ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Chess Express: The Voice-Controlled Moving Chessboard

Team #67

DEAN BISKUP
(dbiskup2@illinois.edu)
ADITHYA RAJAN
(adithya2@illinois.edu)

TA: Megan Roller

March 3, 2020

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1 Introduction

1.1 Objective

There are many people who would like to play chess with their friends and family around the world. Currently, one can do this on the web using services such as *Chess.com* [1], but unfortunately looking at a screen without a physical representation of the chess board is not satisfactory for some chess players.

To solve this problem, we propose "Chess Express", a voice-controlled, automatically moving chess board. This product would still have the look of a traditional chess board, but be able to be controlled using voice commands, with the pieces automatically moving to reflect the state of the board. This board has WiFi capabilities, so that users can play against any other user in the world, provided that both have an internet connection. Players would be able to see their opponents pieces move in front of them, providing a more authentic online chess experience than a representation on a computer screen.

We hope that this product will bring about increased connectivity to the chess community. In particular, we envision "Chess Express" to be able to connect friends across continents through shared games of chess.

1.2 Solution Overview

The project will utilize the attraction between metal feet on the bottom of chess pieces and an electromagnet below the board in order create piece movement. We will use an X-Y plotter system of belts and stepper motors to accurately move the electromagnet directly below the target piece and then drag it to its new location.

Speech commands will be implemented through a microphone and speech-processing software on the microprocessor. We will utilize the cloud-based speech-to-text processing service provided by Google Cloud [2]. By using a proven, cloud-based service from a reputable company in the field, we can better ensure that the user's command is heard correctly. However, this means that Chess Express requires an internet connection for voice-control functionality.

1.3 Background

"Chess Express" was initially inspired by *Wizard's Chess*, from *Harry Potter and the Sorcerer's Stone* [3]. In this novel, Harry Potter and his best friend, Ron Weasley, play a chess game in which the pieces respond to voice commands, and violently destroy the pieces they are capturing. While our pieces will not destroy others, we were inspired by a hands-free chess game that still had physical, moving pieces.

There are existing solutions for automatic chessboards, such as Square Off [4]. Their solution also moves the pieces autonomously, but the method of user input is by hand. Chess Express distinguishes itself with the addition of voice commands as the means for user input. This allows those with physical disabilities to have an authentic, physical chess experience while having limited physical interaction.

This project is based on a previous one started in ECE 395: Advanced Digital Projects Lab [5]. By the end of that class, this project had a physical X-Y plotter system, but no implementations of chess logic, voice control, or internet connectivity. Throughout this project and semester of Senior Design, we will be adding those key features.

1.4 Visual Aid

Figure 1 shows the status of the project at the end of ECE 395 in December 2019. In this new design, the look of the board will remain the same, while the pieces will be changed to include full-sized chess pieces.

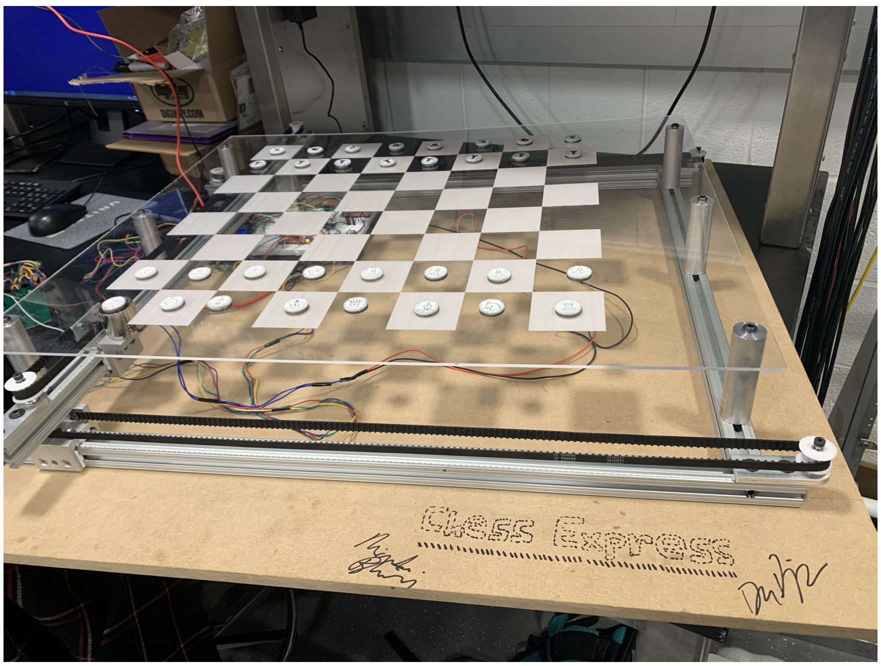

Figure 1: Image of the chess board in December 2019

1.5 High Level Requirements

1. Chess Express must be able to accept voice commands consisting of the specific pattern ”D2 to D4”, in a quiet room with minimal background noise.
2. The piece movement system must successfully move the target piece to the target location in excess of 99% of the time using the X-Y plotter system and electromagnet.
3. Chess Express must prevent illegal chess moves as well as implement the full chess rule set, allowing for advanced moves such as castling and the ”En Passant” [6].
4. Chess Express must be able to send and receive moves from other Chess Express devices over the internet.

2 Design

2.1 Block Diagram

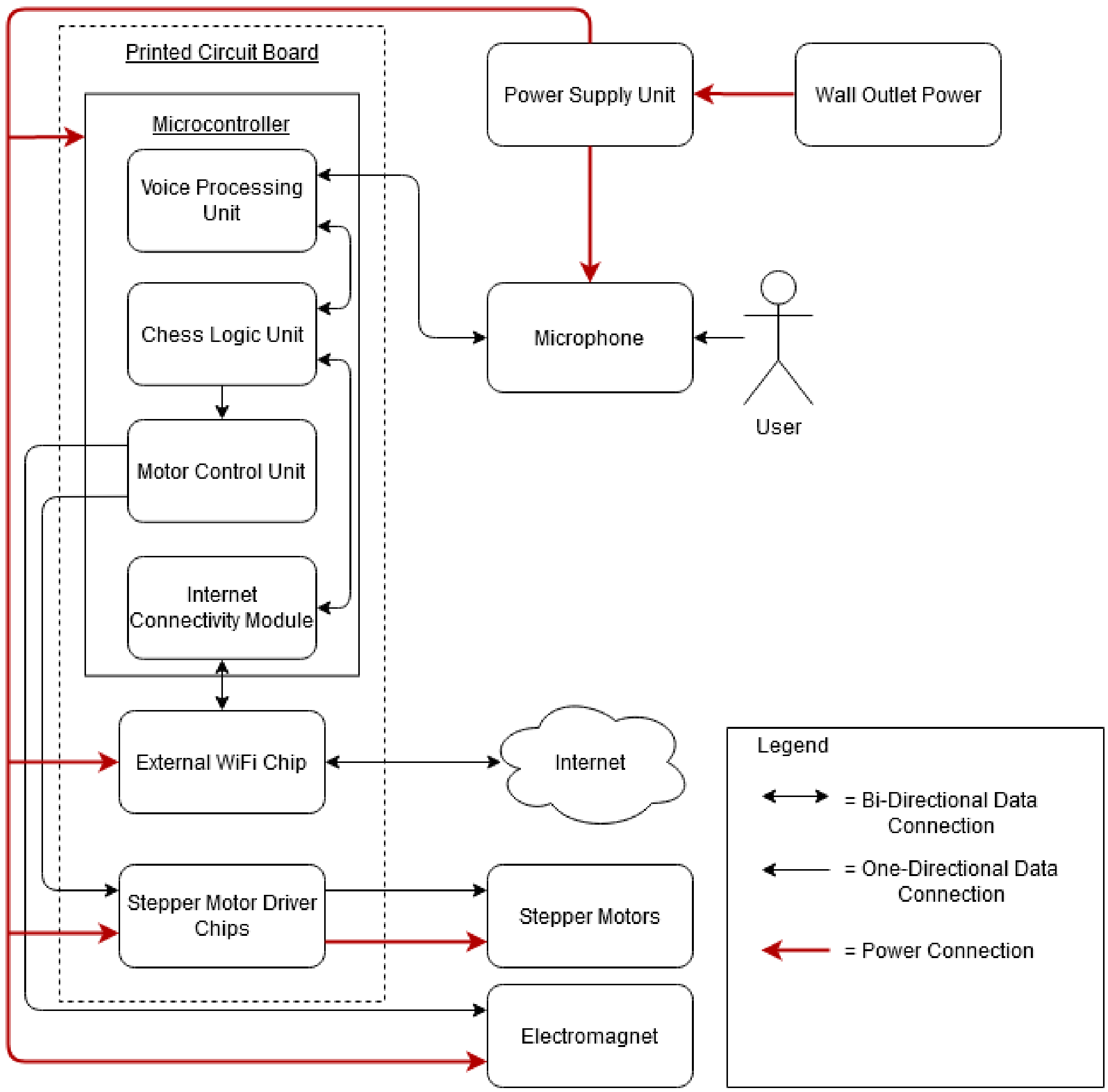

Figure 2: Block diagram of Chess Express

Figure 2 shows the proposed block diagram for Chess Express. In particular, the components on the Printed Circuit Board (PCB) are grouped together. An example of general use is as follows: The user speaks a command into the microphone. That command gets sent to the Voice Processing Unit to be turned into machine-readable data. The Voice Processing Unit then sends that data to the Chess Logic Unit, which, provided that the command is a legal chess move, instructs the Motor Control Unit to move the target piece to the target location. This then repeats for the next move.

2.2 Physical Design

The physical design of Chess Express uses a system of 3 stepper motors, belts, and tracks to move the electromagnet within an X-Y coordinate system. Figure 3 shows a sketch of this X-Y plotter system. The two parallel tracks in black move the red track along the X axis, while the red track moves the electromagnet to the correct Y position.

On the chess board itself (see Figure 4), each square is 2.5 inches wide, creating a total board area of 20×20 inches. Since the X-Y plotter system has to extend beyond the entire board area, the size of entire product is 24×28 inches.

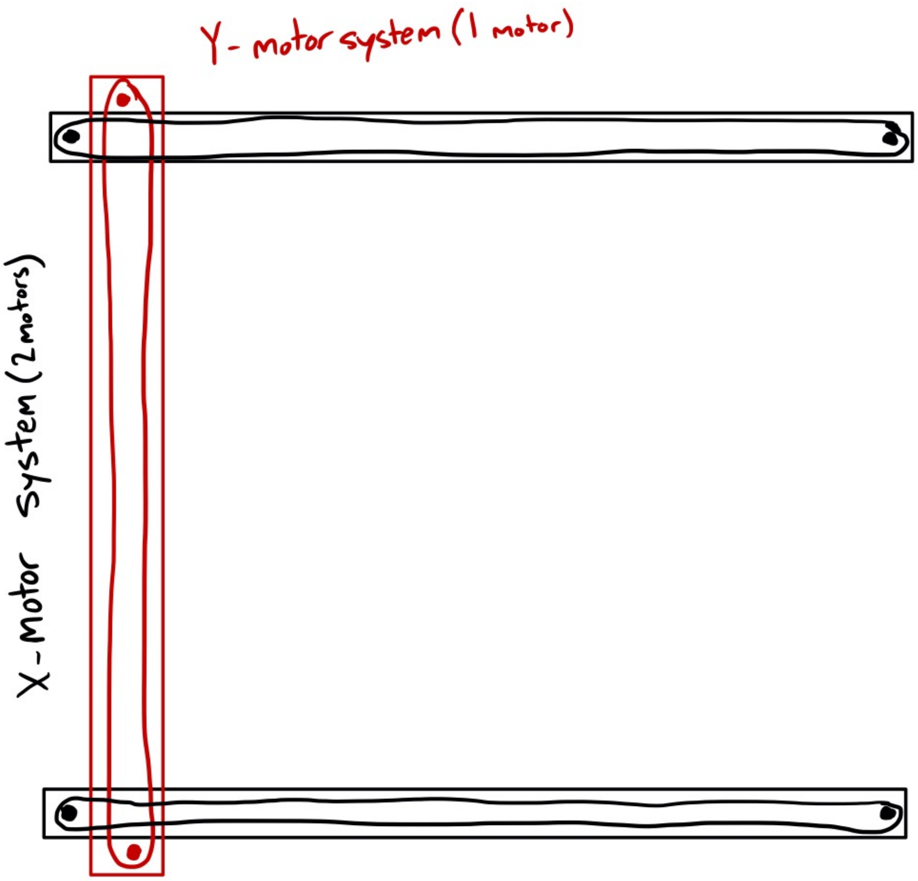

Figure 3: Diagram of the X-Y plotter system

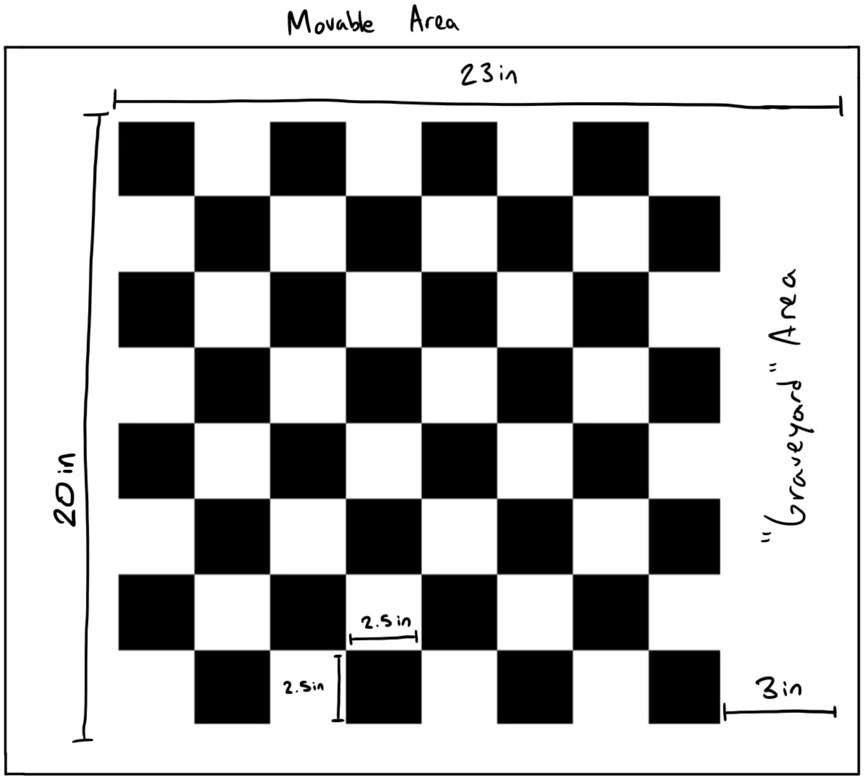

Figure 4: Dimensions of the chess board area

2.3 Power Supply Unit

The Power Supply Unit (PSU) provides power to the PCB as well as all the peripheral devices (microphone, motors, electromagnet, etc.) The input to the PSU is 110V AC, as we plan to have Chess Express be plugged into a standard wall outlet.

Requirement	**Verification**
1. The PSU must be able to provide up to 2.5A at between 11.2 - 12.6V DC continuously to the system.	A. Measure the voltage output of the PSU to ensure it is within 11.2 - 12.6 V. B. Measure the output current at full load (all motors running and electromagnet on) to ensure that it the PSU is adequately supplying up to 2.5A.

2.4 Motor Control Unit

The Motor Control Unit (MCU) controls the movement of the electromagnet below the board. Two sets of motors enable the movement of the electromagnet. One set of two stepper motors allows for movement in the X direction, while another single stepper motor controls movement in the Y direction. The MCU will also control the powering of the electromagnet. Figure 3 shows a diagram of this system.

In our block diagram, we specify the MCU as the specific software module that controls the movement of the X-Y plotter system. The physical X-Y plotter system itself is described in the Physical Design section.

Requirement	Verification
1. The MCU must be able to move the electromagnet to the inputted location within 10 seconds from any initial position. 2. The MCU must have a mechanism to re-calibrate the location of the motors, should external factors affect the motors' locations.	A. Measure the time taken to move from position $(0, 0)$ on the board to position $(7, 7)$, which is the maximum distance between two board locations. Ensure that this value is < 10 seconds. B. Ensure that the recalibration mode returns the electromagnet to position $(0, 0)$. Repeat this 20 times from different initial locations.

2.5 Voice Processing Unit

The Voice Processing Unit (VPU) takes input from a microphone and uses speech processing software to parse the user's command into specific chess piece movements. The chess logic unit would then use use that command as input and relay to the user whether their intended move is accepted.

For the speech-to-text parsing, we plan on using Google Cloud's Speech-to-Text API [2]. This API requires an internet connection, and therefore the VPU depends on the ICU working correctly and for the user to have an active internet connection.

Requirement	Verification
1. The VPU must be able to accurately parse voice commands of the pattern "D2 to D4", in a quiet room with minimal background noise in accordance with our High Level Requirements.	A. Verify that each starting position is processed correctly, for a total of 64 starting locations (A-H, 1-8). B. Verify that each ending position is processed correctly, for a total of 64 ending locations (A-H, 1-8). C. Perform the above tests in a room at an ambient noise of < 30 dB, or around the noise level of a library [7].

2.6 Internet Connectivity Unit

The Internet Connectivity Unit (ICU) consists of the software and hardware required to interface with the ESP32 WiFi chip [8]. The ICU will allow Chess Express to communicate with other Chess Express units over the internet to enable online play.

Requirement	Verification
1. The ICU must be able to connect to a WiFi network. 2. The ICU must be able to connect to the internet through WiFi.	A. Attempt to connect to a WiFi network. Verify that the chip reports it has connected to the network. B. Ping a known server, such as www.google.com, to ensure internet connectivity.

2.7 Chess Logic Unit

The Chess Logic Unit (CLU) is the primary processing unit for Chess Express. It takes, as inputs, some chess board piece movements and processes them in the context of a game of chess, relaying back to the user whether the move is legal and accepted or otherwise. The CLU also would handle the starting of games as well as the ending of games, and be able to recognize checks and checkmates.

Requirement	Verification
1. The CLU must be able prevent illegal moves as specified by the chess rule set. 2. The CLU must correctly relay a series of movement commands to the MCU in order to accurately perform the requested chess move, given that it is legal. 3. The CLU must allow special moves including "En Passant" and castling.	A. Attempt several (> 10) illegal moves, with at least one per type of piece, during the course of a chess game, ensuring none of the illegal moves are allowed by the software. B. Attempt several (> 10) moves, with at least one per type of piece, during the course of a chess game, ensuring that the physical piece performed the correct move. C. Attempt to perform a legal "En Passant", and separately also attempt to perform a legal castle (both king side and queen side) to ensure they are allowed.

2.8 Tolerance Analysis

One component that is vital to the success of our device is the movement of the motors. The requirements for this motor control unit state that the motors must be able to move the electromagnet to any inputted location within 10 seconds from any position.

The step angle of our motors (NEMA-16 Stepper Motor) is rated at 1.8 degrees per step, with a tolerance of 5% [9]. Based on the following dimensional analysis, this indicates a number of 200 steps per one revolution of the stepper motor.

$$\frac{1\,\text{step}}{1.8\,\text{degrees}} \cdot \frac{360\,\text{degrees}}{1\,\text{revolution}} = \frac{200\,\text{steps}}{1\,\text{revolution}}$$

The circumference of the stepper is 0.005π, and using this information we can calculate the number of steps required to travel a certain distance with the following calculation:

$$d\ \text{m} \cdot \frac{1\,\text{revolution}}{0.005\pi\,\text{m}} \cdot \frac{200\,\text{steps}}{1\,\text{revolution}} = \text{\# of steps needed to travel distance } d$$

We can analyse the effect of the tolerances in the step angle of the motor on our movement by applying a worst case analysis to a certain move set. To move from position (0,0) is a horizontal distance of 15 inches and a vertical distance of 15 inches from position (7,7).

Our worst case analysis will assume that the step angle for every step will be at the upper limit of the tolerance, and therefore the value for the analysis will be 1.89 degrees per step.

$$\frac{1.8\,\text{degrees}}{1\,\text{step}} \cdot \frac{1.05}{1} = \frac{1.89\,\text{degrees}}{1\,\text{step}}$$

Based on this new step angle assumption, we can now conclude the new number of steps per revolution as 190 steps per revolution:

$$\frac{1\,\text{step}}{1.89\,\text{degrees}} \cdot \frac{360\,\text{degrees}}{1\,\text{revolution}} \approx \frac{190\,\text{steps}}{1\,\text{revolution}}$$

We travel 15 inches in both directions, the stepper will ideally need a total of 4852 steps, as shown by the following calculation

$$15\,\text{in} \cdot \frac{0.0254\,\text{m}}{1\,\text{in}} \cdot \frac{1\,\text{revolution}}{0.005\pi\,\text{m}} \cdot \frac{200\,\text{steps}}{1\,\text{revolution}} \approx 4852\ \text{steps}$$

However, 4852 steps with the worst case tolerance assumption results in the motor carrying the electromagnet a distance of 15.79 inches

$$4852\,\text{steps} \cdot \frac{1\,\text{rev}}{190\,\text{steps}} \cdot \frac{0.005\pi\,\text{m}}{1\,\text{rev}} \cdot \frac{1\,\text{in}}{0.0254\,\text{m}} \approx 15.79\ \text{in}$$

On the other end of the worst case spectrum, the step angle will be 1.71 degrees per step, using a similar calculation as we did before

$$\frac{1.8\,\text{degrees}}{1\,\text{step}} \cdot \frac{0.95}{1} = \frac{1.71\,\text{degrees}}{1\,\text{step}}$$

This will result in steps per revolution

$$\frac{1\,\text{step}}{1.71\,\text{degrees}} \cdot \frac{360\,\text{degrees}}{1\,\text{revolution}} \approx \frac{211\,\text{steps}}{1\,\text{revolution}}$$

Taking the same 4852 steps with the rated value and applying our new assumption for number of steps per revolution, we can see that the motor will carry the electromagnet a distance of

$$4852\,\text{steps} \cdot \frac{1\,\text{rev}}{211\,\text{steps}} \cdot \frac{0.005\pi\,\text{m}}{1\,\text{rev}} \cdot \frac{1\,\text{in}}{0.0254\,\text{m}} \approx 14.22\text{ in}$$

We can see that from a starting position of A1, or $(0, 0)$, to a target position of H8, or $(7, 7)$, the worst case scenarios in both the higher and lower ends of the spectrum put the electromagnet 0.79 inches or 0.88 inches away from the center, respectively. Note that these are in both the X and Y directions.

Since each square has a height and width of 2.5 inches, our tolerance for a piece to be ”within the square” is $2.5/2 = 1.25$ inches in both the X and Y directions. Thus, even with worst-case stepper motors, our pieces will still be accurately placed within the target square.

3 Costs

3.1 Labor

The cost of the engineering development for Chess Express is estimated at $50 per person (total of 2 people), 10 hours per week, for the semester (a total of 15 weeks). With an extra 2.5$\times$ modifier for exigent circumstances, this totals to $37500.

In terms of the machine shop labor, the ECE Machine Shop [10] estimated around a week's worth of work for one machinist, which is $50 per hour for 40 hours, coming out to $2000 in machine shop labor.

3.2 Materials and Parts

Table 1: Bill of Materials

Part	**Manufacturer**	**Part #**	**Units**	**Unit Cost**
ESP32	Espressif	ESP32-WROOM-32D	1	$4.50
ARM Cortex-M4	Microchip	ATSAMD51J19A-AU	1	$4.09
NEMA-16 Stepper Motor	SparkFun	ROB-09238	3	$15.95
Stepper Motor Driver	SparkFun	ROB-12779	3	$14.95
12V, 30kg Electro-magnet	Kaka Electric	a2018092615	1	$15.59
BJT	ON Semi.	TIP-122	1	$0.63
Resistors, push buttons, diodes	Digikey, etc.	-	-	$10.00
AC/DC 12V Wall Adapter	Tri-Mag, LLC	364-1282-ND	1	$10.16
Power Barrel Jack 5.5mm	CUI Devices	CP-102A-ND	1	$0.64
Magnetic Piece Feet	Radial Magnets	8012	32	$1.03
X-Y Plotter System	ECE Machine Shop	-	1	$382.00
Total Materials	-	-	-	$553.27

3.3 Total Costs

The sum of the bill of materials (Table 1) and labor costs comes out to \$40053.27. This cost is for the development of the project and the prototyping of 1 unit.

4 Schedule

Table 2: Schedule for the team

Week	Task	Who
2/24/20	Begin design of overall circuit schematics	Rajan
	Choose an adequate microprocessor	Biskup
3/2/20	First draft of PCB Layout	Rajan
	Migrate existing code to work with chosen microprocessor	Biskup
3/9/20	Complete PCB Layout and order before EC deadline	Rajan
	Drop in new microprocessor to existing design and test	Biskup
3/23/20	Verify functionality of the PSU and ICU on delivered PCB	Rajan
	Add WiFi connectivity to the software	Biskup
3/30/20	Verify MCU functionality in hardware	Rajan
	Complete chess logic functionality in software	Biskup
4/6/20	Optimize speed and accuracy of the MCU to meet requirements	Rajan
	Complete the entire user-to-movement software stack, but without speech commands	Biskup
4/13/20	Verify functionality of the voice input stack from microphone to software	Rajan
	Implement Google Speech-to-Text API calls for voice control	Biskup
4/20/20	Mock Demo	All
	Troubleshoot issues before Final Demo; ensure all requirements are met	All
4/27/20	Final Demo	All
	Final testing before demo	All
5/4/20	Final Presentation	All
	Prepare for final presentation	All

5 Ethics and Safety

5.1 Ethics

Due to the use of speech as an input in the project, users may be concerned with the privacy implications of storing their speech data on cloud servers. While Chess Express will not store any of the speech data, since we will be utilizing cloud-based speech-processing companies, there is the possibility of speech data being stored by our third-party partners. The exact details of the data collection will be disclosed to users in a clear and concise manner.

Additionally, we plan to make both the software and hardware design of Chess Express open-source, such that the public may benefit from the design knowledge gained throughout this project, as well as accept criticism and suggestions of our technical work, in accordance with points 5 and 7 of the IEEE Code of Ethics [11].

5.2 Safety

There are several safety considerations in this project. One of the main concerns is the possibility of injury due to the moving parts of the project, namely, the X-Y plotter system with servo motors. Since the servos do not have sensors that detect human hands, it is possible for developers to have injury when working with prototypes of the product if care is not taken to keep extremities out of the movable X-Y area while the prototype is operational. For this reason, several suggested safety precautions will be used when working on the motors. First, we will not leave the motor unattended, and also ensure that we do not use voltage greater than the motors' voltage ratings to power the motors as to prevent injury [12]. Our concern is mostly for the students working on this project, as a final product would have the X-Y plotter system enclosed in a case so that the user would not be able to put their hands into dangerous locations.

Another safety concern originates from the electromagnet. In this project, we plan to use an electromagnet with a holding force of > 30 kg. While the strength of the magnet is severely diminished through the chess board itself, the magnetic field created could still pose a danger to users with pacemakers or implantable cardioverter defibrillators (ICDs). This danger would only occur if a user with a pacemaker or ICD brought the device within 6 inches of the electromagnet itself [13], so in the final product we will ensure that proper disclosure of the magnetic components are included in the User Manual. This is in accordance with point 1 of the IEEE Code of Ethics: "to hold paramount the safety, health, and welfare of the public..." [11].

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