AN-NAJAH NATIONAL UNIVERSITY

FACULTY OF ENGINEERING & TECHNOLOGY DEPARTMENT OF COMPUTER ENGINEERING

STADIUM ROBOT

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Disclaimer statement

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Abstract

The Stadium Robot project includes a robotic vehicle equipped with a painting device with the purpose of automating the activity of marking the football fields. This system seeks to solve the problems of manual field maintenance by improving accuracy, lowering workforce costs, and reducing the effective downtime. It is a robot that is meant to independently draw the lines with appropriate accuracy while ensuring that the lines are well painted and durable.

The introduction of the robotic figure involved the design of the mobile platform, development of a complex paint and cleaning system and writing algorithms for a seamless integration of the systems. The use of an Arduino Mega microcontroller provided a way to control motors and connect sensors while the ESP32 module installed, enabled wireless communication. These systems are combined with a web-page based application that enables operation of the systems from a remote location and allows tracking in real-time.

The centre points of the project were the design of a device which can draw the lines on a football field bearing a bear by employing the machine in a fully automated process and less time is spent on manual work. The robotics design involves the use of ultrasonic sensors for avoiding unexpected objects. The results of the project clearly show that, the Stadium Robot is able to carry out its task of marking the football field autonomously with the help of the lines painting robot making it a worthy replacement for manual methods of marking the Field.

1 Introduction

1.1 General Background

In the field of sports field maintenance, efficiency and reliability are essential. Our project focused transforming the process of marking football fields by introducing an automated Stadium Robot that paints the lines of a football field, this robot not only can paint the football field lines, also it can be controlled manually to precise higher accuracy.

1.2 Objectives

We aim to boost automation in sports field maintenance using a Stadium Robot which is capable of painting lines on a football field. This robot has been made so as to remove the complexity of conventional line marking method by allowing users to insert the dimensions of the football fields such as length and width after which it will execute this task without any help. It makes the robot move around the field autonomously and paint its respective lines according to parameters sent to it. The invention is a major step toward fully-automated maintenance of sports fields that involves both less time and physical energy in preparing football matches or training sessions.

1.3 Significance or importance of your work

The possibility of our Stadium Robot project is in its potential to completely change sports field maintenance and therefore, meet the needs for accuracy, efficiency, and cost savings in the market. There are cumbersome ways of marking fields that result in errors leading to disparities in quality of play. There has been an increase in demand for automated solutions to ensure uniform high-quality field markings with less human involvement as a result of increasing number of sports facilities. Our Stadium Robot meets this need through provision of an automatic system that guarantees exactitude and consistency thereby resulting into reduced labour costs and preparation time. Our project offers ef-

ficient solution for automation sports facility management hence it is suitable across different sports fields making it valuable within the industry.

1.4 Organization of the report

Our report is into key sections to guide you through, Begin with Theoretical background and previous work content, followed by methodology which outlines our approach and the components we used. Next, Results and analysis for our findings. To discussion section where the results takes a place, then, Conclusion, Recommendations summarize and future work. The report concludes with a list of references acknowledging the sources we used.

2 Theoretical Background and Previous Work

2.1 Fundamentals of Football field line marking

Making lines on a football field is essential in preparing the ground for the game, as well as making it conform to official measurements and standards. For instance, good line marking is very important because it indicates the limits of play, goal areas, penalty spots, and other key zones of the field. To do this, accurate measurements are needed together with the right materials and techniques used during the process.

2.1.1 Field Dimensions and Layout

To establish official competitions, FIFA has laid down the standard dimensions for a football field even though its size may differ according to the level of game being played. A typical soccer ground is rectangular in shape and has the following dimensions:

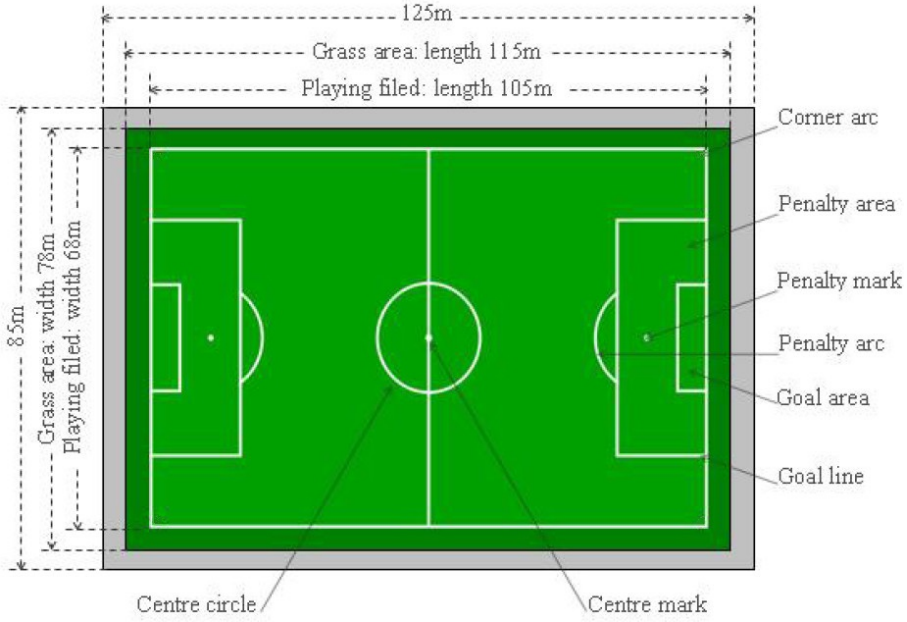

Figure 2.1: Football Field Dimension (FIFA 2007)

The field is divided into several key areas:

- **Goal Area:** a small rectangular area located in front of each goal, usually 5.5 meters away from each goal post and stretching 5.5 meters into the field.
- **Penalty Area:** a larger rectangle that encompasses the goal area, typically 16.5 meters from each goal post and extending 16.5 meters into the field.
- **Center Circle:** a circle with a radius of 9.15 meters is situated at the center of the field.
- **Corner Arcs:** at each corner of the field, there are quarter-circle markings with a radius of 1 meter.

2.1.2 Materials Used for Line Marking

Lime was once used to mark Football Fields, however; this simple and effective material has been replaced with more recent alternatives due to environmental and health issues although it is still affordable and efficient.

The most widely used marking on contemporary football fields is water-based paint which is friendly to the environment as well as easy to apply. These paints are weather-resistant and bond well with the grass.

2.2 Limitations and Challenges

- **Weight and Mobility:** The Stadium Robot weighs approximately 35kg, which makes mobility a challenge, particularly on uneven surfaces. particularly on irregular surfaces. This weight may slow down the robot and make it difficult to navigate efficiently across the entire field. The presence of heavy parts like batteries and tanks causes this problem which could affect overall performance.
- **Power Management:** using two 12v batteries of different capacities (12A and 9A in UPS) needs careful management of power for avoiding imbalances and overloads. In the case where the balance is not well maintained in such a situation, the result could be reduced battery lives or cases of loss in power during operations. Meeting the power requirements of individual elements while at same time preventing rapid battery drain is a huge task. Also the paint gun, which runs on 220V via a UPS, poses power management and safety issues. Particularly when there are variations or disruptions in the primary power source, the UPS needs to be dependable and able to deliver steady power. The design of a mobile robot becomes

more complex due to the need to ensure the safety of handling and operating high-voltage components. Both batteries can be charged using UPS power input or Solar cell.

- **Fluid Mixing Consistency:** Field lining depends on the perfect mix of paint and water. insufficient blending could cause a poor application of paint that might have an effect on the visibility and lines' accuracy. It calls for exact management of pumps, valves and mixing motor which can be hard to maintain especially in changing conditions.
- **Wireless Communication Stability:** The use of ESP32 for wireless communication raises questions about responsiveness and connection stability. It can be challenging to keep the robot and controller connected steadily in a wide open space, especially if there are obstructions or other interference. Field lining could be incorrect or incomplete due to any lag or disconnect.
- **Field Area and Calibration:** The Stadium Robot faced difficulties with the calibration process. It was supposed to be calibrated for a FIFA standard field size of 105 x 68 meters, but due to limited testing space, it was calibrated to drawing the penalty area.

2.3 Previous Work

Previous systems in the automated line painting field were predominantly manual or semi-automated, requiring substantial human involvement. Operators were tasked with manually steering these machines along predetermined paths, with automation typically limited to regulating paint application. These systems lacked advanced functionalities such as wireless communication or real-time adjustments.Some advanced models incorporated GPS guidance, reducing the necessity for manual operation by enabling machines to follow pre-programmed routes with increased accuracy. However, these GPS-guided systems often relied on clear weather conditions for precise signal reception and still necessitated predetermined routes without the flexibility for real-time adjustments. In contrast, our project integrates complete automation, significantly reducing the requirement for human intervention. The system is equipped with wireless communication capabilities, enabling operators to directly send instructions to the robot. Furthermore, it incorporates an advanced fluid management system with separate tanks for water and paint, allowing for mixing and cleaning the tubes from paint after finishing the operation.

3 Methodology

3.1 Standards and Specifications (Codes)

During the development of Stadium Robot, applying several engineering standards to ensure its functionality, safety and feasibility:

- **IEEE 802.11 Standard:** Used for the WiFi communication module, enabling Stadium Robot to connect and be controlled over WiFi
- **ISO 10218-1 Standard:** addresses the safety of Stadium Robot while it is being used on site in field lining and paint application operations, keeping the safety for the whole process of automation.

These standards are included in the design process, ensuring that Stadium Robot meets industry models and operational requirements.

3.2 Materials and Components

3.2.1 Stadium Robot Body

Lightweight iron is used in building the body of the stadium robot thus forming a strong structure. Dimensions of this construction are 51 cm length, 50 cm width and 44 cm height making it convenient to accommodate all needed elements yet still remain small enough for easy movement while engaging on the turf.

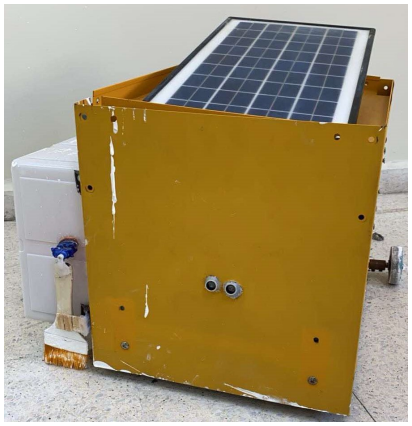

Figure 3.1: Stadium Robot Body

3.2.2 Arduino mega

Figure 3.2: Arduino Mega

Arduino Mega is the central microcontroller for Stadium Robot that handles all the parts of the system. We have interfaced stepper motor drivers so as to control the stepper motors that control the movement of the Stadium Robot. Ultrasonic sensors have been incorporated in the design to measure distance. Moreover, some other module, namely the ESP32, was integrated for WiFi control of the robot. All these parts including the Arduino Mega are programmed in C++ language, using Arduino IDE, for the harmonious working of the system.

3.2.3 ESP32 WiFi Module

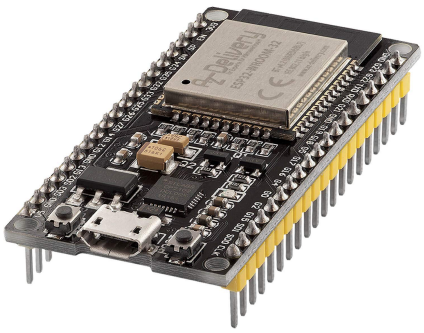

Figure 3.3: ESP32 WiFi Module

ESP32 module is used to establish WiFi connectivity, ensuring the Stadium Robot can be remotely operated. After being powered on, the ESP32 provides a web page which is used to control Stadium robot. The driving motors controlling the movements of the stepper robot and a variety of sensors fitted on it can be turned on and off remotely through this web page.

3.2.4 Motors

- **Nema23 Stepper Motor**

Figure 3.4: Nema23 3.5A Stepper Motor

Stadium Robot movements are done by two stepper motors, also directional stepper motor to make the angular movements more precise and control the steering.

- **Stepper Motor Driver (4A)**

Figure 3.5: 4A Stepper Motor Driver

  - **Quantity:** 3
  - The stepper motor drivers are connected to the Arduino Mega for the purpose of controlling the stepper motors. A 12V input is used to power up the stepper motors drivers.

- **DC Motor**

Figure 3.6: 12V High Speed DC Motor

Used to blend Paint and water in mixed tank.

3.2.5 UPS

Figure 3.7: 800VA 480W UPS

Uninterruptible Power Supply (UPS) in Stadium Robot's steps up the voltage of 12V to that of 220V with the use of the inverter for the use of the paint gun. A direct connection from the 12V batteries wouldn't turn on the paint gun, The UPS ensures stable power, protecting the paint gun from interruptions, ensuring reliable operation.

3.2.6 Power Switch

Figure 3.8: Power Switch

The entire Stadium Robot is controlled by the power switch, allowing all components to be turned on or off simultaneously with one action, which enables easy and efficient operation.

3.2.7 Paint Gun

Figure 3.9: Paint Gun

Used to spray paint to draw the line and there are walls surrounding the paint sprayer head to prevent paint splashing around the line.

3.2.8 Relay Module

Figure 3.10: 12V to 220V Single Channel Relay Module

The 12V to 220V relay module controls the paint gun, which is powered by the UPS at 220V. The relay allows the Arduino's 12V signal to control the 220V paint gun, providing precise on/off functionality.

3.2.9 MG90S Servo Motor

Figure 3.11: MG90S Servo Motor

The servo motor used to move the paint brush paint brush is lowered by the servo motor to apply paint while the Stadium robot moves in a straight line. When Stadium robot requires a change in direction, the servo motor raises the brush to avoid any unintended markings during the turn, then lower down the brush to continue painting the line.

3.2.10 HC-SRO4 Ultrasonic Sensor

Figure 3.12: HC-SRO4 Ultrasonic Sensor

Ultrasonic sensors monitor the fill levels of the water and paint tanks by measuring the distance to the liquid surface.

3.2.11 Water and Paint Tank

Figure 3.13: Water, Paint and Mixed Tanks

- **Quantity:** 3

Stadium Robot comes with three tanks:

- The water tank can hold up to 1.5 liters and is used for blending with the paint and cleaning the system after usage.
- The paint tank, having a capacity of 2.5 liters, is utilized for marking the field with paint.
- The Mixed tank which can hold up to 1.5 liters, filled with appropriate amount of water and Paint and it is mixed using DC Motor.

All the tanks are equipped with ultrasonic sensors to keep track of the fill levels, allowing for easy monitoring.

3.2.12 Paint System

- **Stepper Motor Peristaltic Pump**

Figure 3.14: Stepper Motor Peristaltic Pump

The stepper motor peristaltic pump is provided in the Stadium Robot Paint system which is responsible for pumping water and paint into the mixed tank. With the stepper motor, the pump can dispense the required quantities of each liquid, thus ensuring a perfect blend. This pump assures contaminant free working as the fluids being used are only in contact with the standard flexibility tubing. It is therefore applicable in the paint system of the robot for undertaking water and paint tasks.

- **A4988**

Figure 3.15: Stepper Motor Peristaltic Pump Driver

Used to control the stepper motor connected to the peristaltic pump in Stadium Robot.

- **Mini Peristaltic Pump**

Figure 3.16: Mini Peristaltic Pump

The mini peristaltic pump is responsible for circulating paint within the paint tank to keep it from drying out.

- **Water Pump**

Figure 3.17: Water Pump

The water pump dispenses water from the water tank into the electronic valve then the stepper motor peristaltic pump dispenses the water to the mixed tank, ensuring the proper amount of water is added for mixing with the paint.

- **H-Bridge**

Figure 3.18: H-Bridge

  - **Quantity:** 2
  - Used to control the water pump by allowing the Arduino to regulate the direction and speed of the water pump motor, also to control the servo motor which the paint brush attached on up and down.

- **Two Channel Relay**

Figure 3.19: Two Channel Relay

Used to control the on-off operation of the two electronic valves in the paint system. Each channel of the relay is connected to one of the valves, allowing the Arduino to independently open or close them as needed.

- **Electric Valve**

Figure 3.20: Electric Valve

  - **Quantity:**2.
  - Electric valves are used to manage the flow of water and paint into the mixed tank using Arduino which also controls when these valves should open or close in a manner that water or paint flows into the tank.

- **Paint System Procedure:** The process of the paint system in the Stadium Robot starts by the water pump discharging water into the mixed tank. Next, the water travels through a T-pipe linked to an electric valve and then to the stepper motor peristaltic pump, which pushes it into the tank. Once the water has been added, the water valve is shut, and the paint valve—also connected to the stepper motor peristaltic pump via the T-pipe—is opened. Then, the pump extracts paint from the paint tank and deposits it into the mixed tank. When both liquids are in the tank, a DC motor blends them thoroughly to ensure a consistent mixture. Finally, this mixture is used on the field with the paint gun, while a mini peristaltic pump maintains paint circulation to prevent it from drying out.

3.2.13 Additional Components

- Wires.
- Battery Indicator.
- Paint Brush.
- Whisk.
- 8mm & 10mm tubes.
- Breadboard.
- Wires Connector.
- T-Pipe.
- Paint.
- Water.

4 Circuits

4.0.1 Arduino mega & ESP32

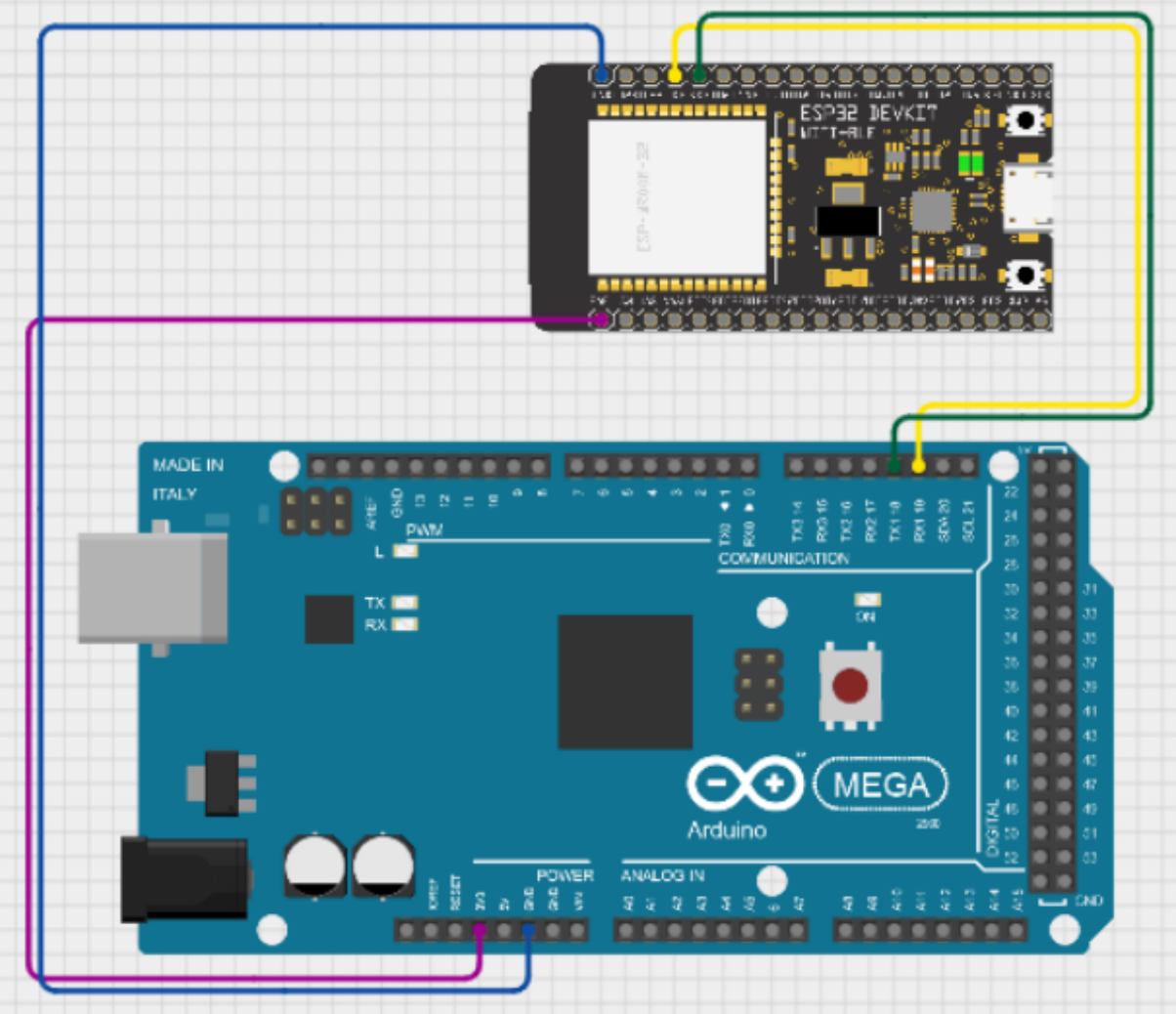

Figure 4.1: Arduino & ESP32 Connection

The figure above shows the connection between Arduino mega and ESP32.

4.0.2 Paint System

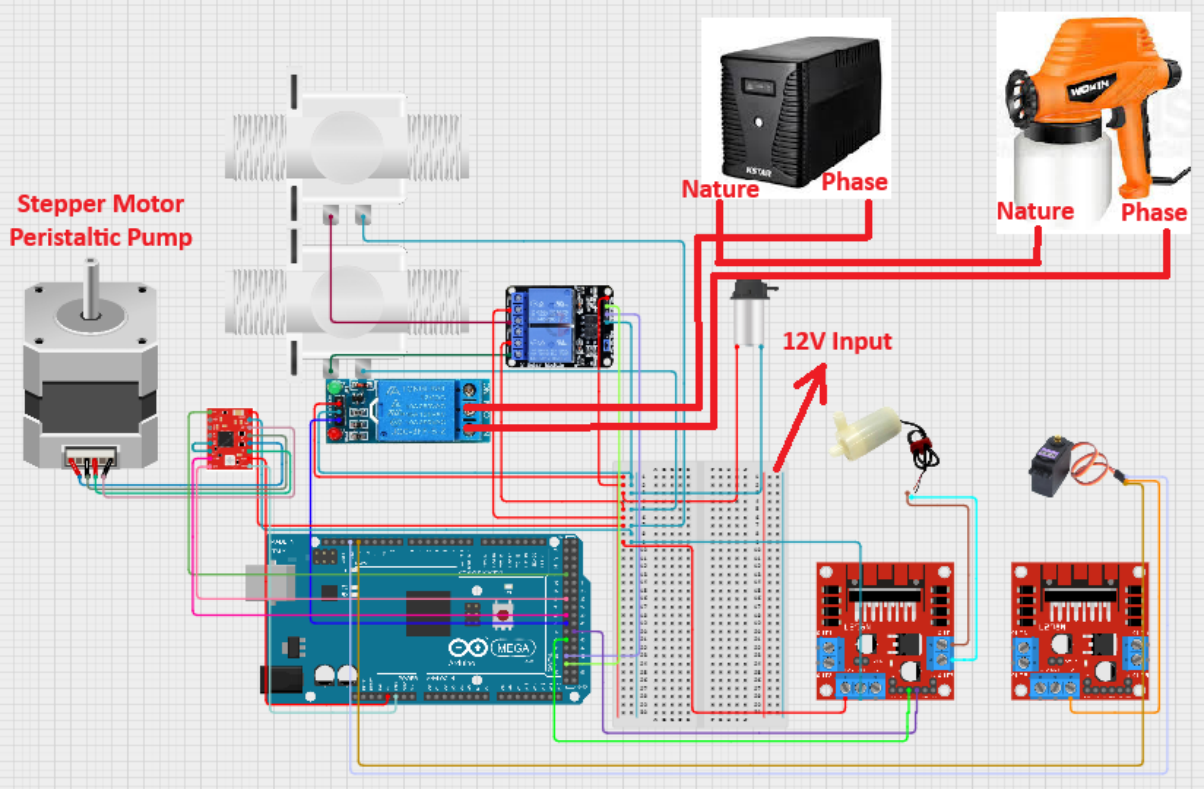

Figure 4.2: Stadium Robot Paint System Connection

The figure above shows the complete paint system connection includes:

- Paint Gun.
- UPS.
- Two Electric valves.
- Dual Channel Relay.
- 12V to 220V Relay.
- Stepper Motor Peristaltic Pump.
- A4988 Stepper Motor Driver.
- Mini Peristaltic Pump.
- Two H-Bridge.
- Servo Motor.
- Water Pump.

4.0.3 HC-SRO4 Ultrasonic

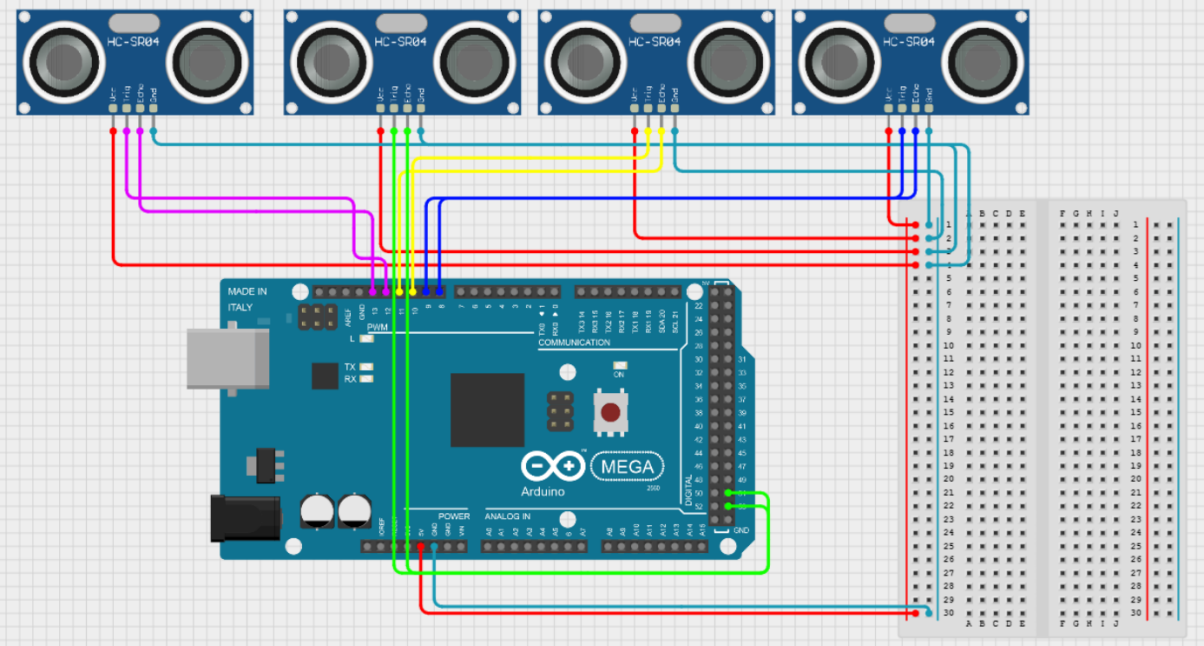

Figure 4.3: Ultrasonic Connection

The figure above shows the connection of HC-SR04 (Ultrasonic) on the Arduino.

5 Software Development

5.0.1 Main Page

We developed an HTML page that allows users to control the robot from any device. This page offers multiple options for interacting with the robot. In the automatic mode, the user is prompted to enter the length and width of the area. Once the user presses ”Start,” the robot begins drawing a football field based on the dimensions provided. Additionally, there is a manual control option where the user can directly move the robot. Several buttons are available for controlling specific functions of the robot, such as cleaning, filling the paint, filling water, starting, stopping, and restarting both the robot and the paint system. In the second section of the page, we provide a manual drawing option. A table is included for users to input points, allowing the robot to draw based on these coordinates. Options are also available for drawing circles and curves (partial circles). Lastly, the page displays the current levels of the paint, water, and mixed tanks.

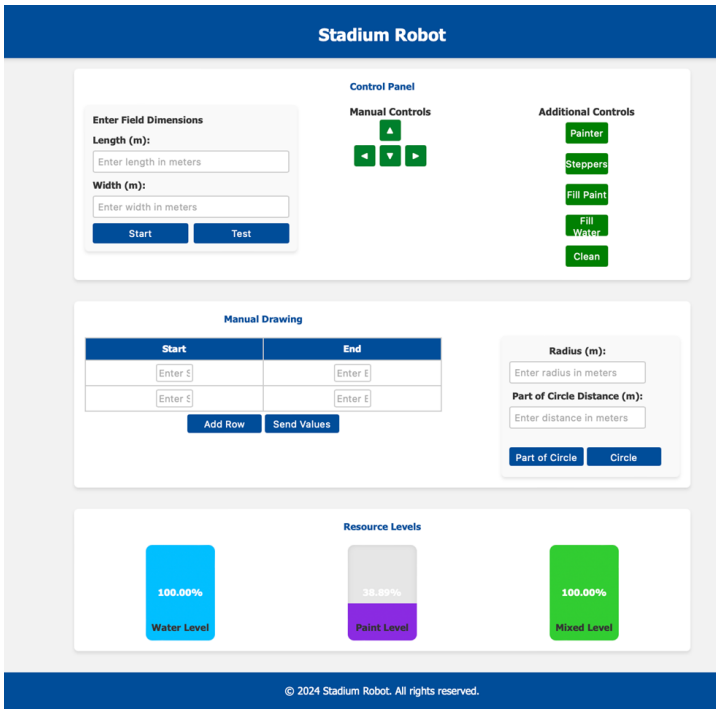

Figure 5.1: Stadium Robot HTML Page

5.0.2 Field Dimensions

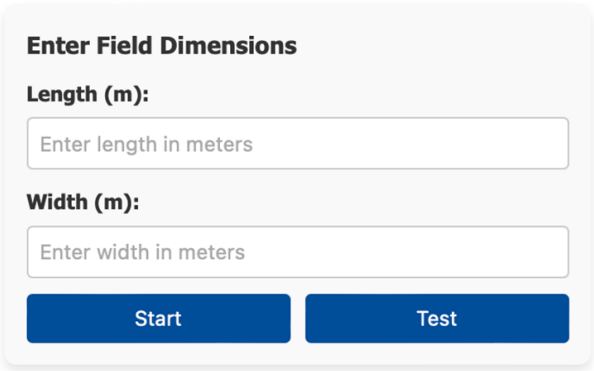

Figure 5.2: Stadium Robot Field Dimensions Section

In this section, the user can input the length and width of the area to draw the lines of a football stadium. When the ”Start” button is pressed, the robot will begin drawing the stadium based on the entered dimensions. The ”Test” button is used to draw a smaller section, specifically the penalty area. This function is mainly for live demo, as we currently do not have enough space to draw an entire stadium.

5.0.3 Manual Control

Figure 5.3: Stadium Robot Manual Control

This section provides manual controls for the robot. The user can use the directional buttons (up, down, left, right) to manually move the robot.

5.0.4 Additional Controls

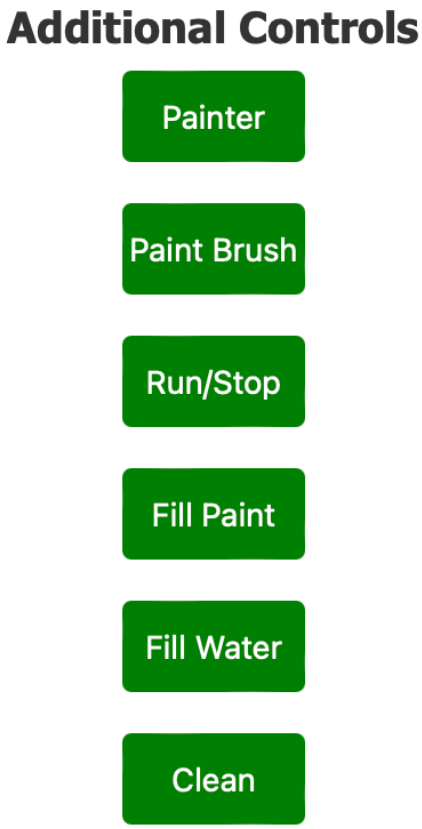

Figure 5.4: Stadium Robot Additional Controls

This section is used to control various parts of the robot:

- **Painter:** This button toggles the paint system on and off.
- **Run/Stop:** This button toggles the stepper motors on and off.
- **Paint Brush** buttons are used to either raise the brush up or toggle it to move down.
- **Fill Paint:** This button initiates the process of filling paint when the mixed bowl level is below 90% and the paint bowl level is above 5
- **Fill Water:** This button fills the water, similar to the fill paint process, but ensures the water level remains lower than the paint level.
- **Clean:** This button is used to clean the tubes of the robot after it finishes drawing.

5.0.5 Manual Drawing

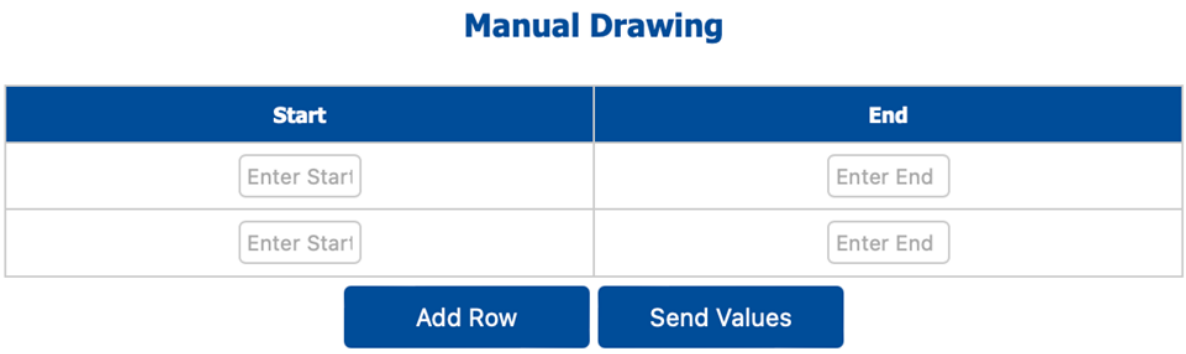

Figure 5.5: Stadium Robot Manual Drawing

This section is for manual drawing, where the user can input the start and end points of the lines to be drawn by the robot. The values entered are in meters.

- The Add Row button allows the user to add more rows for additional points in the table.
- The Send Values button sends all the values entered in the table to the robot. After each point is drawn, the robot will rotate 90 degrees to the left before continuing.

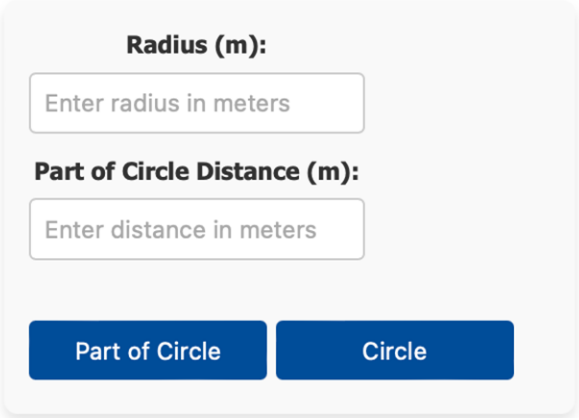

Figure 5.6: Stadium Robot Radius Drawing

- The Radius field is used to input the radius of a full circle (in meters).
- The Part of Circle Distance field is used to input the distance for drawing a curved line (in meters).

When the Circle button is pressed, the robot will draw a full circle based on the entered radius. Similarly, when the Part of Circle button is pressed, the robot will draw a curved line based on the entered distance.

5.0.6 Resource Levels

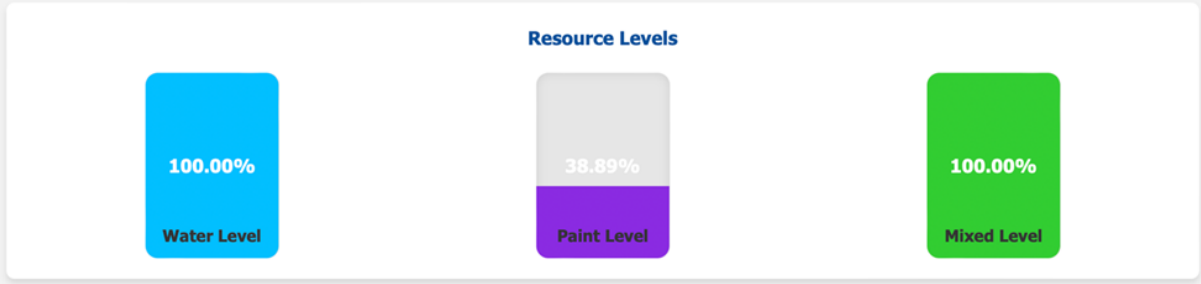

Figure 5.7: Stadium Robot Resource Levels

This section is used to monitor the levels of the water, paint, and mixed bowls. The levels update live without needing to reload the page, providing real-time information on the current resource levels.

6 Results & Discussion

6.1 Results

The development and testing of the Stadium Robot also produced a number of interesting outcomes especially in the field lining aspect:

- **Capability to Line Fields:** Unlike the traditional methods of drawing the lines on the ground, the Stadium Robot was able to draw lines on the football field and clean the tubes from paint using WiFi.
- **Uniform Line Application:** A constant paint circulation during the operations due to a built-in motorized peristaltic pump, a water pump, and electric valves significantly Enhanced the lines on the field.
- **Power Management:** Two 12V batteries, one with a capacity of 14A and the other with 9A, powered the robot, ensuring reliable operation of all components, including the pumps, motors, and sensors.
- **Tank Monitoring:** Three ultrasonic sensors were utilized to determine the levels of water, paint, and the mixed tank. These sensors enhanced the material's efficiency during the lining process.
- **Wireless Communication:** The combination of Arduino Mega and ESP32 module was extremely successful in achieving wireless communication enabling remote operation and management of the robot experienced in the field thereby making the process of lining more effective and easy to the users.
- **Overall Integration:** Following the integration of motion control, paint application, power management, and finally wireless communication systems, it was possible to achieve a functioning and efficient Stadium Robot designed to line the football field.

6.2 Discussion

6.2.1 Problem Resolution

The Stadium Robot directed the need of the users designing a manual and straightforward apparatus for marking of football fields, which also highlighted these necessary parameters of user-defined proportions, and constant paint usage. Though, there was not enough room to draw the full test of a stadium.

6.2.2 Contributions

- **Cost-benefit:** Used inexpensive components like Arduino mega and ESP32 modules within the limits.
- **User Control:** Controls any remote operation for indication of field dimensions using ESP32 module.
- **System Integration:** Quite the movement, paint application, and wireless communication was fitted in one system.

6.2.3 Logical Implications

- **Field Maintenance:** Highly practical for usage for computerized lining of sporting fields and indeed adjustable field sizes are applicable.
- **Labor Reduction:** Lining has been managed such that there is no work to be done physically by a human.

6.2.4 Limitations

- **Constraints:** The limited space available prevented the robot from marking a full-sized stadium.
- **Weight:**Portability is limited due to the weight of 35 kg.
- **Power Management:** Managing two batteries of different capacities introduced complexity.

7 Conclusion & Recommendations

7.1 Conclusion

The Stadium Robot project successfully achieved its primary goal of developing a cost-effective, automated solution for lining football fields. By utilizing affordable components, Stadium Robot demonstrated a feasible approach to automating a traditionally manual task. The integration of movement control, paint application, cleaning system, and wireless communication into a single system proved effective, offering practical benefits for field lining.

7.2 Recommendations

- **Decrease Weight:** Use lighter materials for enhanced portability and ease of operation for the robot.
- **Optimize Power Management:** Standardize battery capacities to ensure more consistent and reliable performance.
- **Improve Paint Application:** Modify the paint system to achieve smoother and consistent line marking in different field conditions.

7.2.1 Future Work:

- **Navigation and Autonomy Advancement:** Create advanced navigation algorithms that enables Stadium robot to independently navigate complex field layouts.
- **Expanded Field Marking Functionality:** Enhance Stadium Robot capabilities to include marking different types of sports fields, such as volleyball or badminton.
- **Improved User Interface:** Enhance the user interface to feature more intuitive controls and real-time feedback.
- **Automated Cleaning and Maintenance System:** Design an automated system for cleaning the robot's components, specifically the paint lines, to minimize downtime and ensure consistent performance.

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