AN-NAJAH NATIONAL UNIVERSITY

FACULTY OF ENGINEERING
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COMPUTER ENGINEERING DEPARTMENT

Hardware Graduation Project: DeepBlack

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Dedication

We would like to thank everyone who supported us those who this work won't be done without from friends, family, and those people who made it their life's journey to write articles that help those who are thirsty for knowledge.
A special thanks to our friend Abdulrahman, who always gave critical input.

DISCLAIMER

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Contents

List of Figures

Abstract

Bringing chess to the physical world, defeating loneliness, and helping players train and be mentally prepared to play on an actual board rather than a mobile app or website are the pillars of this project.
Features the application includes :

- the ability to move the pieces.
- Provide a built-in timer with a button to indicate the turns.
- A warning indication in case an illegal move occurred.
- A sign to show the end of the game.
- Provide a way to let the robot automatically detect the moves.

1. Introduction

1.1 Problem Statement

The "DeepBlack" project aims to solve many problems for certain groups of society, the most prominent of which are:

1. Professional chess players who lack coaches due to high hiring costs.
2. Parents who want to teach their children the game of chess, but they are not good at it.
3. The people who want to relax, get away and get disconnected from society who lack stress-free entertainment without modern screens and companions which all other solutions require.

1.2 Significance

The main objective of the project is to build a robot capable of playing chess at a high level against a human being. The project contributes by providing training for chess players and preparing them psychologically by playing on the chess board instead of playing on the phone or computer, in addition "DeepBlack" serves the field of entertainment providing a playmate for those who suffer from loneliness.

1.3 Objectives and Scope

The purpose of the smart robot "DeepBlack" is to find a fun and practical playmate, and therefore it required the following services to be available:

1. The ability to understand the current state of the chessboard, and this is done through the processing of digital images.
2. Artificial intelligence to figure out the best counter move.
3. The robot's ability to move the pieces over the board.
4. Notify the human opponent if he makes an incorrect move.
5. Informing the human opponent about the end of the match, whether a draw or victory for one of the opponents, "checkmate".

1.4 Report Organization

- **Second chapter:** In this chapter, we covered the important subjects we learned previously, as well as the external courses and the primary constraints and obstacles we encounter while working on the project.
- **Third chapter:** The literature review chapter is a summary of previously published works that are similar to ours in concept. we discuss their qualities and weaknesses, as well as what sets us apart from them.
- **Fourth chapter (Methodology):** We talked about the mentality through which we built the application, in addition to the features that we offer and the technology's used.
- **Fifth and final chapter:** we talked about the results, as well as the lessons we learned from working on the project and future developments.

2. Constraints and Earlier Coursework

2.1 Constraints

2.1.1 Uncertainty of Image Processing

The application requires a good understanding of image processing which even when present may not give the required output, lighting and various other changes affect the process which quickly becomes too big to be a part of the process and becomes a graduation project of its own.

2.1.2 Inexperience

We made different simple demos and tests to make sure that the concept which we are aiming for is achievable. But all of these tests took time which we could have invested in other things.

Even after all the tests, research and time spent, we still made some decisions which are considered safe bets because we could not test certain parts, and we could not afford the whole project failing.

2.1.3 Lack of funds

Some solutions needed more money to make, which would make the project too expensive and unaffordable, especially at small scale.

2.1.4 Lack Of Time

Time is the most important factor in any project. Researching, communicating, testing, developing, understanding the requirements, planning, and the wasted time due to inexperience, all of these things require time which, no matter how tiny, quickly adds up.

2.1.5 Lack Of Mechanical knowledge

The project has a lot of mechanical parts which we partially figured out but even after all the research, an experienced mechanical engineer was needed to answer some questions and plan the execution properly.

Some parts which are 3D printed needed some balancing and mechanical knowledge to fix, so the ideas and the initial designs were presented to the engineer to modify.

2.1.6 Lack Of Tooling

Some special tools were needed to cut, prepare and assemble all the parts which are not available or too expensive for home use, so a specialist was required to help with it.

Some parts required a 3D printing machine to print.

2.1.7 Lack Of Market Knowledge

Some parts are not just store bought but are custom-built to a given specification, so more research was needed and more planing to get the correct specifications to give a correct order.

2.1.8 The need of a massive AI/Math knowledge

AI was used to play against the user, and calculating the value (worth) of a move in chess needs a lot of research that could easily become a graduate research topic, so a tested researched approach was taken and modified to our needs, but the AI knowledge was still needed to not ruin the researched approach.

2.2 Earlier coursework

2.2.1 Digital Image Processing

The course was a big part of the project, as almost all the steps taken to handle the images to get what piece the user moved were from this course, let alone the important lifelong concepts that were taught.

2.2.2 Microcontrollers and PIC

All the basics of the Raspberry and Arduino like basic serial communication were taken in these courses.

2.2.3 AI

The main part of the project is the brain which considers the human move and counters it with its own, an algorithm was taken to look ahead to the next few possible moves and evaluate them to pick the best move from the list.

2.2.4 Operating Systems

We used the Raspberry Pi OS, which we flashed on the Raspberry and used the Linux command line to install libraries and packages needed for the project. All those are some things discussed in the course.

2.2.5 Networks and Communication

We made the Raspberry have a static IP that connects to the hotspot of one of our laptops that shared the Wi-Fi connection with it, and we connected the two laptops to the same network and accessed the Raspberry through an ssh connection all that couldn't be possible without the Networks and Communication courses.

2.2.6 Critical Thinking and Research Skills

The research and the writing of this report were all taught in this course, and it's one of the few non-technical courses which also is life long.

3. Literature Review

When building this project, our focus was to build a game that could be used without a smart device or a connection and without a partner to play against, so three main types of chess games come to mind, and we list them as follows:

3.1 Regular Old Chess

Chess, as we know it today, was born out of the Indian game Chaturanga before the 600s AD. The game spread throughout Asia and Europe over the coming centuries, and eventually evolved into what we know as chess around the 16th century[**historyOfChess**].

Chess could have the power to "materialize" some mathematical abstract concepts so that children can learn and manage them much more easily [**MathematicalChess**], so a lot of parents like to encourage the children to learn and play chess but sometimes the parents themselves can't play or are not free to play, and regular plain old chess is a two player game that requires a companion to play, so we decided to make a smart electrical companion to play against.

3.2 Virtual Chess

As one of the main kinds of chess, which only requires a device and sometimes a connection to work, it may seem that it is the better and easier solution, which is partially true, but it also comes with many negatives mainly that virtual chess is simply virtual and not real, so it does not give that wonderful feeling of moving chess pieces and the biggest problem which is the use of a screen that has many things that could distract the player other than the good deal of research that indicate that time spent engaging in sedentary screen-based activities was significantly associated with severity of depression and anxiety, after controlling for relevant covariates. Regarding the type of screen time behavior, video game playing and computer use were significantly associated with depressive symptoms, while only video gaming was significantly associated with anxiety, [**MARAS2015133**] with research demonstrating that excessive video game playing and internet use were significantly associated with sadness and suicide. [**Messias2011SadnessSA**].

So to help limit this effect we created this project which does not require a visible device to operate.

Despite this, there is a great trend these days from documented federations to hold tournaments online To make it easier for the players and reduce travel costs, and not to forget that we are in light of a pandemic such as Corona, which Which requires physical distancing, and thats why the new trend of virtual chess appeared.

as a solution for online chess problems, two deepBlack robots can be made so that the first player plays in his house and the piece moves as well on the board in front of the other player wherever they are, which brings life back to the game of chess while gaining all the benefits that virtual chess brings.

3.3 Similar Projects

Our project is not unique, as we are not the first people to think of removing the need of a companion for regular chess, but we are making this project as a proof of concept and that we could make it through a different approach and limited resources with the same effectiveness. Square off is one of those competitors that uses a mobile app to add many features but as we are trying to ditch smart devices, we found that it defeats the purpose of our project, also it was a startup that had many funds so a lot of the research and development that was done could not be replicated in a small

amount of time or with few resources, in addition we are using image processing to get the board state which is a completely different approach.

4. Methodology

This section provides detailed information about the methods and techniques we used to develop the robot, starting from designing and assembling the mechanical structure to image processing walking through chess AI and how they are linked together to reach the final product.

4.1 Choosing the idea

As always choosing an idea is an important part of any project if not the most important, when we were searching for a project to build we found a lot of ideas some of which are not fit for a graduation project and some others that we could not feel into it as there was no "Click", until one day we were at the university and found someone holding a chessboard looking for an opponent, so we laughingly discussed how wonderful it would be if the pieces were smart enough to play on their own, and it clicked right there it was our "Eureka" moment as one of us loves playing chess and the other is fascinated by the game, it's complexity and the different possible combinations, so a quest to make something that thinks and moves the chess pieces began, the first idea was to build an arm, but we quickly figured that it was a massive mechanical problem not a computer's and the thing that we hated is the massive bulky arm that would keep hanging around, and it also loses the wow factor of the pieces moving on their own which we set out to achieve, and the current solution was forming throughout the process.

Our solution was inspired by the CNC machine and the 3D printer, the two of which have a basic concept of a bridge consisting of three metal rods in the shape of "I" and a belt connected to a motor on top of each rod, the two parallel rods are stationary and act as a track, and the third rod is moving on the track, the rod also has a part specific to the machine that moves on top of it, the rods, belts, and motors make an XY movement possible. We used the same concept and used an electromagnet as the part specific to our machine, so the electromagnet activates when it reaches under the piece we want to move, moves and drags the piece with it until it reaches the destination where it deactivates.

4.2 Mechanical Part

The mechanical part of the project is the part responsible for moving the chess pieces, and this requires the presence of motors, Belts, and others to generate movement in cooperation with a controller to direct it. To do this, it requires performing the following steps :

4.2.1 Mechanical Design

The first step is to design the structure that will give the agile movement and provide accurate and stable information about where the pieces are and how they move. This was done using the "SolidWorks" program, and we found during the design stage that there was a need to print some pieces (3D Printing) and we got help from specialists to print them.

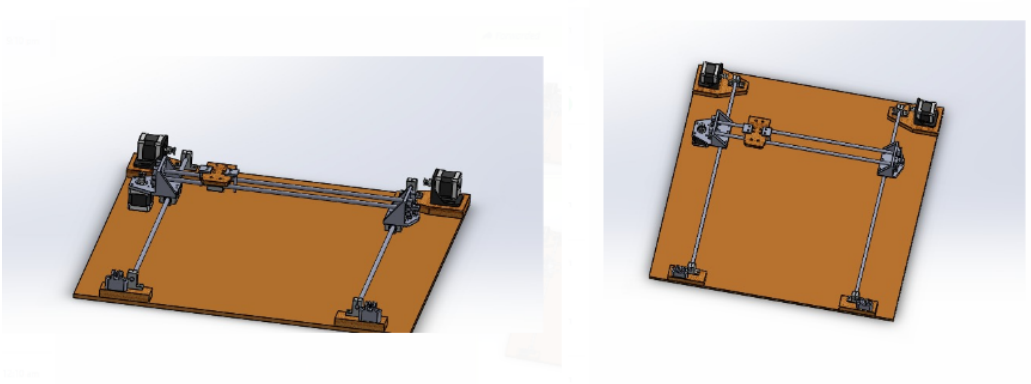


Figure 4.1: Mechanical Design

4.2.2 Assembling

It is the part that requires the use of screws and screwdrivers to assemble the pieces together, and this must be done accurately in order for the project to work as required.

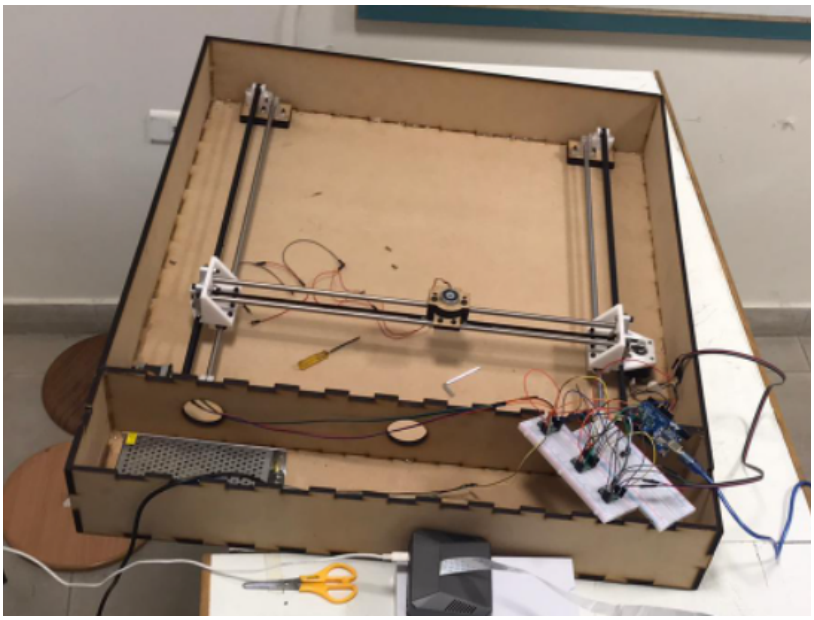


Figure 4.2: Mechanical Body

At this point, we also tested the agility to make sure that everything was moving freely. In addition to testing the ability of the magnet to move the pieces, several models of board materials and sizes of pieces were used to verify stability, and we end up using glass with a thickness of 4 mm.

Some parts required special tools to cut and handle, so a specialist was required.

4.2.3 Parts

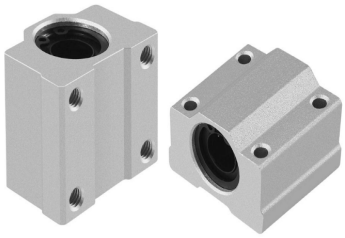
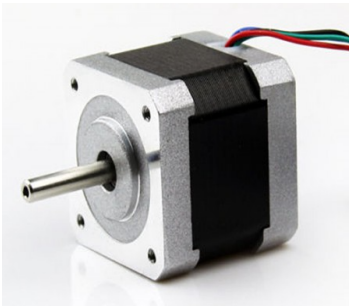
Item Name	Item Image	Quantity
Timing Belt		1
Motion Ball Bearing		5
Stepper Motor		3
Stepper Motor Holder		2
Pulley		2

Table 4.1: Project Parts

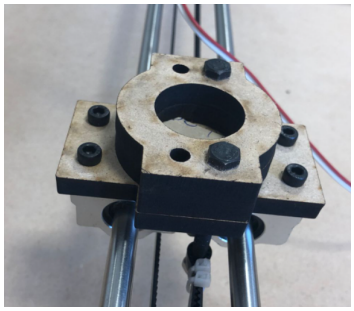
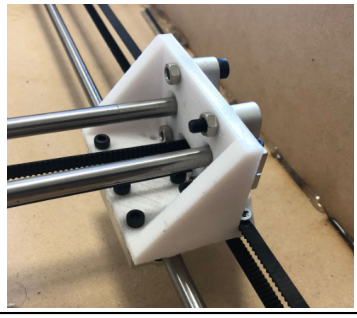
Item Name	Item Image	Quantity
Metallic rod		4
Rod Holder		4
Moving Rod Holder		4
Magnet Holder		1
3D Printed piece 1		1

Table 4.2: Project Parts

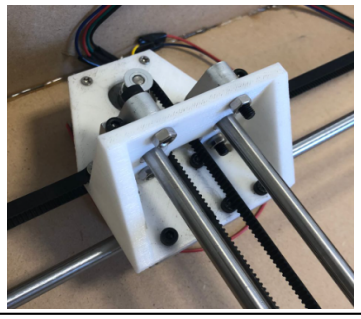
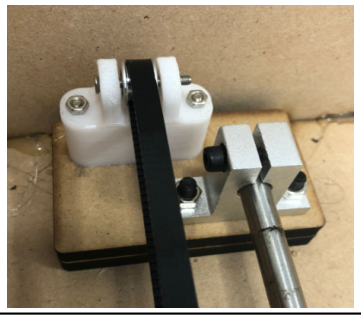
Item Name	Item Image	Quantity
3D Printed piece 2		1
3D Printed piece 3		2

Table 4.3: Project Parts

4.3 Controller Part

The controller part is responsible for directing the mechanical part and providing it with power, and it includes two main parts :

4.3.1 Arduino

We could have used the raspberry as a complete controller, but we separated the motors and electromagnet for two reasons, one of which is safety and the other is the separation of responsibilities so that the team can work separately.

4.3.1.1 Parts

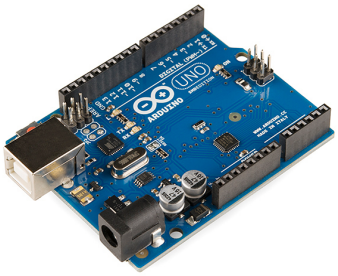
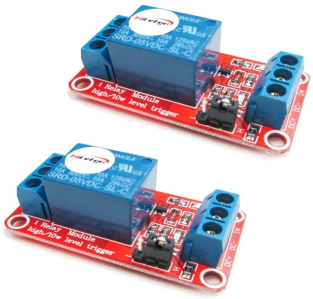
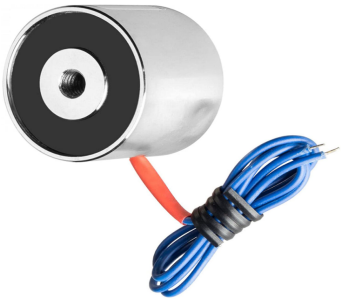
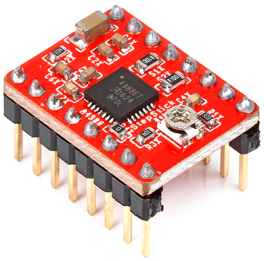
Item Name	Item Image	Quantity
Arduino UNO		1
Relay		1
Electromagnet		1
A4988 Driver		3

Table 4.4: Parts

4.3.1.2 Driving Motors

The motors are controlled using the A4988 driver, which is an inexpensive and readily available microcontroller that offers many features.

Stepper motors have 1.8° steps meaning 200 steps per revolution, referring to full steps. Higher resolutions are possible with a micro-stepping driver, such as the A4988, because intermediate step locations are supported. This is accomplished by supplying intermediate current levels to the coils.

In our case, we needed the most precise way, so we drive the motors in 1/16-step mode that will give a 200-step-per-revolution motor 200×16 micro-steps each revolution. and that is done by connecting MS1,MS2 and MS3 to High voltage, after taking the pulley and belts in consideration that moves 32 mm-per-revolution, so we end up with 100 steps per 1 mm.

$$(200 * 16)/32 = 100$$

Here is the circuit:

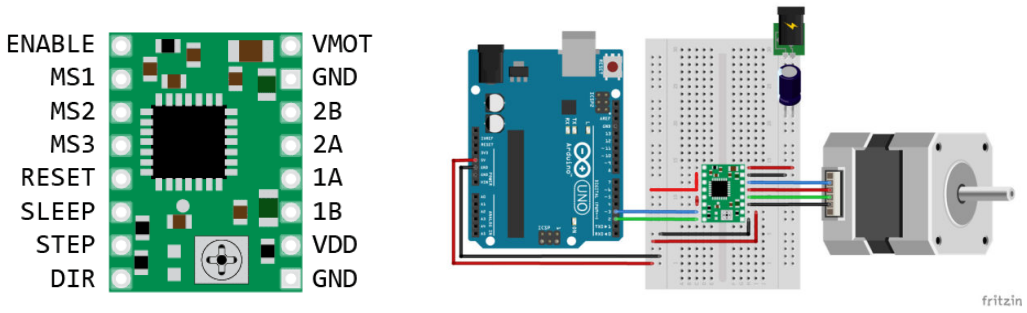


Figure 4.3: Driver Circuit

To control the motor, we give it two input signals, the direction indicating the spinning direction and the step pulse which drives the motor to rotate.We have a y-axis motor which is responsible for the horizontal movement and two x-axis motors that responsible for the vertical movement

4.3.1.3 Controlling Electromagnet

The magnet is responsible for moving the pieces from under the chessboard, and this requires it to work at the right time when it is specifically under the piece to be moved, and it is activated using the Arduino and Relay.

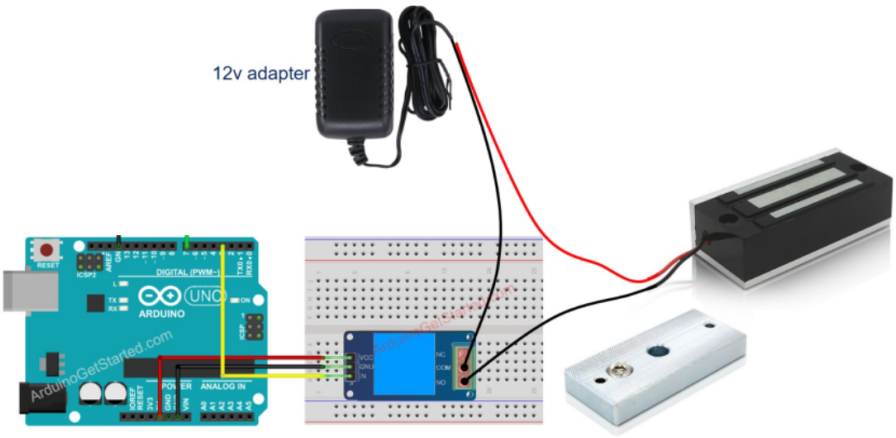


Figure 4.4: Relay Circuit

4.3.2 Raspberry Pi

We used Raspberry Pi 4 for image processing, as well as writing the AI code in Python. The Raspberry has 8 megabytes of RAM and Linux 10 as operating system.

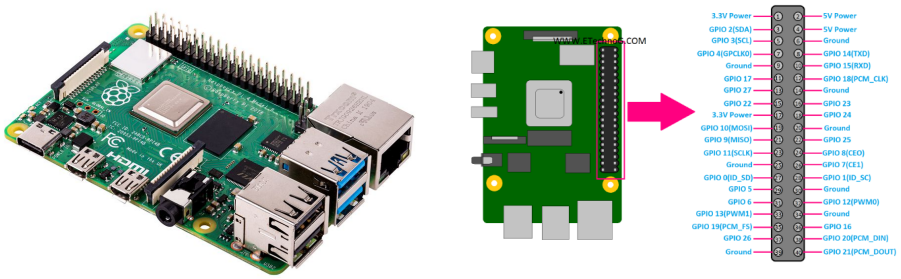


Figure 4.5: Raspberry Pi4

4.3.2.1 Image Processing

The goal of the digital image processing part is to know the location of the piece that the opponent moved to be transferred to the AI, where it responds to it and directs the motors to shift the arm in the appropriate direction.

The program takes a picture of the board before the movement and another after the opponent's move, and then it searches for the board to separate it from what is around it, and by using canny algorithm the edges are captured in the image, followed by the use of python OpenCV contours to search for the largest square in the image, which contains the chess board, and then select The corners of the board in order to convert it into a square image with dimensions of 500 $\times$ 500 pixels using wrap. And we reach the final stage in which the two images are subtracted to find the location of the different in the images, from which to deduce what the piece and its movement are.

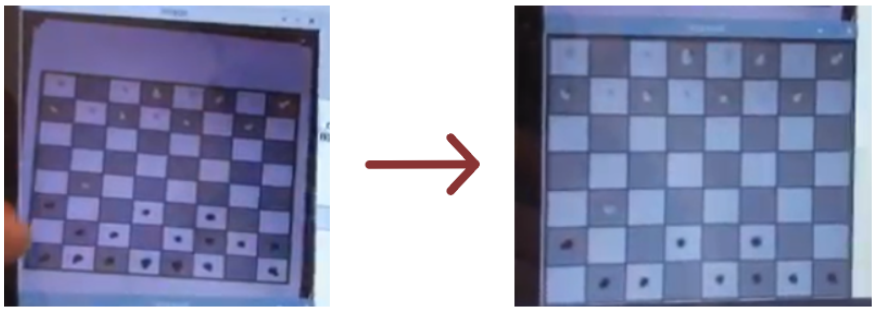


Figure 4.6: Image Processing

4.3.2.2 AI

The AI used in this project uses an algorithm that "sees" a few moves ahead and evaluates the game state, based on this evaluation, it chooses one of the possible moves that leads to a better state. The alpha-beta algorithm is a very famous algorithm based on the Min-Max algorithm which in essence is Maximising the effectiveness of ones moves while Minimising the opponent's, there is a lot of research on using different ways to build a chess AI engine, **sabatelli2018learning** suggests using deep neural networks and limited lookahead to evaluate positions because despite what most people think, highly rated chess players do not differ from the lower rated ones in their ability to calculate a lot of moves ahead. On the contrary, what makes chess grand-masters so strong is their ability to understand which kind of board situation they are facing very quickly.

We chose a simple approach that has a simpler evaluations, it gives certain points for the position of the chess pieces on the board, for example it gives a 0 for a Queen in a position but a 10 to a Rook in that same position, those numbers are given based on experience and trial and error, then we sum these points to get a board evaluation.

So by the end of it all the AI gets the move from the image processing picks a move by looking two steps ahead and choosing the best board that could maximise it's position while minimising the opponent's, then sends the move coordinates to the motors so they could move the piece.

5. Results And Discussions

5.1 Movement

The initial goal we set to complete was to give the user the impression that the chess pieces are smart and moving on their own, which was achieved wonderfully, the feeling the user gets when the piece moves is undescribable.

5.2 Ai

The Ai is a simple solution, but we sadly could not build from scratch as it requires extensive math knowledge and a lot of testing to catch all the bugs and our math and chess knowledge are sadly not up to bar.

5.3 Image Processing

The image processing was the only part that still leaves something to be desired, as it is not 100% accurate all the times.

5.4 Final Results

The final result is a great project that works well in most cases that we tested, and achieves all the goals that we set out to achieve.

6. Conclusion

6.1 Summery

We built a good smart mechanical game that added a twist to regular chess, the project may need some improvements that we could not do either because of limited time,resources or even knowledge, but the most important part is that we completed a working project that has a lot of potential for improvements and we hope it's a step in the right direction, our long term vision of this project is that it is the first project of a series of projects that add to it and improve it, and we would love it if someone made the project and added a little twist to it as a future computer engineering hardware project.

6.2 Improvements

Some improvements are needed in the image processing section as it is not 100% accurate all the times, make the motors move out the "dead" pieces, tidy up the project, make holes to wire everything nicely and finally make a proper place to put the camera.

6.3 Future Work

6.3.1 Different Games

Make the system support different games like checkers and maybe even Chinese GO.

6.3.2 Make it compact

The project is currently bulky as it's only for demo, and we were too afraid of anything failing that we purposely avoided making it smaller as to eliminate any measurement errors.

6.3.3 Make it faster

We are currently using the slow but precise option in the motors as a proof of concept, but we could make it faster but less precise, and that would require some various adjustments.

6.3.4 Add difficulty levels

Currently, only one difficulty level is present, but this is not the final goal as we are planning to support different levels.

6.4 Outcome

We made a fun smart game system that works well, not reliant on a smart device nor on a connection, so it could be taken anywhere to have some quit and comfort out of the usual rush of daily life and without the usual pressure of communication.