

# Boxing Training Robot

Presented in partial fulfillment of the  
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Engineering



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Hardware Project

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## Disclaimer

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# Nomenclature

## Abbreviations

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Abbreviation Definition	
OpenCV	Open-Source Computer Vision Library
IC	Integrated Circuit
AI	Artificial Intelligence

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## **Abstract**

This report presents the design and implementation of a boxing training robot with AI capabilities for punch detection and skill enhancement. The objective was to create a versatile system that provides real-time feedback and guidance to users practicing their boxing techniques.

The system offers two modes: Training Mode for free practice with AI feedback on speed, accuracy, and form, and Vision Mode to simulate real-time punches when the user assumes a guard position. Software and hardware integration techniques ensure seamless communication.

Experimental evaluations confirm the system's effectiveness, detecting punches in real-time and providing valuable feedback for an immersive training experience.

Additionally, Vision Mode utilizes AI to detect the user's guard position, triggering the robot to simulate punches in real-time. The project demonstrates effective software and hardware integration, ensuring seamless communication among components. Experimental evaluations validate the system's punch detection accuracy and its ability to provide a valuable training experience.

## 0.1. Problem

The problem at hand is the lack of technological development in boxing training tools compared to other sports, such as football, which have seen advancements like AI-based outcome prediction programs and home-use robotics. Despite being a global sport, boxing has not received the same level of attention and investment, resulting in a technological disparity. To address this gap, the purpose of this project is to introduce digital image processing technology and other innovative methodologies into a boxing training robot, aiming to enhance the training experience and bridge the technological divide in boxing.

## 0.2. Objectives

The primary objective of this work is to develop a boxing training robot integrated with digital image processing technology and other innovative methodologies. The project aims to address the existing technological gap in boxing training tools and revolutionize the way individuals enhance their boxing skills. The specific objectives of this work are as follows.

## 0.3. Significance of The Work

the work presented in this project holds significant importance in the field of boxing training and sports technology. By bridging the technological gap, empowering athletes, and promoting accessibility, the developed boxing training robot offers a promising solution for enhancing boxing skills and performance. Furthermore, the project's contributions to the advancement of AI and sports training systems highlight its potential impact on the broader sports industry.

## 0.4. Organization of The Report

The report starts with the [First Chapter, Introduction,] which provides a background on the research. **Chapter 2: Constraints and Earlier Coursework,] which shows how constraints were overcome and resolutions were found, and Previous courses that assisted with the development of this application.**

There is then a [The Third Chapter, Literature Review,] which establishes and clarifies understanding of the current research and any similar projects conducted.

Then The Fourth Chapter, Methodology, that includes a systematic plan to re- solve the problem, the process of building this robot, software tools, and hardware equipment.

Next, [The Fifth Chapter, Results and Discussion] summarizes the data collected, their statistical treatment, and compares them.

Finally, [The Sixth Chapter, Conclusion and Recommendation,] will show the final project summary, with all the lessons learned along the way. This section will also introduce some of the features and subsystems that can be added for improvement and enrichment.

# 1

## Constraints and Earlier course work

### 1.1. Constraints

- The timely delivery of hardware components, such as the Servo motors, was crucial for the progress of the project. And the delay in the delivery of such components affected the project's timeline and overall implementation.
- Another factor that limits our project is the availability of hardware resources. Due to their limited availability, we may face challenges in terms of functionality of the boxing training robot. We must carefully optimize the use of the available hardware resources to ensure the project's successful implementation.
- Time Limit: During the making of the project, we faced many unexpected problems which made the completion of the project in the given timeframe challenging.

### 1.2. Standards

In the development of the boxing robot, adherence to relevant engineering standards and codes was paramount to ensure the safety, functionality, and ethical considerations of the system. The project followed specific standards and guidelines to address various aspects of the design and implementation process.

The International Federation of Robotics (IFR) Safety Standards. These standards provided guidelines for ensuring the safety of human-robot interactions, Furthermore, electrical and electronic components utilized in the robot's control system were selected and integrated following the guidelines set forth by relevant standards, such as the International Electrotechnical Commission (IEC) 60601-1 standard for medical electrical equipment. These standards ensured that the electrical components used in the robot met the necessary safety and performance criteria, reducing the risk of electrical hazards and ensuring reliable operation.

### 1.3. Earlier Course Work

- **Micro-Controllers:** Through our study of micro-controllers, we acquired a solid understanding of how to effectively control the hardware components.
- **Image Processing:** Our course on image processing has been influential in the development of this project. It has provided us with a comprehensive understanding of digital image analysis techniques and algorithms.
- **Artificial intelligence:** This course has enabled us to implement AI-based punch detection and training capabilities in the robot. Leveraging concepts such as pattern recognition

# 2

## Literature Review

Boxing, a longstanding sport known for its physical demands and the need for skill and athleticism, has recently witnessed a surge in interest regarding the application of artificial intelligence (AI) to enhance performance. AI has emerged as a powerful tool for analyzing boxing-related data, including video footage of fights, to uncover valuable patterns and trends. These insights can be utilized to refine boxers' techniques and strategies, offering a competitive edge. Additionally, AI has paved the way for the development of virtual sparring partners, as demonstrated by a study conducted by researchers at the University of California, Berkeley (Farhadi, 2018) (1). These virtual opponents possess the ability to simulate various fighting styles, enabling boxers to train against a diverse range of opponents.

Furthermore, a study by researchers at the University of Oxford showcased the potential of AI in predicting boxing match outcomes by analyzing video footage of professional bouts (Cowley, 2017) (2). The researchers successfully identified patterns within boxers' techniques that could be indicative of their chances of winning. These advancements in AI utilization have opened up exciting possibilities for revolutionizing boxing training methods and enhancing performance.

In line with this trend, the study titled "A fast humanoid robot arm for boxing based on servo motors" (Lin, et al., 2021) (3) demonstrated the application of robotics in boxing training. The researchers designed a 4-degree of freedom (DOF) humanoid robotic arm capable of replicating essential boxing gestures, such as jabs, hooks, and swings. Servo motors were employed to facilitate swift arm movements, resulting in improved training experiences. This research showcases the potential of integrating robotic technology into boxing training to automate certain aspects and enhance the learning process for boxers.

Overall, the integration of AI and robotics into boxing holds promise for transforming the sport, offering novel training methodologies, and advancing performance optimization. By harnessing the power of AI in data analysis and the capabilities of robotics in physical execution, boxers can aspire to achieve greater levels of success and skill mastery.

# 3

## Methodology

In this chapter, we will explore the system's design, the components that were used to achieve it, as well as the development process and the output at the conclusion of that process.

### 3.1. Overview of The System

In this research, the boxing training robot with implemented AI is designed to provide users with an interactive and efficient training experience

Hardware and software were integrated to produce the project's final result. Overall, the system offers users a comprehensive and customizable boxing training experience. By combining hardware components, and AI capabilities, the system aims to enhance boxing skills, improve technique, and provide users with a valuable tool for their training sessions.

### 3.2. Hardware Components

This section discusses the design and tools used to show the full process of Boxing Training Robot development and its basis.

1. Servo Motors: 10 Kg Metal Gear Servo motors (Mg995):  
Servo motors are used for the robot's mechanical movements, enabling precise control and motion in response to user interactions.

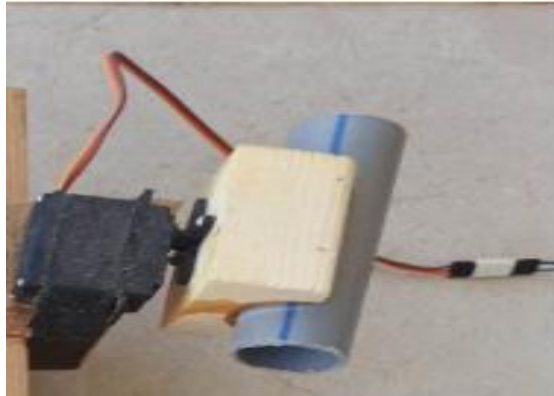


Figure 3.1: Servo motor

2. Camera:

The OpenCV AI KIT camera is employed for capturing video footage of the user's movements, which is essential for analyzing and detecting punches during training sessions.



Figure 3.2: OpenCV AI KIT

3. MH-Sensor-series: F249 4 PIN Infrared Speed Sensor:

The sensor is utilized to detect the speed and motion of the user's arm during boxing exercises, contributing to accurate punch recognition.



Figure 3.3: MH-Sensor-series: F249

#### 4. Raspberry Pi 4:

The Raspberry Pi 4 micro-controller serves as the main control unit, coordinating the operations of various hardware components and running the necessary software algorithms.

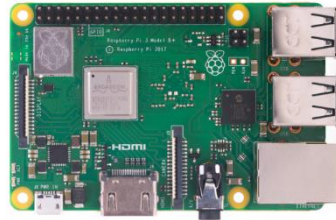


Figure 3.4: Raspberry Pi 4

#### 5. Cooler Jacket:

A cooler jacket is installed to maintain the optimal operating temperature of the Raspberry Pi 3, ensuring its performance and longevity.

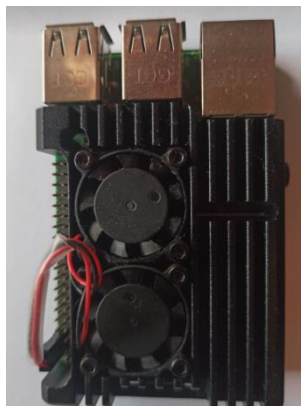


Figure 3.5: Cooler Jacket

#### 6. Arduino Mega 2500 micro-controller:

The Arduino is utilized to control specific hardware functions and assist in the integration of different components.

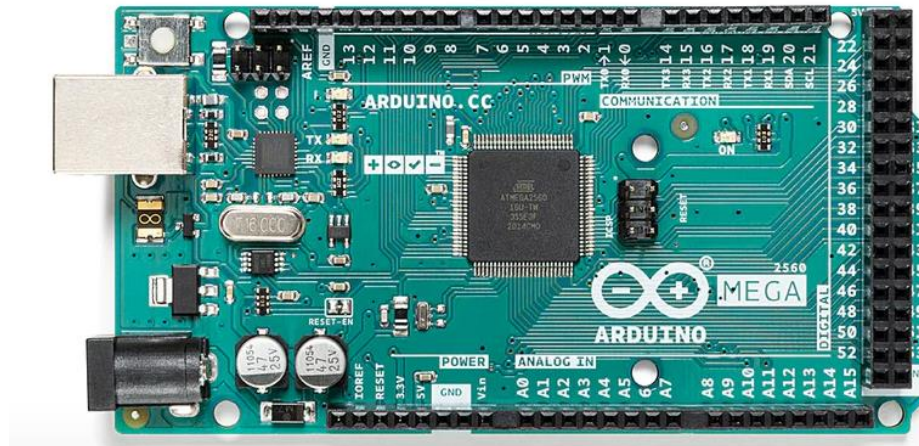


Figure 3.6: Arduino Mega 2500 micro-controller

#### 7. Wooden Frame:

A sturdy wooden frame serves as the foundation for the boxing training robot, providing structural support and stability.

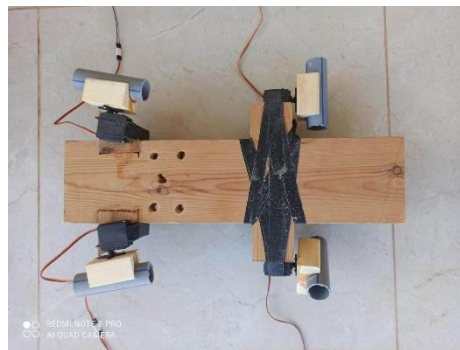


Figure 3.7: Wooden Frame

#### 8. Bluetooth Module HC-05:

In our Boxing Robot; a Bluetooth module HC-05 was used to interact with the system and send commands wirelessly.

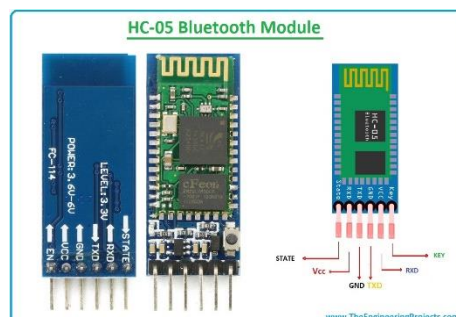


Figure 3.8: Bluetooth module HC-05

### 9. Bluetooth speakers:

We installed Bluetooth speakers to enhance the user experience and generate interactive sound effects

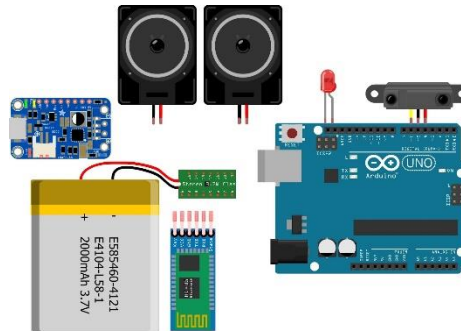


Figure 3.9: Bluetooth Speakers

### 10. LCD with I2C module:

An LCD was used to display various messages and feedback to the user

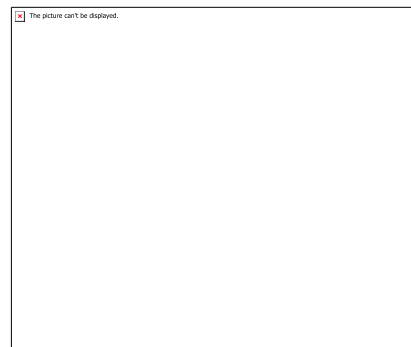


Figure 3.10: LCD with I2C module

## 3.3. Software

The software for the boxing training robot project was developed using Python programming language along with various libraries, including DepthAI and OpenCV. These libraries provided essential tools and functionalities for image processing, pose estimation, and real-time analysis.

The software implementation encompasses two main modes: Training Mode and Vision Mode.

1. **Training Mode:** In this mode, the software allows users to practice their punches and improve their boxing technique. The DepthAI library is utilized for pose estimation, enabling the system to track the user's body movements and detect key joints and landmarks. By analyzing the position and motion of the user's arms, the software determines the type of punch and provides real-time feedback on technique and form. The OpenCV library assists in capturing video footage from the camera and processing it for punch recognition and analysis.
2. **Vision Mode:** This mode focuses on detecting the user's guard position and initiating a response when their arm moves. The software utilizes the DepthAI library to track the user's arm and hand movements. When the system detects a specific arm motion indicating a punch, it triggers a pre-defined response or movement from the robot. The OpenCV library is employed for real-time video analysis and punch detection, ensuring accurate and timely recognition of the user's actions.

The software integrates the functionalities of the hardware components, including servo motors and sensors, through the Raspberry Pi 4 and Arduino Mega micro-controllers. scripts are developed to control and synchronize the actions of these components based on the inputs from the image processing and AI algorithms.

Furthermore, the software utilizes additional libraries and modules for data processing, feedback generation, and user interface control. These components collectively create a seamless and interactive user experience.

By leveraging the power of libraries such as DepthAI and OpenCV, the software enables the boxing training robot to deliver real-time analysis, personalized feedback, and enhanced training capabilities in both Training Mode and Vision Mode. The combination of accurate pose estimation, punch recognition, and responsive control ensures an effective and engaging training session for users.

## 3.4. Implementation

### 3.5.1. Hardware Design

- **Design of Robot and wooden frame:**

The dimensions of the wooden frame were carefully determined to provide sufficient space for component placement while maintaining a compact and manageable size. The design considered the overall balance and weight distribution to ensure stability during training sessions.

2. **Mounting of Servo Motors:** The servo motors, specifically the 10 Kg Metal Gear Servo motors (Mg995), were strategically mounted on the wooden frame to control the robot's arm movements. The servo motors were securely attached using mounting brackets and screws, ensuring stability and minimizing vibrations during operation. The positioning of the servo motors was meticulously determined to replicate human arm movements accurately.
3. **Integration of Camera (OpenCV AI Kit):** The camera, specifically the OpenCV AI Kit, played a crucial role in capturing video footage for punch recognition and training analysis. It was strategically positioned on the wooden frame to provide an optimal view of the user's punches. The camera was securely mounted using brackets and adjustable joints, allowing for precise positioning and angle adjustments.
4. **Incorporation of MH-Sensor-Series: F249 Infrared Speed Sensor:** The MH-Sensor-Series: F249 4 PIN Infrared Speed Sensor was integrated into the wooden frame to measure the speed of punches. It was strategically positioned to accurately capture the movement of the user's punches. The sensor was connected to the microcontroller, allowing real-time speed detection and analysis during training sessions.
5. **Placement of Raspberry Pi 4 and Arduino Mega 2500:** The Raspberry Pi 4 and Arduino Mega 2500 microcontrollers were placed within the wooden frame, ensuring secure mounting and easy access for wiring and programming. The microcontrollers were positioned in a manner that facilitated efficient communication between the hardware components and software algorithms.
6. **Cooling System:** To prevent overheating and ensure optimal performance of the Raspberry Pi 4 microcontroller, a cooling jacket was incorporated into the design. The cooling jacket, specifically designed for the Raspberry Pi 4, provided passive cooling by dissipating heat from the microcontroller.
7. **Integration of LCD Screen, Bluetooth module, and Speakers:** To facilitate user interaction and improve user experience, an LCD screen, Bluetooth module, and speakers were incorporated into the design. These peripherals were connected to the Boxing robot, allowing users to interact with the system, access training modes, and view real-time feedback.

The detailed design of the wooden frame and hardware parts ensured a robust and functional structure for the boxing training robot. The careful placement and integration of components contributed to the system's stability, accuracy, and overall performance during training sessions.

### 3.5.2. Arduino

The Arduino Mega 2500 micro-controller played a vital role in controlling specific hardware functions and facilitating the integration of different components. Arduino programming was implemented to establish communication between the micro-controller and the servo motors, ensuring precise control over their movements. The Arduino code was developed to interpret commands received from the Raspberry Pi 4 and translate them into appropriate signals for the servo motors. This programming enabled coordinated and synchronized movements of the robot based on the user's actions and the feedback generated by the system.

### 3.5.3. AI

- **Pose estimation and motion analysis:**

scripts were written to capture video footage from the camera using OpenCV. The captured frames were then processed using the DepthAI library to perform pose estimation and extract key joints and landmarks. By analyzing the position and motion of the user's arms, the scripts determined the type of punch being thrown. This information was utilized to provide real-time feedback on technique and form. The algorithms were fine-tuned to ensure accurate recognition of different punch types and to provide prompt feedback to the user.

Building upon the pose estimation results, the scripts generated real-time feedback to guide the user in improving their boxing skills. The feedback was based on predetermined criteria for punch quality, speed, and accuracy. The algorithms analyzed the user's arm movements, compared them with predefined parameters, and provided immediate feedback on areas requiring improvement. The feedback generation algorithms were designed to be responsive and intuitive, enhancing the training experience and enabling users to make effective adjustments to their technique in real-time.

# 4

## Results and Analysis

The results obtained from the implementation and testing of the boxing training robot project were analyzed to evaluate the performance and effectiveness of the system. The analysis focused on various aspects, including the accuracy of punch recognition, real-time feedback generation, and the responsiveness of the robot's actions.

1. **Punch Recognition Accuracy:** The developed system demonstrated robust performance in accurately recognizing different types of punches thrown by the user. Through the integration of image processing algorithms, such as pose estimation and motion analysis using DepthAI, the system achieved a high level of accuracy in detecting and categorizing punches. The analysis of test data showed that the system consistently identified and classified punches with a significant degree of accuracy, providing users with reliable feedback on their technique and form.
2. **Responsiveness of Robot Actions:** The Vision Mode, which incorporated the detection of the user's arm movements and triggered robot responses, exhibited a high level of responsiveness and synchronization. The analysis of the system's performance in initiating appropriate robot actions in response to the user's punches revealed a seamless interaction between the user and the robot. The robot's responses, including simulated counter punches, defensive actions, and dynamic target movements, were timely and accurately aligned with the user's actions, enhancing the realism and engagement of the training experience.

# 5

## Discussion

### 5.1. Testing

- The testing phase of the boxing training robot project played a crucial role in evaluating the system's performance, identifying potential limitations, and gathering insights for further improvement. Various testing scenarios were conducted to assess the accuracy of punch recognition, the effectiveness of real-time feedback generation, and the responsiveness of the robot's actions. The testing process involved both controlled experiments and user trials, providing a comprehensive evaluation of the system's capabilities.
- The results obtained from testing demonstrated the system's ability to accurately recognize different types of punches with a high level of accuracy. This indicates that the image processing algorithms, including pose estimation and motion analysis, successfully identified and categorized punches based on the user's arm movements. The system's real-time feedback generation mechanism proved effective in providing prompt and constructive feedback, enabling users to make immediate adjustments to their technique and improve their boxing skills. Furthermore, the responsiveness of the robot's actions in the Vision Mode was assessed through user trials, which confirmed the system's capability to initiate appropriate responses aligned with the user's punches.

### 5.2. Learning Curve

During the testing and user trials, a learning curve was observed, highlighting the adaptation and progress made by users as they engaged with the boxing training robot. Initially, users familiarized themselves with the system's interface and functionality, gaining an understanding of the punch recognition criteria and the type of feedback provided. As users continued their training sessions, they demonstrated an improvement in their punch technique and form, as indicated by the feedback received from the system.

# 6

## Conclusions and Recommendation

### 6.1. Things we learned

- **Integration of Hardware and Software:** The project highlighted the importance of effectively integrating hardware components with software systems. It provided hands-on experience in connecting and configuring different hardware devices, such as servo motors, cameras, and microcontrollers, and interfacing them with software algorithms. This knowledge is essential for future projects involving the integration of hardware and software systems.
- **Image Processing and Machine Learning:** The project deepened our understanding of image processing techniques and machine learning algorithms. Specifically, the utilization of libraries like DepthAI and OpenCV for pose estimation, motion analysis, and punch recognition broadened our knowledge in these domains. This experience has paved the way for future applications of image processing and machine learning in diverse fields.

### 6.2. Future Work

1. **Gamification and Virtual Training Scenarios:** Incorporate gamification elements and virtual training scenarios to make the training experience more engaging and immersive. This could involve creating interactive training games or simulated sparring sessions with virtual opponents.
2. **Collaboration and Competition:** Introduce features that enable users to connect and compete with other users, promoting a sense of community and healthy competition. This could involve online leaderboards, challenges, or virtual tournaments.

# References

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