within a reasonably sized table. Limiting the size of the main PCB and the chess clock electronics is important to conform to the existing physical components. Measurements of the dimensions of the system will be necessary to write software that moves the chess pieces as intended.

2.2 Block Diagram

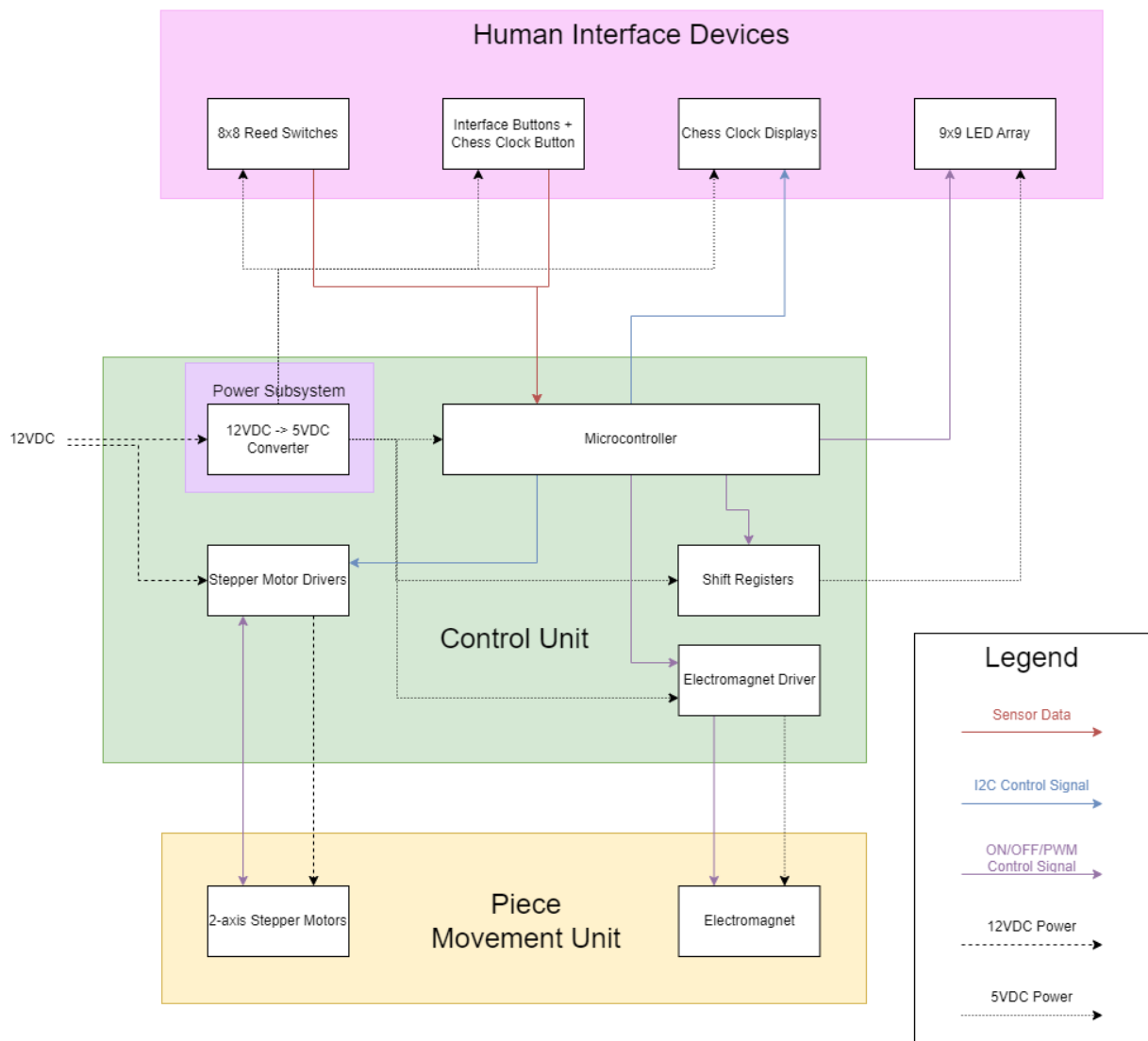


Figure 6: Block Diagram for Whole System

2.3 Block Descriptions

2.3.1 Power Unit

The power unit supplies power to the entire system, including the microcontroller in the control unit, the microcontroller in the robot unit, the chess clock displaying the user interface unit, etc. The power unit is connected to the rest of the other units, and it consists of a power converter.

Converter

The converter circuit will most likely consist of an off-the-shelf AC/DC power converter that takes 120VAC in and outputs 12VDC. The only components of our design that will require 12VDC will be the stepper motors, and most everything else will run on 5VDC power, thus, we will have another smaller DC/DC converter to step 12V down to 5V. This will make up the entirety of the Power Unit.

| Requirements | Verification Methods |
|--|--|
| <ul style="list-style-type: none">• The power unit is able to provide 12V to the motor and 5V to everything else• The ripple of the converter's output voltage stays within 5% of the rated voltage<ul style="list-style-type: none">○ 12V: 11.4V~12.6V○ 5V: 4.75V~5.25V | <ul style="list-style-type: none">• Probe the voltage output of the power unit and converter with a multimeter or an oscilloscope to make sure that it is within the rated range |

2.3.2 Control Unit

The control unit focuses on processing data from sensors and generating moves. It will then turn these moves into functional directions for the stepper motors under the board so that they can maneuver to displace pieces on the board. In addition, it will also control the use of the chess clock on the board's behalf, and be able to light up LEDs on the board to indicate different information to the player during gameplay.

Microcontroller

The main task of the microcontroller, the MSP430F6726A from Texas Instruments, is to detect and respond to the player's moves. It will detect pieces by reading data from the hall effects sensors in each space. When the microcontroller detects that a piece was moved from one square to another legally and the chess clock was switched, it will use the Stockfish chess engine to calculate a good response and translate the move into movements for the servo motors and modulation of the electromagnet. Once the move is done, the microcontroller will send a signal to switch the chess clock back via the solenoid with a

plunger. During this process, it will control the chess clock with respect to the player's and its own moves. It will also control the LEDs within the board to indicate previous moves and the legality of moves.

| Requirements | Verification Methods |
|--|---|
| <ul style="list-style-type: none"> The microcontroller can be programmed and debugged via a JTAG connection | <ul style="list-style-type: none"> When connected via JTAG to a computer running TI CCS IDE, the IDE can upload a basic blink program, step, and throws no errors regarding the connection |
| <ul style="list-style-type: none"> The microcontroller is able to identify that a chess piece has been moved from one square to another | <ul style="list-style-type: none"> When a piece is moved between squares, interpretation of sensor data should allow the microcontroller to register that a piece is absent from one square and present in another |
| <ul style="list-style-type: none"> The microcontroller is able to translate the response of the Stockfish chess engine into actions that are executed by motor and electromagnets | <ul style="list-style-type: none"> An example move of a queen taking a rook laterally, longitudinally, or diagonally from the other side of the board can be translated into servo motor and electromagnet control The example move can be executed with the pieces in the intended ending positions. |
| <ul style="list-style-type: none"> The microcontroller is able to control the chess clock accurately | <ul style="list-style-type: none"> The counting down of the chess clock matches that of a smartphone clock The switch being actuated by the user or computer following a valid move changes which time is counting down |

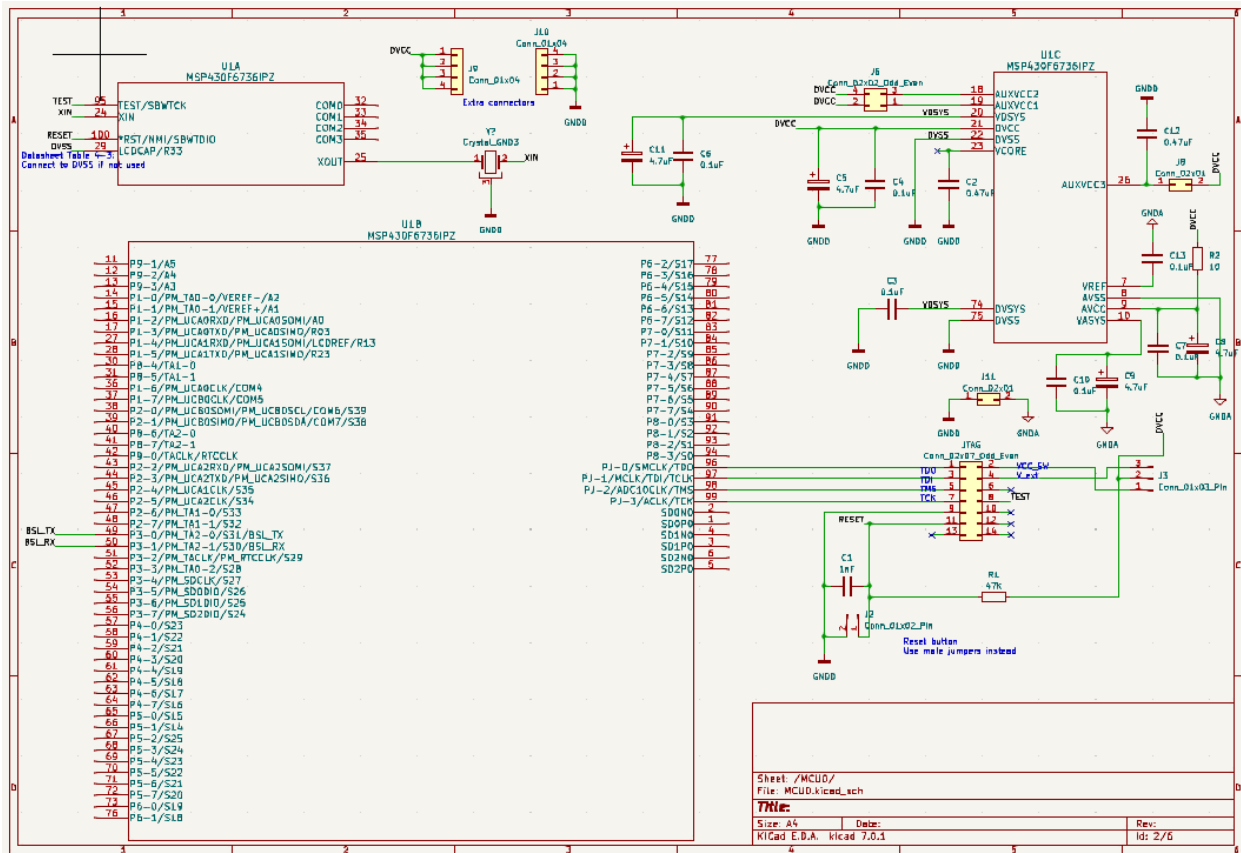


Figure 7: Schematic for Microcontroller

2.3.3 Piece Movement Unit

The Piece Movement unit consists mostly of stepper motors and electromagnets. Both of these components will receive data through the microcontroller and will operate according to the instructions given by the control unit. A motor driver component will be used to interface with the microcontroller and stepper motors, and will ensure that with the control signals given by the microcontroller, the motor will move the correct amount of steps at a certain speed.

Stepper Motors

The stepper motors are simple 2-phase, variable reluctance machines. They have a 1.8° step angle, which means that when the motor is told to move one step in any direction, the motor will spin 1.8° and remain stationary until told to do otherwise. These motors communicate in steps, so careful math must be done in order to translate the desired rotation angle into steps. Furthermore, an additional step of calculations must be done in order to understand how far you wish the motor to move, based on the diameter of the gear-belt system used. This will directly translate to an angle, and that angle will directly translate to steps. Additionally, the direction of rotation about the motor axis is important as the motor is able to take steps in any direction it is instructed to, those directions being clockwise or counterclockwise.

Electromagnet

The electromagnet will remain at a position at the intersection of the two-axis motor set-up. A simple transistor will be used to turn the electromagnet on and off. The transistor must be able to withstand a large enough amount of current such that the electromagnet can create a large enough magnetic field to carry a piece along the surface of the board. Additionally, the transistor will receive its gate signal directly from the microcontroller.

The following set of requirements detail the extent to which the Piece Movement Unit should be able to function, and along with it are some ways to verify each of these requirements:

| Requirements | Verification Methods |
|--|---|
| <ul style="list-style-type: none"> The motors are able to move precisely and quickly as specified by the controller | <ul style="list-style-type: none"> Orient the two-axis motor system such that the electromagnet begins at a specified starting point, such as the center of the board Give the motors a set of instructions, (such as move up two spaces, to the left three spaces, etc.) Ensure that the set of instructions should have the motor end up back at the starting point, and measure the variation from the start point and end point location using distance as a metric. If all steps are equal by magnitude of angle, then the electromagnet should return to the exact starting point with little error. Steps should be taken to reduce this error |
| <ul style="list-style-type: none"> The electromagnet shall produce enough magnetic field to reliably move pieces across the board despite variation in mass of the piece or position. | <ul style="list-style-type: none"> The electromagnet will begin to move a piece at a rated speed. This speed will be determined by the speed needed to be faster than other chess boards If the piece fails to move completely though the end of the move, the supplied current through the electromagnet will be increased. This can be repeated until a piece is able to make the move. |
| <ul style="list-style-type: none"> The electromagnet shall not interfere with other pieces on the path when moving a chess piece from one place to another | <ul style="list-style-type: none"> Test whether the electromagnet will attract nearby pieces when moving a chess piece to its destination |

| | |
|--|--|
| | <ul style="list-style-type: none"> • Determine the minimal distance between the electromagnet and chess pieces |
| <ul style="list-style-type: none"> • The motors shall not run too far off the board causing damage, harm, or defects in the table | <ul style="list-style-type: none"> • The number of steps taken will be processed by the control unit carefully, and the electromagnet and motor unit will always return to the same spot • With the piece movement unit always returning to the same spot, bounds can be set for how far the unit moves in any one direction. • The number of steps in a given direction can be counted by the processing unit, and can be checked with an upper bound limit before executing a move to ensure motors do not drive too far off the rails. |

2.3.4 User Interface

The user interface allows users to interact with the board in several ways. It is connected to the control unit, and it consists of the led display, chess-clock components, and several buttons. We hope to be able to have some sort of On/Off switch, a button to operate the chess clock on the user side, HEX displays to denote time on the clock, and LEDs to provide extra information to the user during gameplay.

LED Display

LEDs embedded in the board will display the most recent move by highlighting the moved piece's current and previous positions. They will be driven by a multiplexer that receives control signals from the control unit. These LEDs can also be activated to denote when an illegal move has been made by the player, or when time runs out on the clock by lighting up the board in an alarming red color.

Hall-Effect Sensors

The Hall effect sensors underneath the board floor report the position of chess pieces to the microcontroller. They detect the presence of the magnetic field generated by the magnets placed in the base of the pieces, and their output voltages are directly proportional to the strength of the magnetic field. These will not affect the use of the electromagnet for moving pieces as the signals they provide to the control unit won't be processed while the electromagnet is moving, and they will be placed out of the physical way of the Piece Movement Unit.

Chess-clock Display

The clock on the side of the board will display the time limits for both players (computer and human). The clock's display will be four seven-segment LEDs per player and will have a button for the player. Each player's time in minutes and seconds will be shown and counted down according to whose turn it is. When either clock reaches its final minute, that clock will begin displaying time in seconds and hundredths of seconds.

Further on the Chess-clock and Interface Buttons

The user pressing the button will finalize a move, allowing it to be registered by the microcontroller. An LED will illuminate when the computer's move is made or to when the user makes an illegal move. Note, when an illegal move is made, the LEDs will all light up RED and the board will automatically undo the move. The microcontroller will check if moves are legal.

The following set of requirements detail the extent to which the User Interface Unit should be able to function, and along with it are some ways to verify each of these requirements

| Requirements | Verification Methods |
|---|--|
| <ul style="list-style-type: none"> The LEDs in the table top should be able to denote the most previous position of a piece as well as its current position after either party makes a move. | <ul style="list-style-type: none"> Pieces should not get left behind by the electromagnet, the piece should stop at the location it is being sent to The electromagnet should not interfere with pieces that aren't being moved, thus it should only move one piece at a time for normal moves During a "take", the electromagnet will use the piece performing the move to push the "taken" piece out of the way. This is the only time that movement of a piece with the electromagnet should affect another piece After the "taken" piece is pushed away and the piece performing the take is placed, the electromagnet should be able to move the piece off the board. |
| <ul style="list-style-type: none"> The hall effect sensors should be able to reliably detect whether or not the magnets used in the chess pieces are present above them | <ul style="list-style-type: none"> With all sensors connected to the rest of the system and no magnets on the board, the system will register a voltage that doesn't change by more than 10% For each sensor, one part of a magnet in a chess piece being above one part of the sensor registers a range of voltages that doesn't overlap with that of when there are no magnets present |

| | |
|---|--|
| <ul style="list-style-type: none"> • The HEX displays will reliably keep time | <ul style="list-style-type: none"> • Set the HEX displays with specified amount of time (~3 minutes) • Ensure the HEX displays now read 3 minutes each. • Allow time to pass on either clock • Using a separate stopwatch or clock, record the time passed and then stop the clock using the lever switch • Ensure that the clock stops at the press of the switch • Further, ensure the time passed is represented accurately by the HEX displays. If 1 minute has passed, then the time left on the clock should have decreased by one minute. • This can be verified by an number of different play times, down to the seconds |
| <ul style="list-style-type: none"> • The intended numbers are displayed and readable | <ul style="list-style-type: none"> • The microcontroller can control which LED segments are lit up, and the lit segments can be distinguished from non-lit segments by a person indoors |
| <ul style="list-style-type: none"> • The LEDs can communicate when an illegal move has been made by lighting up the entire board with red lights and stopping flipping the clock back to the player until the move is corrected. | <ul style="list-style-type: none"> • To test this, we simply take a player piece and move it to a spot it is not able to move • When this move is made ensure the lights are activated. • Additionally, before correcting the move, ensure the board keeps the clock in the players control and does not run the computer's clock during this move • Once the move is corrected, verified, and the clock button is pushed to signal it is the computer's turn, deactivate all lights, and resume play. |
| <ul style="list-style-type: none"> • The chess clock solenoid should only fire when the computer's turn is complete and that time only stops running on the computer clock once this occurs. | <ul style="list-style-type: none"> • Ensure that after every move the computer makes, it activated the solenoid to switch the clock • Ensure the clock stops at an accurate time as well, there should be no early clock stop before the solenoid fires, and there should be no delay where both clocks can be running at the same time. |
| <ul style="list-style-type: none"> • The solenoid doesn't consume more power than predicted | <ul style="list-style-type: none"> • The IV and power characteristics of the solenoid are as described in the datasheet • The predicted amount of power consumed by a pulse sent to the solenoid for the |

| | |
|---|--|
| | period of time necessary to actuate the switch based on available specs is accurate to within 10% |
| <ul style="list-style-type: none"> The solenoid can actuate the switch with a 5V pulse that lasts less than 500 ms | <ul style="list-style-type: none"> Out of 20 5V DC pulses sent to the solenoid, all times the switch was actuated by the solenoid |

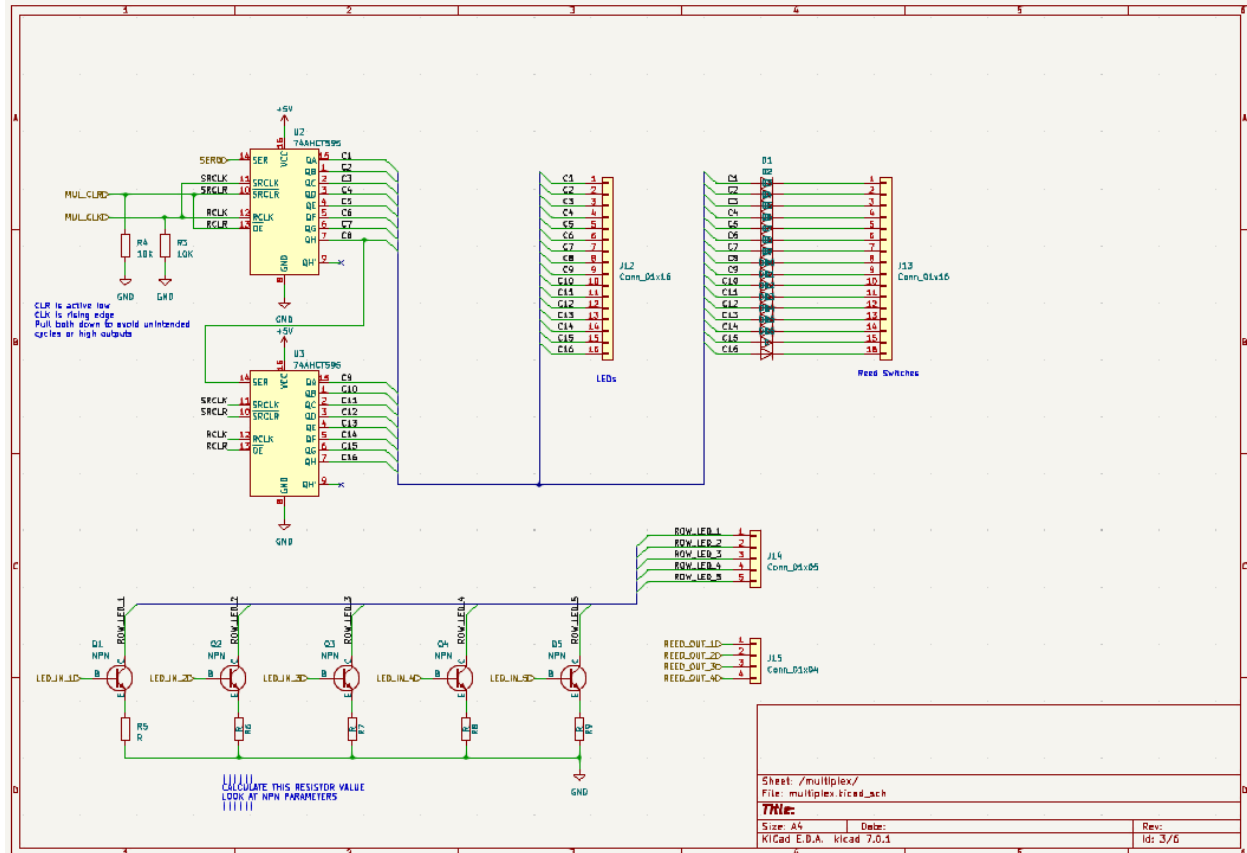


Figure 8: Schematic for Circuit to Multiplex LEDs and Reed Switches

2.4 Software Design

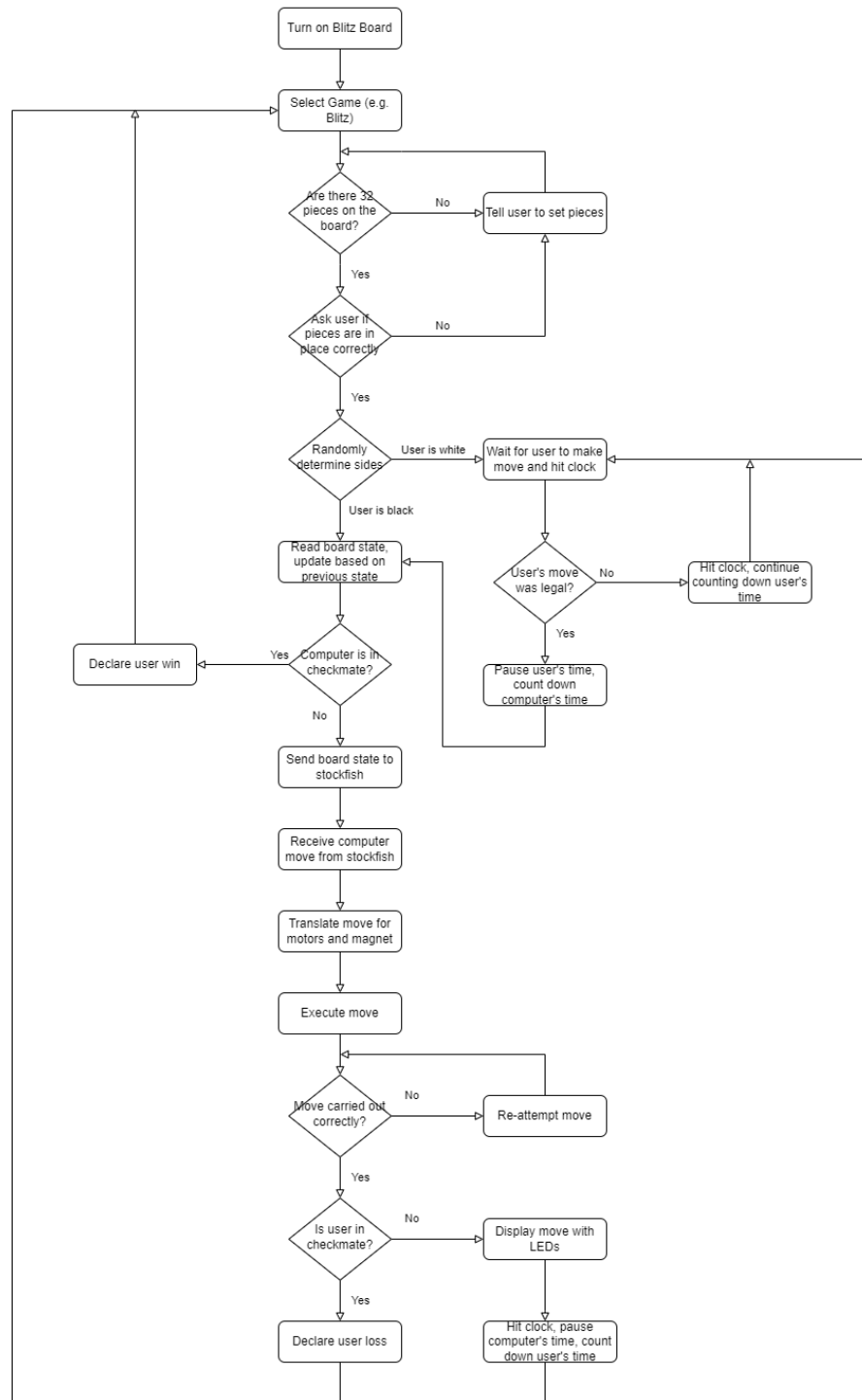


Figure 9: Flow Chart for Software

The software implemented for the board will check the user's moves for legality and checkmates, and execute its own moves calculated by stockfish.

2.5 Tolerance Analysis

One of the most crucial parts of our design is the Piece Movement unit. Without it, the board becomes a regular chess board with some fancy lights. However, in order to be able to move pieces quickly and effectively, the movements made using the two-axis motor system must be very precise. Each playable spot on the board will measure approximately 2in^2 , and the average chess piece has a circular base that measures just under an inch in diameter.

This leaves about 1 inch of clearance between other chess pieces for the piece movement unit to move the desired piece through, with tenths of an inch as room for error. This will require great precision on the motor and belt system. Luckily, the stepper motors are able to move in steps that are about 1.8° . This means that for every step the motor is prompted to move, the rotor shaft will rotate by approximately 1.8° or $\pi/180$ radians. Additionally, the sprockets placed on the rotor shaft measure 2.5cm in diameter. Using these measurements and ratings, the average step produced from these motors and sprockets will move the electromagnet about 0.031 cm or 0.012in.

The rated step angle of the motor is given with a 5% tolerance rating, meaning that our movements will generally range from 0.029-0.032cm, or just over a hundredth of an inch. This will be a suitable tolerance rating as long as the board spaces do not decrease in size as we begin assembly and testing. If we find that we have to reduce the size of the board spaces, we can always drive the motor in half-step operation to increase the angular resolution of the motor's movements, thus allowing for more precise movements.

3 Cost Analysis and Schedule

3.1 Cost Analysis

| Part Name | Part Number | Manufacturer | Quantity | Price | Link |
|-----------------------------|---|------------------------|-----------|----------|----------------------|
| Hall Effect Sensor | DRV5053RAELPGMQ1 | Texas Instruments | 64 | \$74.88 | Link |
| Chess Piece Magnet | 8060 | Radial Magnets, Inc. | 32 | \$50.91 | Link |
| On/Off Switch | RF1-1A-DC-2-R-1 | Switch Components | 1 | \$1.26 | Link |
| Chess Clock Button Solenoid | Mini Push-Pull Solenoid - 5V Product ID: 2776 | Adafruit | 2 | \$9.90 | Link |
| Chess Clock Display | COM-18565 | SparkFun Electronics | 2 | \$19.90 | Link |
| Microcontroller | MSP430F6726A | Texas Instruments | 1 | \$6.91 | Link |
| LED Multiplexer | 595-SN74AHCT594DR | Texas Instruments | 1 | \$0.91 | Link |
| In-Board LED | L314ED | American Opto Plus LED | 81 | \$9.90 | Link |
| Total Parts Cost | -- | -- | -- | \$174.57 | -- |
| Engineering Cost | -- | -- | 70 hr * 3 | \$18375 | -- |

| | | | | | |
|-------------------------|----|----|-------|------------|----|
| Machine Shop Cost | -- | -- | 30 hr | \$1500 | -- |
| Total Labor Cost | -- | -- | -- | \$19875 | -- |
| Total Cost | -- | -- | -- | \$20049.57 | -- |

3.2 Schedule

| Week | Task | Person |
|---------------------|--|----------------|
| Feb 27th - Mar 5th | Complete PCB board design (1st round) | Nick and Owen |
| | Finalize machine shop requirements | Nick and James |
| | Order components | James |
| Mar 6th - Mar 12th | Modify PCB board design (2nd round) | Nick and Owen |
| | Start working on the software while waiting for components | Everyone |
| Mar 13th - Mar 19th | Modify PCB board design (2nd round) | Nick and James |
| | Continue working on the software | Owen |
| | Start assembling components and soldering PCB boards | Everyone |
| Mar 20th - Mar 26th | Complete PCB board design (2nd round) | Nick and James |
| | Ensure software is compatible with microcontroller, begin testing on development board | Owen |
| Mar 27th - Apr 2nd | Solder PCB boards, assemble the components, and finish the hardware part | Nick and James |
| | Finish the software | Owen |
| Apr 3rd - Apr 9th | Finalize the construction of subsystems and start testing them | Everyone |
| Apr 10th - Apr 16th | Combine all subsystems | Owen and James |
| | Test the final product and make sure it meets all high-level requirements | Nick |
| Apr 17th - Apr 23rd | Perform mock demo | Everyone |
| | Make final changes to the final product | Everyone |
| Apr 24th - Apr 30th | Perform final demo | Everyone |

| | | |
|-------------------|----------------------------|----------|
| May 1st - Mar 7th | Perform final presentation | Everyone |
|-------------------|----------------------------|----------|

4 Ethics and Safety

4.1 Ethics

Our project has little ethical aspects to it. It is merely a board meant for playing a game of chess. However, games can often be taken too far, or the boards they are played on incite annoyance and anger. While we consider our project to be safe to play with and use, it may not be best for mental health and safety. For users that struggle with interaction, loneliness, depression or other mental health issues, this board may not be healthy to play on as it lacks human interaction and cannot provide emotional support like a true human companion and chess mate can provide.

Additionally, it is our responsibility to provide users with a board that works and will not cause issues to upset the user, and we are aware of and adhere to point 3 of the IEEE Code of Ethics: “to avoid real or perceived conflicts of interest whenever possible...” [1]. This would ultimately hurt the development of and sale of this board were it to hit the free market. Ultimately though, the goal is to provide the average chess player with a chance to challenge themselves against the processing power of computers in a physical location in their home that is both safe and fun to use when you lack the ability to play with another.

4.2 Safety

Our project has few safety concerns. One of the safety concerns is that children or animals may accidentally swallow chess pieces. Swallowing foreign objects can be harmful, especially when multiple magnets are ingested. The magnets can attract to each other, causing severe problems such as bowel puncture or blockage. According to point 1 of the IEEE Code of Ethics: "to hold paramount the safety, health, and welfare of the public..." [1], we will notify the users to keep the chess pieces out of the kids' and animals' reach.

The magnetic field of magnets and electromagnets poses the other safety concern. Magnets are attached to the chess base, and electromagnets are on top of the robot. There is a slight possibility that the field can interfere with electronic implants such as pacemakers and implantable cardioverter-defibrillators. Conforming to point 1 of the IEEE Code of Ethics: "to hold paramount the safety, health, and welfare of the public..." [1], we will have a warning on the outer packaging to ensure the users are aware of the magnets in the product.

References

[1] “IEEE code of Ethics,” *IEEE*. [Online]. Available: <https://www.ieee.org/about/corporate/governance/p7-8.html>. [Accessed: 09-Feb-2023].