ECE 445
Senior Design Laboratory
Project Proposal

AI Chess Robot with Computer Vision

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Introduction

1.1 Problem

Our project's goal is to address the need for a tangible and interactive chess-playing device, enabling users to play in the physical world against a chess AI rather than relying on digital platforms. Designed for both beginners and advanced players, the chess-playing robot would provide an engaging alternative to mobile apps, allowing for skill development and strategic thinking in a hands-on manner.

1.2 Solution

We plan to develop an autonomous chess-playing robot that eliminates the need for a human opponent by incorporating our own chess algorithm with varying difficulty levels. Using a system involving a magnet and motors beneath the board, the computer opponent's chess pieces will move autonomously while the human player will simply pick up and place their pieces. Then, our robot will analyze the current board position by capturing an image through a camera and will identify all the pieces on the board by identifying each piece's color, associating it with the corresponding chess piece. With this updated board, we will now be able to determine the optimal move based on the chosen difficulty level and current board position. When identified, our code will output the necessary information to the system with the magnet and the motors underneath the board to move its intended piece and wait for the subsequent human player's move (additionally, a button press will "submit" the player's move).

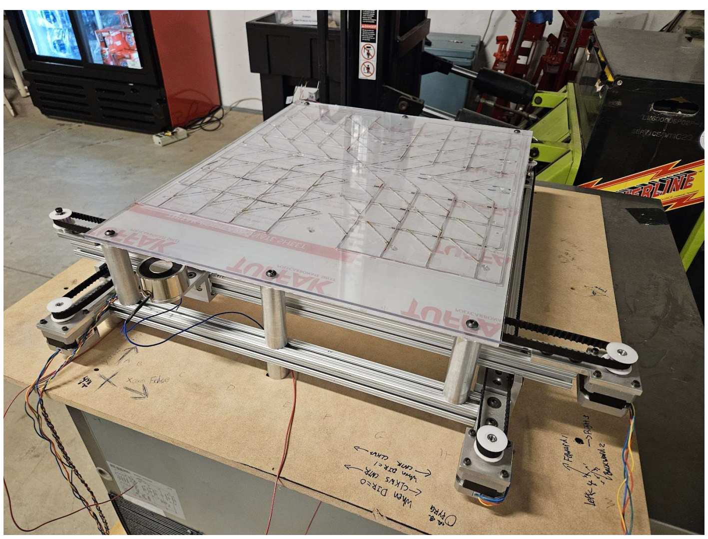

Figure 1. Chess board's rail & magnet system

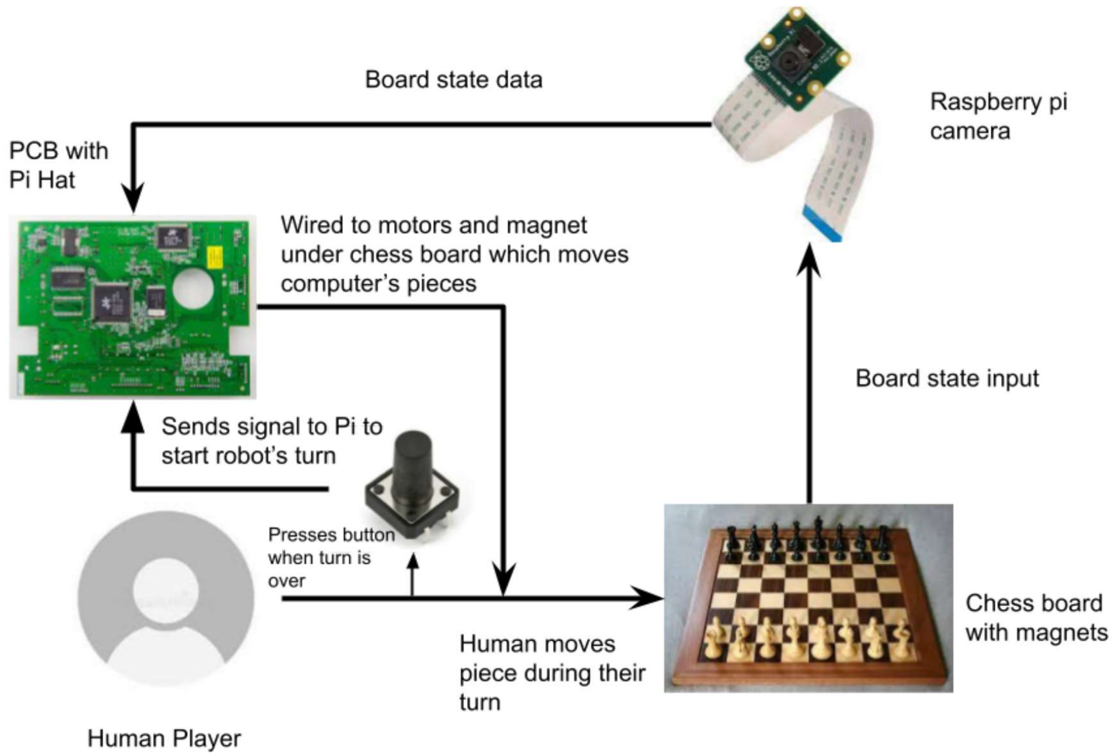

Figure 2. High-level project overview

1.3 High-level Requirements List

- Computer vision algorithm correctly identifies chess piece positions and their identity on the board with 95% ± 5% accuracy.
- Chess AI is implemented in a way that is able to identify when the human player has cheated with 95% ± 5% accuracy.
- Rail and magnet system grabs the intended chess piece to the intended location on the chess board with 95% ± 5% accuracy.

Design

2.1 Block Diagram

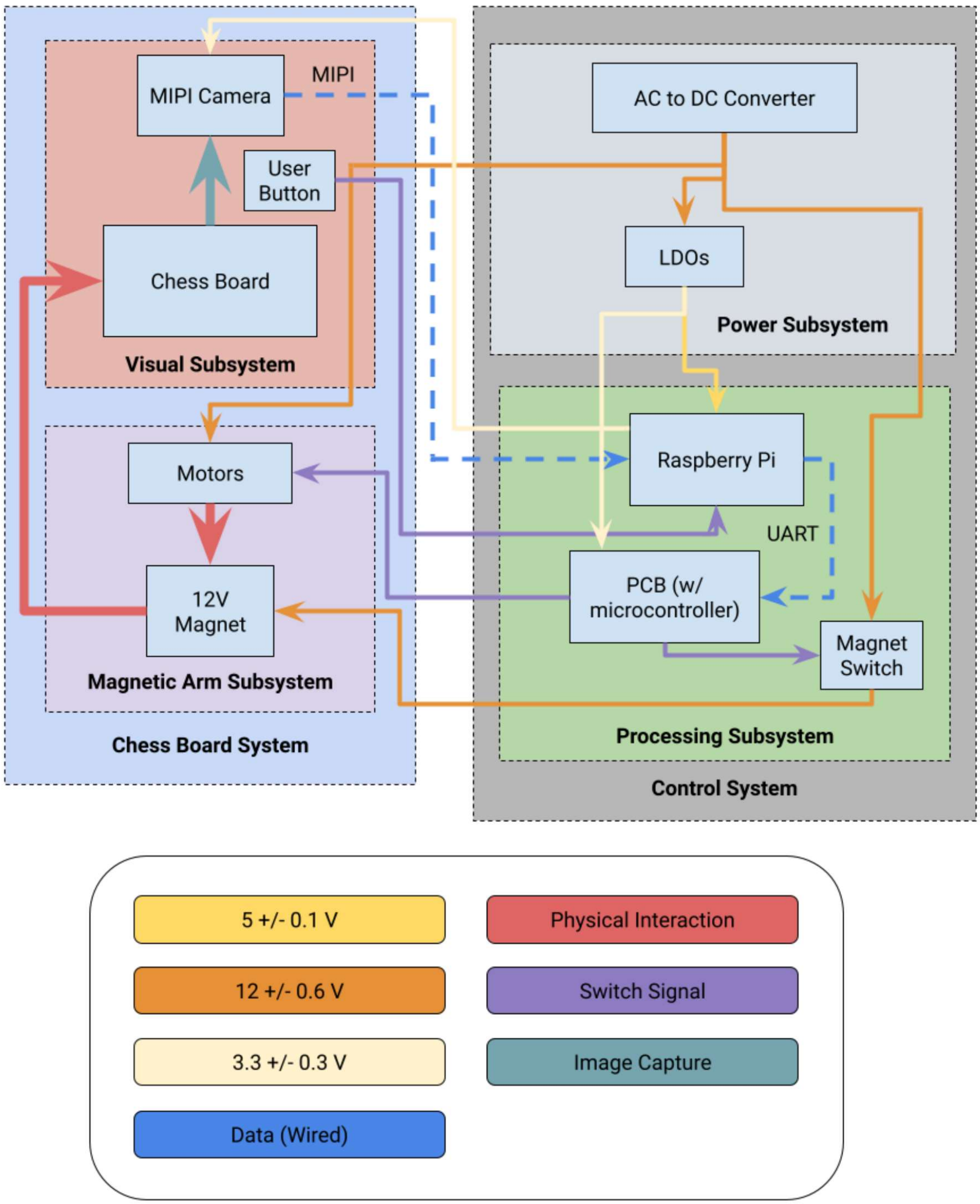

Figure 3. Block diagram of the chess-playing robot

2.2 Subsystem Overview

The design is broken down into four subsystems, which are implemented in hardware and software.

2.2.1 Power Subsystem

The Power System is responsible for powering all electrical and mechanical pieces associated with our project. Such as the motors, magnet, camera, Raspberry PI, and microcontroller. It is comprised of:

- (1) AC/DC Converter Output: 12V ± 0.6V, 5A
- (1) LDO 12V to 5.0V USB-C connection
- (1) LDO 12V to 3.3V

The main source of power will come from a wall outlet where the AC to DC converter will output the 12 volts we need to power our project. The 12V output will be connected straight to the 3 Stepper motors and the Electromagnet. From the output of our 12V to 5.0V LDO, we will connect the Raspberry PI 4 as a type USB-C connection. One final LDO will be used to step down 12V to 3.3V where it will be used as input to our microcontroller.

2.2.2 Processing Subsystem

The Processing System is where all of the image processing, data analysis, path planning, and execution takes place. It is comprised of:

- (1) Raspberry PI 4 Model B
- (1) ESP32 S3 Microcontroller
- (1) Magnet Switch

The system is split up between the 2 components, one is the Raspberry Pi, which will handle the computer vision code we write as well as the python library for the chess AI we use and the microcontroller will be handling the planning and execution of moves once a move has been made by the chess AI. The only communication between these two devices will be telling the microcontroller the best move or if the human player has cheated. Since the Raspberry Pi will handle the computer vision, it needs to be connected to the camera to receive the images, and the microcontroller needs to be connected to the motors and magnet in order for it to execute the moves. Whenever a piece needs to be moved, the magnet will turn on by sending current to it straight from the power input. Whenever we need to turn the magnet off, a switch will cut off the current to the magnet which is controlled by the microcontroller.

2.2.3 Visual Subsystem

The Visual System will serve as the part of the project that the human interacts with and the part where the AI receives its visual input to the algorithm via the camera. The System is comprised of:

- (1) Chess Board created by machine shop
- (1) Arducam for Raspberry PI
- (1) User controlled button

- (32) Colored chess pieces

The chess board will be provided by the machine shop, and it already includes the Magnetic Arm System underneath the board. Additionally, there will be the camera that will be hung above the board looking down that will be used as input to the Raspberry Pi.What the camera sees is what our image processing code will work on and send to the chess AI. There will also be a button that the user will press at the end of every turn to signal that it is the end of their turn and the robot will begin analyzing the board. This will loop until there is either a winner or a stalemate.

2.2.4 Magnetic Arm Subsystem

The magnetic arm system will receive data from the processing system telling the Magnetic Arm system how to move its motors and when to turn on the magnet in order to grab and move the AI's pieces effectively. It is comprised of:

- (3) Mercury Motor SM-42BYG011-25 2 Phase 1.8° 32/20
- (1) KK P-50/27 50 kg Electromagnet

There will be two motors parallel to each other and dedicated to operating in the same 3-dimensional plane. They will be responsible for moving the third motor which will rest perpendicularly on each of the other two motors. This will allow the rail system to move in 4-directions. Resting on the third motor's axis will be the electromagnet that will be fed voltage to turn on and off the magnetism. The magnet will pick up and drop off pieces through the metal pieces that are secured underneath each chess piece. To allow special movements from the knight chess pieces, the magnet will drag pieces along the lines of the chess board to maneuver around them. As a result, the chess board tiles will be around 1½ times larger than the diameter of the magnet.

2.3 Subsystem Requirements

2.3.1 Power Subsystem

- Maintain a voltage of 12 +/- 0.6 V from the voltage regulator
- Output 5 +/- 0.1 V and 3.3 +/- 0.1 V from our LDOs
- Connected to the magnet switch properly in order for the microcontroller to be able to control the magnet being on/off

2.3.2 Processing Subsystem

- Computer vision algorithm correctly identifies chess piece positions and their identity on the board with at least 90% accuracy
- Raspberry Pi is able to communicate the best move to the microcontroller
- Microcontroller plans a path to move the necessary pieces and executes it successfully 90% of the time

2.3.3 Visual Subsystem

- There is an interchangeable sheet for chess board layout on top of the actual board that stays in place
- Camera has clear view of the entire board
- Pictures of the board are able to be sent to the Raspberry Pi

2.3.4 Magnetic Arm Subsystem

- Rail system can move to specific chess board positions with at least 95% accuracy
- Rail system can move from one chess tile to another while holding onto a chess piece without bumping into other pieces
- Magnet will hold on to desired chess piece will 100% consistency and will not grab undesired pieces

2.4 Tolerance Analysis

In order to calculate our tolerances, we need to decide on how we are going to power our chess-playing robot. Currently, we have two methods and depending on TA input we will decide which one to go with for the Design Document. The first is to buy an AC to DC adapter with a 12V 5A output, and the second is to get a high-current low-dropout regulator, which would allow us to use a 20V 12A AC to DC adapter that we already have. We could not find a datasheet for the AC to DC adapter, but we do know that for the 5A LDO we have a tolerance of +/-1% provided by its datasheet (+/- 0.12V).

12V 5A AC to DC adapter:
https://www.amazon.com/ALITOVE-Adapter-Converter-100-240V-5-5x2-1mm/dp/B01GEA8PQA/ref=asc_df_B01GEA8PQA&mcid=e95e9ff1b1eb3b1cbcf17d5e15152945?tag=bingshoppinga-20&linkCode=df0&hvadid=79920803409646&hvnetw=o&hvqmt=e&hvbmt=be&hvdev=c&hvlocint=&hvlocphy=&hvtargid=pla-4583520382284892&psc=1
5A LDO: https://www.microchip.com/en-us/product/mic29500

Other points of information to consider:
- Raspberry Pi 4 has a recommended input voltage of 5.1V with a range of -0.5 to 6V

	Voltage (V)	Current (A)	Min Power (W)	Max Power (W)
Stepper Motors	12	0.33	3.96	3.96
Electromagnet	12	0.83	9.96	9.96
Raspberry Pi 4	5 +/- 0.1	3.0	14.7	15.3
ESP32 S3	3.3 +/- 0.3	0.5	1.5	1.8

Arducam IMX219	3.0 +/- 0.3	0.3	0.81	0.99

Table 1. Power Draw Calculation Table

As shown in Table 1, our current draw will be 4.96A. The 12V 5A AC to DC adapter has a max output wattage of 60W and the LDO has an output wattage range of 59.4 (11.88*5) to 60.6 (12.12*5). Considering the tolerance analysis, both power supply options meet the voltage, current, and power requirements for all components. Therefore, we will be in contact with our TA as well as other TA's for guidance on which will be the better option based on our budget and design plans.

Ethics and Safety

3.1 Overview

As we create the AI chess board, we must worry about the software and hardware components that will make up the project from license coverages to patents and copyrights.

3.2 Concerns about Chess Algorithm

Creating a chess algorithm from scratch to evaluate countless chess moves and how optimized they are for victory can be challenging and time-consuming; it may require time that is out of scope of a semester's worth of time. As a result, we will be assisted by Python's chess library "python-chess" to compute moves and their varying efficiency. Because we are using a library, there is a need to be aware of the potential licensing conflicts. The library has a GPL v3 license which means that it can be involved in commercial use. In accordance to a GPL v3 license (Free Software Foundation, Inc., 2007), but not limited to:

- Terms and Conditions, Section 4, Paragraph 2:
    - You may charge any price or no price for each copy that you convey, and you may offer support or warranty protection for a fee.
- Terms and Conditions, Section 7, Group C:
    - Prohibiting misrepresentation of the origin of that material, or requiring that modified versions of such material be marked in reasonable ways as different from the original version.
- Terms and Conditions, Section 8, Paragraph 1:
    - You may not propagate or modify a covered work except as expressly provided under this License.

3.3 Concerns about Hardware Components

We are utilizing a Raspberry Pi to act as a microcontroller in our project's design and with it comes their terms for usages (Raspberry Pi, n.d.). Under Raspberry Pi trademark rules and brand guidelines, they explicitly mention a list of allowances and prohibitions that deal with Raspberry Pi and all they own. If our project ever decides to commercialize, we will need to contact them to obtain a license. We can use the Raspberry Pi's word mark to refer to products or services, or to describe that there is compatibility between products. We cannot use the logo unless it is connected to sale or distribution of genuine products. The Raspberry Pi marks must be less prominent than what it is used for/connected to.

For the MIPI camera, we can use the product for personal use according to the MIPI Alliance's Frequently Asked Questions for the ECE 445 project, but if any desires for commercialization occur, we will stay within their boundaries for intellectual property and more. Lastly, for the CAD models of the chess pieces, the designs we are most likely going to use can be found here and are under a BY-NC-ND 4.0 DEED creative commons license. Since we are not selling this chess robot, will give credit, and will not distribute our modifications, we are following the terms of the license agreement. If we were to sell this commercially, we would end up hiring someone to design the chess pieces or find a different design online that would allow for commercial use.

3.4 Concerns about Ethical Practices

The Committee on Professional Ethics (COPE) promotes ethical conduct amongst the computing professionals with a code of ethics. In accordance to their code of ethics (ACM Ethics, 2018), some of the guidelines include:

- PRINCIPLES, Principle 1: PUBLIC, Section 1.01:
  - Accept full responsibility of the work
- PRINCIPLES, Principle 1: PUBLIC, Section 1.03:
  - Approve software if it does not diminish the quality of life, privacy, or harm the environment
- PRINCIPLES, Principle 1: PUBLIC, Section 1.06:
  - Be fair and avoid deception in all statements, particularly public ones, concerning software or related documents, methods and tools.
- PRINCIPLES, Principle 3: PRODUCT, Section 3.02:
  - Ensure proper and achievable goals and objectives for any project on which they work or propose.
- PRINCIPLES, Principle 5: MANAGEMENT, Section 5.01:
  - Ensure good management for any project on which they work, including effective procedures for promotion of quality and reduction of risk
- PRINCIPLES, Principle 6: PROFESSION, Section 6.06:
  - Obey all laws governing the project and its components

We will uphold the code of ethics to the best of our ability and not tarnish the University of Illinois Urbana Champaign's reputation.

References

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”Frequently Asked Questions | MIPI,” www.mipi.org. https://www.mipi.org/resources/frequently-asked-questions#f

GNU general public license v3.0. Choose a License. (2024, February 14). https://choosealicense.com/licenses/gpl-3.0/

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“Stepper Motor with Cable - ROB-09238 - SparkFun Electronics,” www.sparkfun.com.
https://www.sparkfun.com/products/9238