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Design Project Report

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Submitted To
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Project Title

Tennis Robot: a design for WRO™RoboSport competition

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DECLARATION STATEMENT FOR THE ORIGINALITY OF THE DESIGN PROJECT

We hereby declare that this design project comprises our original work. No material in this design project has been previously published and written by another person, except where due reference is made in the text of the problem definition statement.

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Abstract

Robots are specially designed machines used to accomplish dedicated and repetitive actions with high speed, precision, and endurance. The demand for automation and robotics is gradually expanding into the field of sports.[1] Moreover, competitions are the best places to showcase the state-of-the-art techniques and methods in the aforementioned fields. The purpose of this project is to build an autonomous robot that participates in the WRO^{TM} (World Robot Olympiad). The document presents the design process of a two-wheeled mobile robot capable of competing in a tennis game, exploiting our understanding of microprocessors, algorithms, and design principles. The robot is built using the Raspberry Pi 4 microcontroller along with motor drivers, DC motors, rack-pinion mechanism, and Pi camera for vision system. Detection of the tennis ball and the mechanical control of the device are implemented using Python. The following pages begin with an introduction of the project motivation, a theoretical background about the game rules, and a design layout of the tennis robot prototype. The optimization analysis of the design is next discussed; namely, determining the optimal parameters for the detection algorithm. This work concludes that (1) the robot can distinguish any tennis ball based on its sphericity and specific color, (2) a search algorithm is sufficient to determine the optimal detection parameters, and (3) The system is able to move, interact, and play, forming an autonomously controlled robot. Finally, the prospects of our project are mentioned, and the implementation of algorithms such as reinforcement learning was recommended.

Contents

1.0 Introduction

In the past three decades, robot adaptation for sports has been a widely discussed research topic. Control of machines without human interaction accurately and intelligently has also been discussed amongst the society.[2] Moreover, significant improvements in speed and consecutive cycles have been shown. Therefore, improvements will have to be made for the betterment of the field and for the benefit of the human community.[3] In fact, fast moving games like Table Tennis are dominant in the field of study as a lot of researcher studies as well as experiments have been done under them. First, Dennis Beaver got a patent in 1975 as the inventor of the serving device of table tennis.[3,4] In 1983, a competition had been announced to build a microprocessor-based robot to play ping pong.[2] In 1986, John Knight built the systems, which had been the current European robot ping pong champion after winning the finals of the competition in September 1985.[5] A patent was awarded in 1986 for a table tennis robot prototype, which could spin the ball. Robotics table tennis is growing area of research under imitate human motions as shown in figure [1].

Figure 1 The World Robot Olympiad Finals [8]

Furthermore, this work documents the design process involved in creating an autonomous tennis robot for a robotics competition. The project was carried out by a team from the Faculty of Engineering at the Islamic University of Medina, with the goal of representing the university at the World Robot Olympiad (WRO).[6] This Olympiad is a global robotics competition, organized by the Saudi Wireless Sports Federation. The competition was established in 2003, and it attracts more than 28,000 teams from more than 85 countries every year, Figure [1]. Our team is made of students and mentors from both the mechanical and electrical engineering departments. In particular, we worked in RoboSport competition, a category of WRO®.

Additionally, this project took two months of working, and the team focused on enhancing the construction and functionality of the robot to ensure its optimal performance in the competition.

The paper consists of four parts, and it commences with a discussion about the theoretical background including the strategy of play and the design criteria. The second part discusses the design process, namely hardware and software. The third part investigates the setup for an experiment to understand the optimal condition of operation. The fourth part is devoted to the experimental results and its analysis.[6] The report concludes with some key findings and suggestions for future improvements.

Applications

Since our design is an autonomous mobile robot, it is convenient for a wide range of applications. For instance, the automation of service activities, which allows users to live in ease by automating routine activities.[8] With some modifications, our design can be used as a tennis ball collector, a tennis game trainer, or an air-defense system, Figure [2].

Figure 2 Tennis robot applications

2.0 Design method, simulation, theory

The design process of the robot is divided into three phases, electronics, mechanical design, and the software development. However, the first step is to lay down the foundations, so we set the objectives and become aware of the limitations. This is done by understanding the game and the field environment first.

Game description and game field

RoboSports is a competition where two teams each have two autonomous robots on the field playing a sports game. The game changes every 3 or 4 years, and the current game is Double Tennis. Each year little changes are introduced to motivate the students to keep on developing their robots. The game resembles a real table tennis game except it is for robots. Each two robots operate on the same half of the field and their goal is to collaborate on the common task - push all the balls from their half to the other team's half. Initially each half of the field contains 4 balls. During the match, balls will be pushed from one half to another. As well as pushing their own balls, a team's robots must constantly continue to find new balls delivered from the other half by the robots of the opposing team. As soon as these balls from the opposition are found the robots must plan and perform actions to push these balls back. A match takes maximum 2 minutes and at the end of the match the winner is the team with the least number of balls on their half of the game field. At RoboSports, judges have a more active role as they need to decide on certain situations during the match as well. This is part of playing sports. Figure [3] shows the game field with the game objects. Moreover, the game field consists of two halves, and each half contains one ramp where a barrier separates them. One of the rules is that robot’s dimensions must not exceed 200x200 mm and 200 mm in height during the match. Whereas there is no restriction on programming language or components, teams can only have a maximum of two controllers with themselves in the competition area. Furthermore, the official score will be calculated at the end of each match by the judges. The winner in the group of two teams is identified after three matches.

The environment for the robot

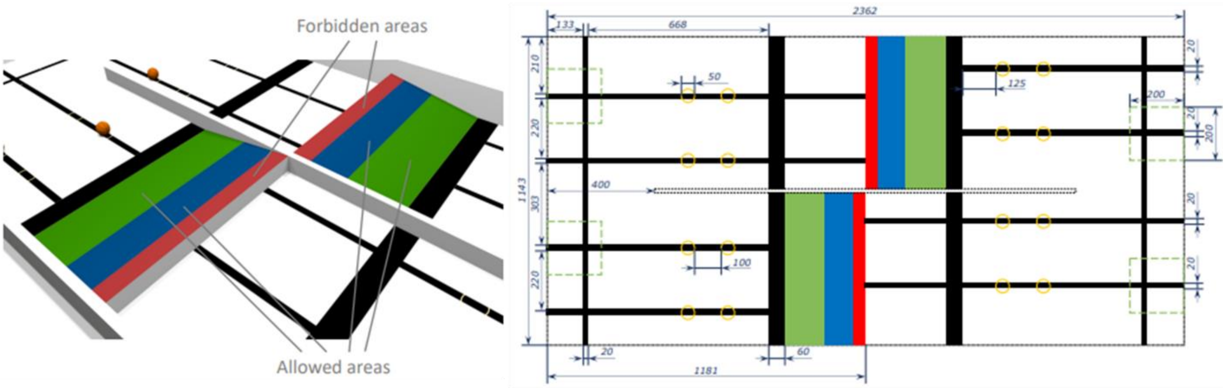


Figure 3 The field allowed areas and its dimensions [9].

The dimensions of a WRO mat are 2362 mm x 1143 mm and with a height of 100mm. The size of robot is 200 x 200x 200 mm. Two ramps 300 x 563 x 50 mm are fixed on the field, and they are made of wood. The barrier size is 1562 x 17 x 50 mm. In addition, every ball is a standard ping pong ball with a diameter of 40mm. The color of the ball is orange. Two intersections of the black lines are used as starting positions of the robots as shown in figure [4].

Figure 4 Detailed game field.[9]

Another added value is the implementation of computer vision in which the robot detects and tracks balls. For example, if the design lays down a basis for object tracking capabilities, it can be utilized for research purposes. The importance of building vision aided robots has increased. The market size in the computer vision market is projected to reach US$22.27bn in 2023. The market size is expected to show an annual growth rate (CAGR 2023-2030) of 12.56%, resulting in a market volume of US$50.97bn by 2030 [5], as shown in Figure [5].

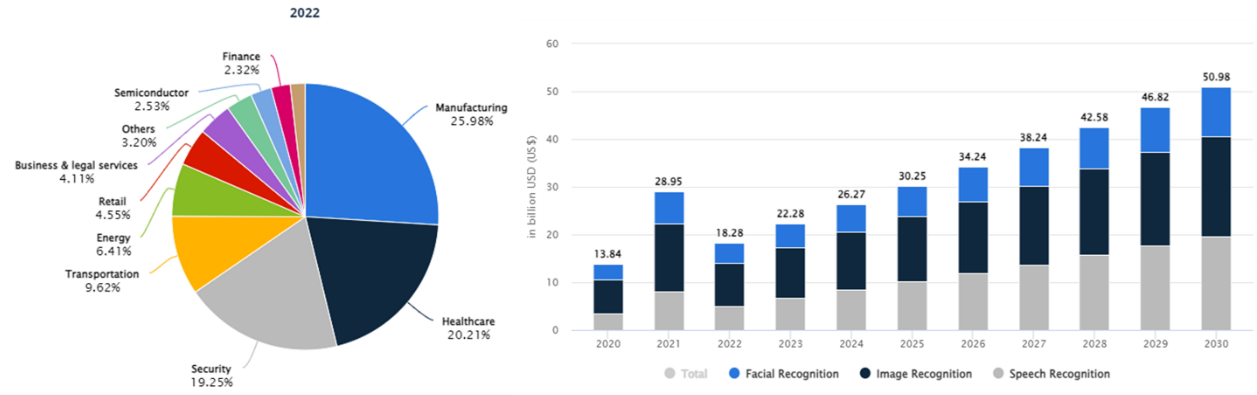


Figure 5 Left: Targeted sectors of computer vision. Right: Computer vision market,[4]

Specifications of the design

For our design, we want to build an autonomous robot that competes in Double Tennis game against a robot of another team. The design criteria are:

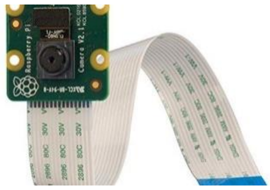
- Robots must constantly look for balls delivered by the robot of the opposing team.
- After finding a ball, the robot must move towards it and shoot the ball back to the opponent's field.
- The robot must be autonomous.
- Robot's dimensions during the match: 200x200x200 mm

3.0 Description of design

The design of the robot includes the electrical circuitry, the mechanical parts, and the software. Thus, the robot should supply enough power, shoot with sufficient force, and interact according to an algorithm. Moreover, the resources and materials required to complete the project are shown in Table 1, and the prototype cost us a total of 1135SR.

Table 1 The components and materials

Items	Quantity	Total price	Notes	Source	Image
Raspberry Pi	1	600SR	Gen.4, 8GB 1.5 GHz CPU speed Operating system is Linux 2 USB 3.0 ports; 2 USB 2.0 ports. Bluetooth 5.0	Amazon.com	

Motor Driver	1	30SR	drive two 3 30V DC motor, control the DC motor speed Driver: L298N Dual H Bridge Size: 55mm*60mm* 30mm	Amazon.com	
Raspberry Pi Camera	1	150SR	5mp camera, 1080p video, ribbon cable to Serial Interface port, mechanical focus adjustment. Weight: 3g Size: 25mm x 20mm x 9mm	Amazon.com	
Breadboard	1	15 SR	Solderless Size: 10x5cm	Amazon.com	
Jumper Wires	20	20 SR	Length: 10cm Male-to-male Male-to-female Female-to-female	Amazon.com	
Resistors	4	12 SR	1kΩ, 0.5W power dissipation	Amazon.com	
Power bank	1	150SR	5 Volts Lithium Ion Battery. Capacity: 10000 mA Power output 30W Weight: 0.25Kg	Jarir.com	
DC Motor	3	30SR	Operating voltage: 3-1.5 Volts Max RPM (No-Load): ~12000 Nominal current: 800-560mA Weight: 13.5g	Amazon.com	
Acrylic Sheet	3	50SR	Transparent glass, used for the chassis It is cut by laser	Amazon.com	
Wheels	2	30SR	Wheels made of rubber and plastic	Amazon.com	

Roller wheels	1	20SR	Installed in the front, consists of a ball for higher degree of freedom	Amazon.com	
Bolts and nuts kit	1 kit	40SR	Stainless steel bolts and nut, types of number is 12: M1 M1.2 M1.4 M1.6	Amazon.com	

Circuit and electronics

The electrical components were connected, as depicted in Figure [6]. The electrical components require the rating volts and amps to operate, so the power source must be reliable. As a result, we used a power bank with lithium-ion battery that delivers 5V and 30W output. The choice was reliable and effective due to its low size as well as rechargeable and mobility advantage.

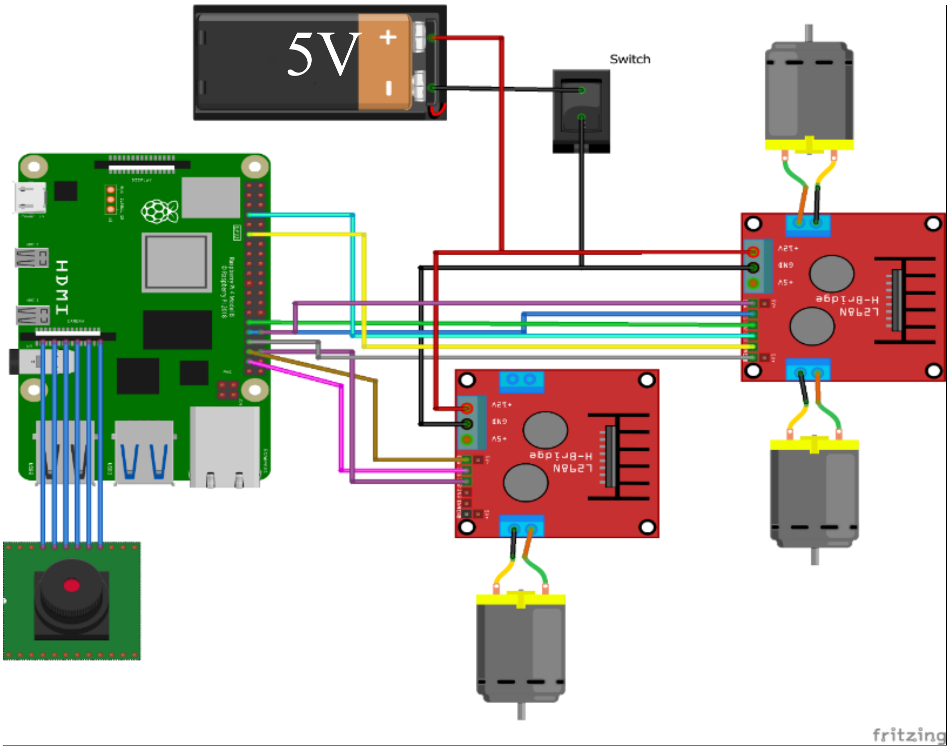


Figure 6 The circuit schematic [10]

Mechanical design: Lunching mechanism

The rack and pinion mechanism is a popular choice in robotics, particularly for shooting mechanisms in robots designed to propel balls. This mechanism utilizes a linear gear (the rack) and a circular gear (the pinion) to convert rotational motion into linear motion, or vice versa. This system is pivotal in achieving accurate and controlled launches, as shown in Figure [7].

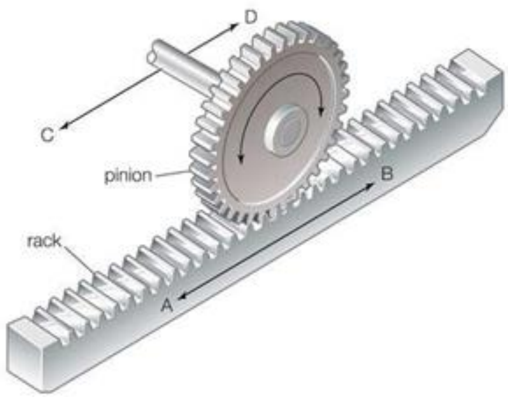


Figure 7 Rack and pinion working principle.[3]

For instance, when the motor rotates the pinion, the teeth on the pinion engage with the teeth on the rack.[4] The rotation of the pinion converts into linear motion, causing the rack to move in a straight line. This linear motion achieved through this mechanism enables precise control. However, an appropriate motor for the pinion is required to ensure a sufficient force ball propulsion.[3] Therefore, we overcome this by connecting the DC motor with a separate motor driver that's connected to the main power supply, as in Figure [8].

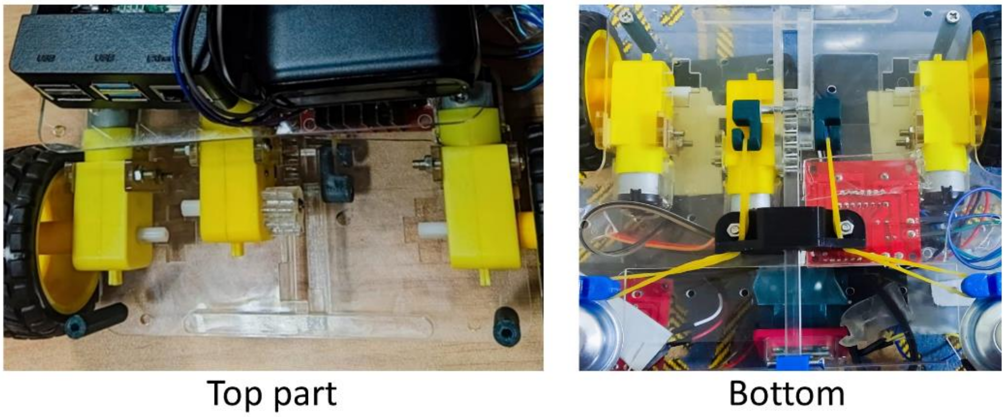


Figure 8 The final design of the lunching mechanism

Software development: the robot's algorithm

The software flowchart is shown in Figure [9]. The code executes three multiple tasks simultaneously, and this is ascribed to the implementation of the concept of parallel processing. This approach is designed to enhance the overall efficiency, speed, and multitasking capabilities of robots. Unlike sequential processing, where tasks are executed one after the other, parallel processing enables parallelism. One of its challenges is keeping up with synchronization and the efficient allocation of resources. We overcame this by choosing raspberry pi instead, as the main microcontroller. Since it has higher performance and capabilities, it was a great choice for an aided vision robot.

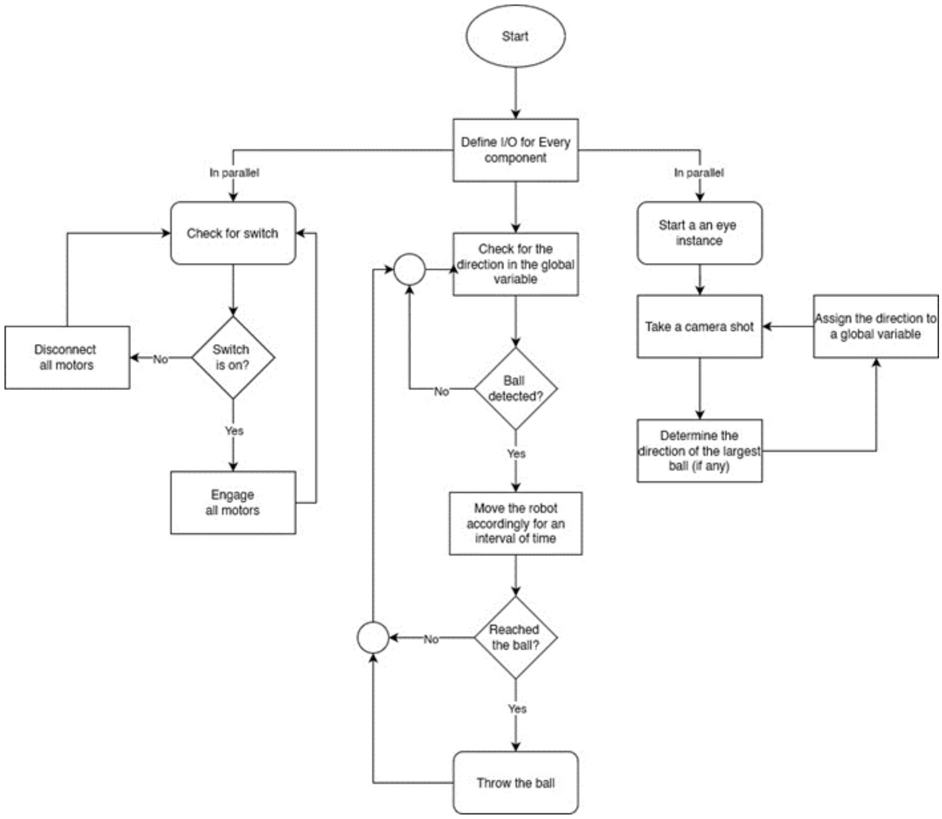


Figure 9 The code flowchart [11]

The integration of all these aspects, namely mechanical, circuit, and software, results in a complete autonomous robot. Figure [10] shows the final design from different views [11].

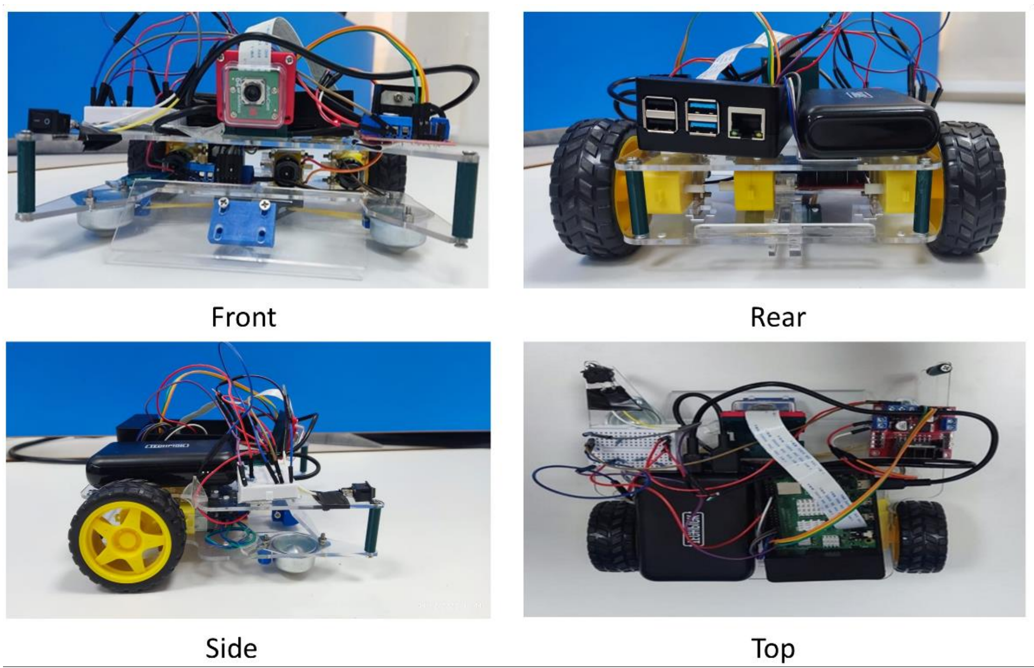


Figure 10 Different view of the final design

4.0 Measurement Methods

For the analysis purposes, we used MATLAB software and Python language. Most of the measurement was done in the lab using a digital multimeter to ensure accurate outputs. An experiment was done to optimize the robot functionality. Since Shadows and the environment lighting is one of the limitations. The goal of this experiment, posed as an optimization problem, is to determine the optimum condition for precise and flexible object detection. Our five lighting examples range from worse to better.

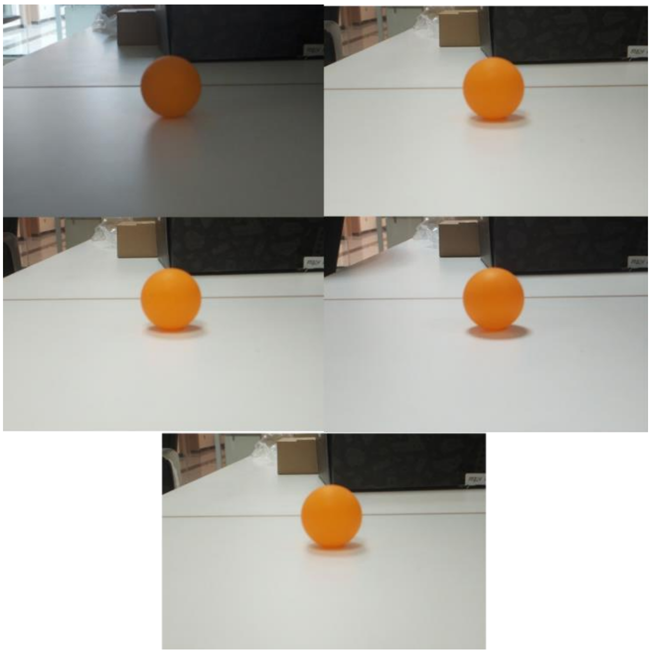


Figure 11 The five different lighting conditions

Meanwhile, different pictures were taken of the tennis ball in these condition variations. For accurate results, we maintained specific parameters fixed. Therefore, the camera was 200 centimeters far, and the ball was placed on a white surface. Figure [11] shows the taken pictures for the five different cases. Afterwards, all pictures were analyzed by executing a python code, and measurements were gathered for all different conditions. The raw data includes Hue spectrum and saturations for all taken pictures. The method of analysis used is to select the optimum parameters depending on the IoU measure. IOU (intersection over union) provides a measure of how well a predicted object aligns with the actual object annotation. It assesses the model accuracy and the fine-tuning of algorithms for improved results. Therefore, a higher IOU value indicates a better alignment between the predicted and actual regions.

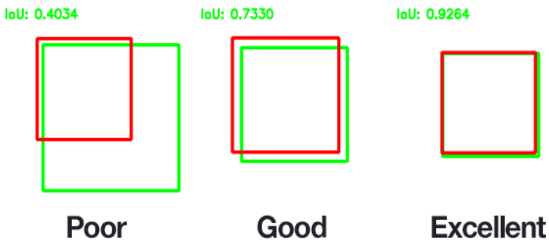


Figure 12 Illustration of the intersection over union method (IOU)

IoU values were measured from real-time object detection, and then the IoU values range was determined as well. Similarly, the raw data was processed by identifying the Hue and saturation range and various other parameters. Likewise, the IoU average was calculated across all IoU values of the five conditions. Figure [12] illustrates the implementation of IoU measurement which is the process of detection using optimal parameters.

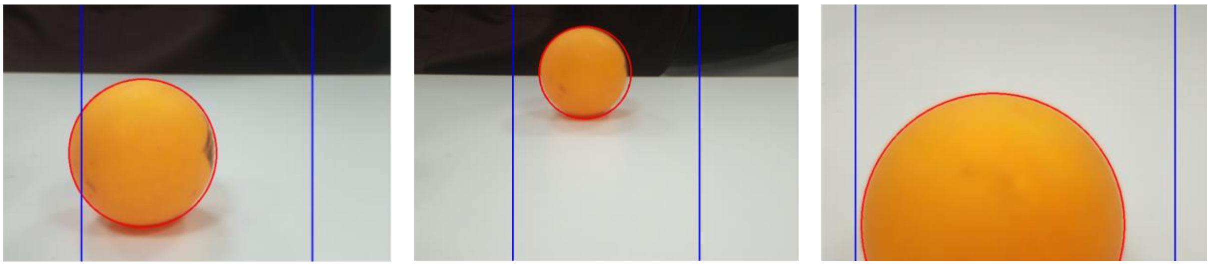


Figure 13 Detection using optimal parameters.

Furthermore, we built a setup that resembles the competition field, so many experiments and tests can be done. Using RealVNC software, we were able to see the robot's point-of-view. Therefore, the development of the algorithm was made easier due to the higher accessibility and control. Since the troubleshooting of problems became much faster, this saved more time, figure [14].

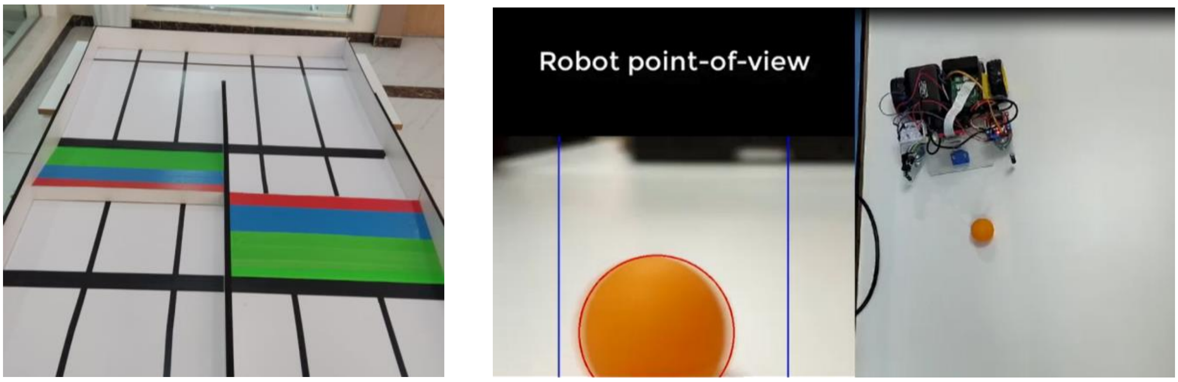


Figure 14 The setup of experimenting and testing the robots.

5.0 Measured and simulated results

Accordingly, a graph of average IoU versus Hue range was plotted using the MATLAB environment, as shown in Figure [15]. The provided measurements related to the analysis were done considering following parameters: Hue, saturation, value, Hue_range, sat_range, val_range, avg_iou. The graph emphasizes the fact that detection is for orange balls since Hue values of interest are between 10 to 20. It can be shown that while keeping other parameters constant, the most accurate model is at 16 Hue and 0.75 Avg IOU. Although more than 0.7 IoU is considered acceptable, the robot should operate in an environment with 14 to 18 Hue.

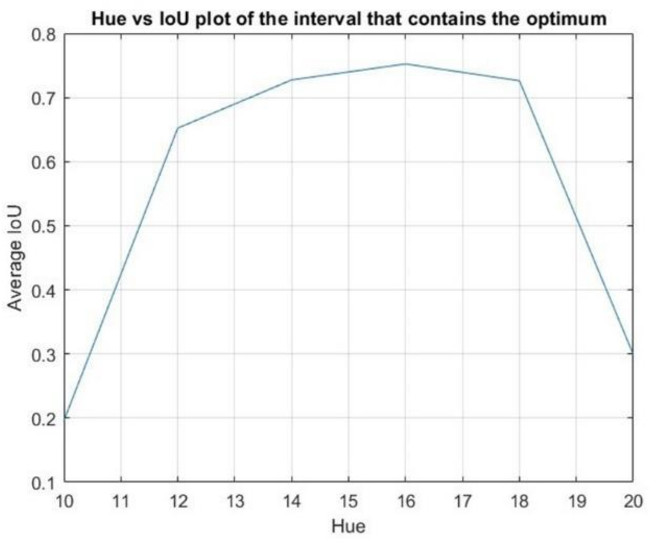


Figure 15 Analysis results

6.0 Conclusions

In conclusion, the autonomous tennis robot was designed, and this report documents the process. The goal was to build a robot that competes in Double Tennis game against a robot of another team. In this project, we proposed a robot that distinguishes any tennis ball as it travels in any direction based on the color and shape. The mechanical design facilitates the lunching mechanism since the robot moves towards the ball and shoots it back to the opponent's field. In addition, the report investigates the process of optimizing the design. MATLAB and Python were used for the analysis. According to the results, the hue for various lighting conditions is 16.

7.0 Recommendations

On the light of conclusions and findings, we recommend the following:

- Implementing the method of Reinforcement learning would be a huge advancement for our design. This method is a type of machine learning that teaches robots to learn tasks by receiving feedback in the form of rewards.
- Improving the playing strategies, such as searching algorithm and the awareness of the environment [6].

8.0 Acknowledgment

The group would like to thank Dr. Hussam Alharbi who directly supervised this project and Mr. Ahmed Emam who fabricated all the mechanical parts of the robot. Also, many thanks to Dr. Muhammad Uzair who gives us the chance of showcasing our work. Without their support, this project would not exist.

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