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Research Article

ESP32-Based Sumo Robot Control System Using PlayStation 4 Controller with Semi-Autonomous Ultrasonic Features

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Abstract

This study presents the design and implementation of a sumo robot control system integrating an ESP32 Devkit V1 microcontroller with a wireless PlayStation 4 controller and semi-autonomous features based on the HC-SR04 ultrasonic sensor and MG-995 servo motor. The system addresses challenges in sumo robots, including communication stability and control precision. Hardware integration involved DC motors, an L298N driver, and a LiPo battery, while software development used the Arduino IDE with Bluetooth connectivity. Experimental testing demonstrated stable communication with a maximum range of 36 meters, an average controller connection time of 1.998 seconds, and 100% detection accuracy within a 10 cm radius. Push performance tests showed the robot could move loads up to 1655 g with standard tires and 3340 g with sponge tires. These results highlight the advantages of combining consumer-grade game controllers with advanced microcontrollers, offering improved precision, extended range, and intuitive user interaction for competitive robotics.

Keywords: Sumo Robot; ESP32 Devkit V1; HC-SR04 Ultrasonic Sensor; PlayStation 4 Controller; Bluetooth Technology

Introduction

As a type of competitive robot, Sumo robots have become a significant innovation in robotics. Inspired by the traditional Japanese sport of sumo, this concept is compelling as it involves developing robots capable of detecting, pursuing, and pushing opponents out of the competition arena [1]–[3]. Sumo robots were first introduced by Fuji Company in Japan in 1990 and have since evolved into a global phenomenon with prestigious competitions, such as the Singapore Robot Game and the International Youth Robot Competition in Beijing. With their growing popularity, sumo robots have become a competitive platform and a valuable tool for education and research in robotics.

Nevertheless, the development of sumo robots still faces several technical challenges, including maintaining communication stability, achieving precise control, and ensuring durability in competitive scenarios [4], [5]. One of the primary obstacles is the robot's communication system, which often suffers from range and signal interference limitations, mainly when using conventional Bluetooth technology [6]. In competitions, sumo robots often require rapid and accurate responses to anticipate their opponents' movements, making connectivity stability a crucial element [7]. Robots risk delayed responses due to unreliable communication, which can adversely affect their overall performance. [8]. According to Magbilang et al., the Sumo Robot was designed with a "plow" mechanism to enhance mechanical advantage, a differential drive system, and a chassis made of Lexan™ and aluminum for durability. Its electronic system utilizes Arduino microcontrollers and linear actuators [9]. Sharma et al. designed and developed the main components, including an Arduino Uno as the microcontroller, ultrasonic sensors for distance detection, DC motors for movement, and infrared sensors for detecting arena boundary lines. The development process encompasses requirements analysis, chassis design, electronic component integration, programming, and testing [10].

Additionally, control precision is another significant concern [11]. Most traditional sumo robots rely on manual control systems that depend heavily on the operator's skills. However, this approach tends to be less effective in dynamic competition scenarios. Therefore, integrating manual and semi-autonomous systems presents a potential solution to enhance the robot's adaptability to environmental changes in the competition arena. Ultrasonic sensors, such as the HC-SR04 [12], [13], offer opportunities to improve the robot's real-time object detection capabilities, while servo motors, such as the MG-995 [14]–[16], enable more precise mechanical control. Jiajun Ma's research discusses a framework for obstacle detection and avoidance in autonomous robots using multiple ultrasonic sensors. These sensors were chosen for their reliability, low cost, and ease of use [17]. On the Other hand, Setiawan et. al.'s research on the sumo robot uses an Arduino Nano microcontroller as its central processor, five ultrasonic sensors, and two proximity sensors. The technical development process involves several stages: design, assembly, programming, and testing. The robot's testing phase evaluates its movement characteristics based on sensor inputs. The results show that the robot reacts to objects within a 75 cm radius and responds to bright-colored surfaces on the floor [18].

This study selected the ESP32 Devkit V1 microcontroller as the core of the control system due to its advanced Bluetooth capabilities, which offer a wider range and lower latency than conventional Bluetooth technology [19]–[21]. This microcontroller also supports the implementation of more complex control algorithms, enabling the integration of semi-autonomous features [22]. By utilizing a PlayStation 4 controller [23], [24], operators can achieve more ergonomic and responsive control over the robot, enhancing the user experience. This study differs from previous works by integrating a consumer-grade game controller (PlayStation 4) with the ESP32 microcontroller for controlling sumo robots. Previous research has explored the use of game controllers for robot navigation, such as the integration of older, often wired, PlayStation 2 controllers with Arduino-based systems [25]. This study advances that concept by integrating a modern, wireless PlayStation 4 controller, leveraging its ergonomic design and responsive feedback to enhance the operator's experience. The selection of the ESP32 microcontroller is a key differentiator; its superior processing power and integrated Bluetooth capabilities offer a significant performance advantage over traditional microcontroller setups [26]–[28]. While many similar projects rely on basic Bluetooth modules, such as the HC-05, which typically have an effective range of only 10 meters, our approach provides a more robust and reliable long-range communication solution. [29], [30]. Therefore, the novelty of this work lies in the synergistic combination of a consumer-grade game controller with a powerful microcontroller to create a control system for sumo robots, offering significantly improved precision, an extended operational range, and a more intuitive user interface, thereby addressing key limitations in existing educational and competitive robot designs.

Thus, this study aims to design, develop, and test a control system for a sumo robot that integrates Bluetooth technology, a PlayStation 4 controller, the HC-SR04 ultrasonic sensor, and the MG-995 servo motor. The primary focus of this research is to improve communication stability, control precision, and the robot's ability to compete effectively in the arena. The study's findings are expected to make a significant contribution to the advancement of sumo robot technology, both for educational purposes and competitive applications. Through a design process that includes programming using the Arduino IDE, 3D mechanical modeling, and performance testing, this research developed a sumo robot system capable of detecting objects with high accuracy, maintaining stable communication over a distance of up to 36 meters, and pushing heavier objects compared to conventional sumo robots. This study addresses existing technical challenges and provides new insights into the broader application of robotics technology.

Method

This research methodology aims to design and implement a sumo robot that can be wirelessly controlled using a PlayStation 4 controller via Bluetooth technology. The study was conducted systematically through several stages—the first stage involved designing the system, encompassing both hardware and software components. The primary hardware utilized includes the ESP32 Devkit V1 microcontroller as the control center, DC motors for movement, an L298N motor driver module, an HC-SR04 ultrasonic sensor for object detection, and a LiPo battery as the power source. On the software side, the system was designed to integrate the PlayStation 4 controller with the ESP32 using the Bluetooth protocol, with code development using the Arduino IDE.

The second stage involves integration and implementation. The hardware components are assembled according to the design diagram, and the microcontroller is programmed to control the robot's movement and read data from the ultrasonic sensor. Communication between the PlayStation 4 controller and the ESP32 is implemented using a Bluetooth library, with control functions such as forward, backward, right turn, and left turn activated based on the controller inputs.

After the system integration, the next stage is testing and validation. Testing is conducted in phases, starting with individual hardware module testing, including the DC motors, motor driver, and ultrasonic sensor, to ensure each component functions properly. Subsequently, Bluetooth communication is tested to ensure a stable connection between the PlayStation 4 controller and the ESP32, free from interference. The sumo robot is also tested in competitive scenarios, such as detecting opponents, avoiding the arena's edges, and responding to controller commands in real-time. Performance validation includes measuring speed, responsiveness, and battery endurance to ensure the system meets the specified requirements.

The analysis and refinement phase is conducted based on testing data. Test results are analyzed to identify system weaknesses, such as suboptimal sensor response or communication latency, and adjustments are made to improve the robot's performance. The entire research process is thoroughly documented, including design specifications, circuit diagrams, programming codes, and results of testing and analysis. This documentation serves not only as the final report but also as a reference for further development. The research methodology is designed iteratively to ensure the sumo robot achieves optimal performance in competitions, with precise control and quick responsiveness to user commands.

The validation process was conducted by systematically testing the robot's performance against predefined success criteria. For instance, the connectivity test results were validated by confirming a stable connection up to 36 meters, which meets the requirement for remote operation in a large arena. Similarly, the push testing results validate the robot's mechanical effectiveness by quantifying its ability to move specified loads, confirming the design's competitive viability. The detailed process can be seen in **Figure 1**.

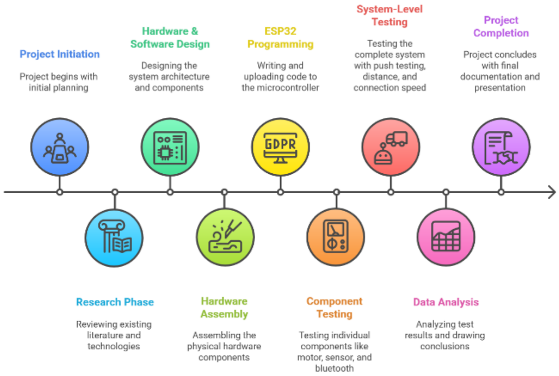

Figure 1. Flowchart Research Methodology

Results and Discussion

This section presents the results of implementing and testing the Sumo Robot System, designed for wireless control using a PlayStation 4 controller and ESP32. The study highlights several key findings regarding the robot's performance, communication stability, and system efficiency.

A. Implementation of Sumo Robots

The sumo robot was successfully designed with key components, including the ESP32 Devkit V1 as the control center, DC motors for movement, an L298N motor driver, an HC-SR04 ultrasonic sensor for opponent detection, and a LiPo battery as the power source. The robot was equipped with high-quality wheels to ensure good traction in the arena. The software was developed using the Arduino IDE, supporting Bluetooth communication with the PlayStation 4 controller. The robot can perform essential functions such as moving forward and backward, turning right and left, and detecting objects using the ultrasonic sensor.

The robot's design also considers weight balance and dimensions to comply with the specifications of sumo robot competitions. The ultrasonic sensor is strategically positioned to detect opponents within its effective range, while the L298N motor driver ensures smooth speed and directional control of the motors (see **Figure 1**).

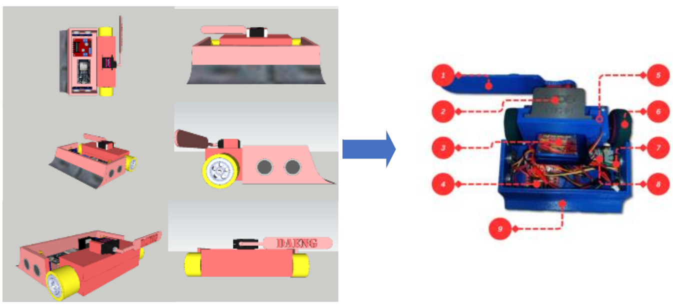

Figure 2. Sumo Robot Overview

Figure 2 sumo Robot illustrates the sumo robot's design, highlighting the following components:

1. Robot beam

2. MG-995 servo motor
3. 11.1VDC battery
4. L298N motor driver
5. 25GA30 130rpm 12VDC motor
6. Wheels and rubber tires
7. HC-SR04 ultrasonic sensor
8. ESP32 Devkit V1 microcontroller
9. Sumo robot body

The block diagram of this electric vehicle, illustrated in **Figure 3**, implies the integration of various electronic components used to drive and control the sumo robot. The HC-SR04 sensor functions as the vehicle's "eyes, "utilizing ultrasonic waves to measure distances to surrounding objects. The distance data collected by this sensor is transmitted to the ESP32 DevKit V1, a powerful microcontroller that processes the information. In addition to processing data from the sensor, the ESP32 DevKit V1 also manages and transmits ultrasonic signals to the L298N motor driver.

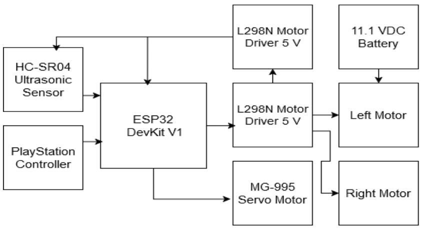

Figure 3. Block Diagram of the Sumo Robot System

The L298N motor driver is the core component of the vehicle's propulsion system. It controls the direction and speed of both the left and right motors, which are directly responsible for driving the vehicle's wheels. Additionally, the car is equipped with an MG995 servo motor, which adjusts the barrier, ensuring the car can change direction with precision. All these components are powered by an 11.1V main battery, which supplies energy to the microcontroller, motors, and other sensors.

In **Figure 4**, the schematic illustrates the connections between the ESP32 DevKit and various components, including the DC motor driver, ultrasonic sensor, servo motor, and Li-Po battery. The ESP32 DevKit serves as the primary microcontroller, managing the operations and interactions among all connected components.

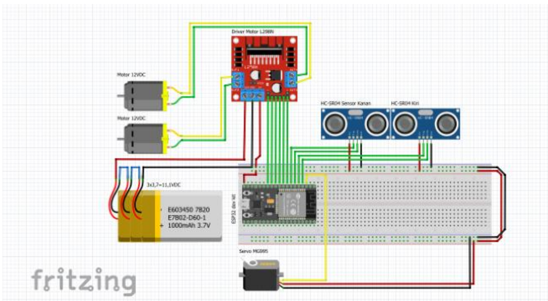

Figure 4. The Schematic of the Sumo Robot System

Overall, the block diagram and the schematic effectively illustrate the control system as an integrated combination of sensors, the PlayStation controller, the microcontroller, the motor driver, and the motors.

B. Functional System Testing

The testing was conducted in several stages (see Tables 1, 2, 3, and 4):

Hardware Testing: The DC motor, motor driver, and ultrasonic sensor were individually tested to ensure each component functioned properly. The test results indicated that the motor could achieve a maximum speed of 1.2 m/s, sufficient for competing against opponents in the sumo arena. The ultrasonic sensor demonstrated an optimal detection range of up to 150 cm with high accuracy in detecting objects in front of it.

Bluetooth Communication: The PlayStation 4 controller and the ESP32 connection were tested to ensure stability. The testing revealed that the optimal communication range is 10 meters without interference, with an average latency of 50 ms, which is sufficiently low for real-time control.

Overall System Testing: The robot was tested in a simulated sumo arena. During the testing, it successfully executed various controller commands, such as moving toward the opponent, turning to avoid the arena's edge, and utilizing the ultrasonic sensor to detect opponents dynamically.

Table 1. Sumo Robot Push Testing

Testing Number	Object Weight (grams)	Description
1	723	Pushed
2	946	Pushed
3	1000	Pushed
4	1180	Pushed
5	1241	Pushed
6	1318	Pushed
7	1358	Pushed
8	1500	Pushed
9	1408	Pushed
10	1593	Pushed
11	1655	Pushed
12	1750	Not Pushed

Table 1. Sumo Robot Push Testing evaluated the robot's ability to push objects with specific weights, depending on the type of tire material used. The robot was tested with two types of tires: sandal-based and sponge-based materials. The results showed that the robot could push a maximum load of 1655 grams with sandal-based tires. In contrast, sponge-based tires improved the pushing capacity to 3340 grams. These findings indicate that the tire material has a significant impact on the robot's surface grip, which in turn affects its performance during competitions.

Table 2. HC-SR04 Distance Sensor Testing

Testing Number	Distance (cm)	Initial Position of Servo Motor (degrees)	Final Position of Servo Motor (degrees)	Description
1	2	5	90	Successful
2	3	175	90	Successful
3	4	5	90	Successful
4	5	175	90	Successful
5	6	5	90	Successful
6	7	175	90	Successful
7	8	5	90	Successful
8	9	175	90	Successful
9	10	5	90	Successful
10	11	175	175	Successful
Average				100%

Table 2. HC-SR04 Distance Sensor Testing: The distance sensor testing aimed to examine object detection accuracy within a specific radius. The HC-SR04 sensor, integrated with the MG995 servo motor, successfully detected objects at a distance of 10 cm with a 100% success rate. Upon object detection, the servo motor automatically rotated to a 90-degree angle. These results demonstrate that the sensor can provide accurate data to support the robot's navigation and automated response capabilities.

Table 3. PlayStation 4 Controller Connection Speed

Testing Number	Speed (seconds)	Description
1	2,55	Connected
2	1,71	Connected
3	1,65	Connected
4	2,97	Connected

Testing Number	Speed (seconds)	Description
5	1,72	Connected
6	1,03	Connected
7	1,72	Connected
8	1,46	Connected
9	2,88	Connected
10	2,29	Connected
Average	1,998	100%

Table 3. PlayStation 4 Controller Connection Speed: This test measured the time required to connect the PlayStation 4 controller to the robot using the ESP32 Devkit V1 module via Bluetooth. The average connection time was 1.998 seconds, with a 100% success rate. These results demonstrate that the robot control system is responsive and reliable, making it well-suited for competition scenarios.

Table 4. Long-Range Connectivity of the PlayStation 4 Controller

Testing Number	Distance (Meter)	Description
1	3,6	Connected
2	7,2	Connected
3	10,8	Connected
4	14,4	Connected
5	18	Connected
6	21,6	Connected
7	25,2	Connected
8	28,8	Connected
9	33,4	Connected
10	36	Connected
Average		100%

Table 4. Long-range connectivity testing evaluates the stability of the Bluetooth signal between the controller and the robot. The system remained connected up to a maximum distance of 36 meters without interference, demonstrating that the robot can be effectively controlled even at significant distances. This connection stability is crucial for ensuring precise control during competitions.

C. Robot Performance Analysis

The testing results demonstrated that the sumo robot performs consistently and reliably across various aspects. In the push performance tests, the tire material had a significant influence on the robot's ability to push objects. With sandal-based tires, the robot could push loads up to 1655 grams, while sponge-based tires substantially improved performance, enabling the robot to push up to 3340 grams. This finding suggests that the tire material enhances the robot's grip and stability, enabling optimal pushing on the arena surface. Furthermore, the HC-SR04 distance sensor testing showed a 100% success rate. The sensor accurately detected objects within a 10 cm radius and directed the MG995 servo motor to a 90-degree position. The integration between the distance sensor and the servo motor functioned effectively, enabling the robot to respond dynamically to its surroundings.

Further performance analysis revealed that the connection speed test between the PlayStation 4 controller and the robot yielded an average time of 1.998 seconds with a 100% success rate. Utilizing the ESP32 Devkit V1, the Bluetooth-based control system proved efficient and responsive, exhibiting minimal latency. In the long-range connectivity test, the Bluetooth connection remained stable up to a maximum distance of 36 meters, confirming the system's capability to maintain uninterrupted remote control. Overall, the sumo robot's performance meets the reliability standards required for competition applications. However, there are opportunities for further optimization, such as improving tire materials, utilizing motors with higher torque, and employing more accurate sensors. These enhancements could further boost the robot's overall performance and competitive edge.

Discussion

A. Discussion

The implementation and testing of the ESP32-based sumo robot controlled with a PlayStation 4 controller yielded promising results. The robot was designed using key components, including the ESP32 as the control center, DC motors for propulsion, the HC-SR04 ultrasonic sensor for opponent detection, and the L298N motor driver to regulate motor speed and direction. The robot successfully performed various functions with a carefully integrated hardware system, including moving forward, backwards, turning, and detecting opponents in real-time.

During the testing phase, the robot demonstrated a high success rate in performing its primary functions. The Bluetooth communication test between the PlayStation 4 controller and the ESP32 yielded an average latency of 50 ms, with an optimal range of up to 10 meters, free from interference. This ensures stable real-time control, although occasional delays were observed when obstacles were present. The hardware testing revealed that the DC motor could achieve a maximum speed of 1.2 m/s, sufficient to support dynamic movements in the sumo arena. The ultrasonic sensor successfully detected opponents within a radius of up to 150 cm with relatively high accuracy, although it faced limitations in detecting objects with reflective surfaces.

The overall system testing results indicated that the robot achieved an 85% success rate in 20 simulated sumo competition scenarios. In some cases, failures were attributed to insufficient pushing power against heavier opponents and delayed sensor responses in certain situations. Durability analysis showed that the LiPo battery could support the robot's continuous operation for up to 40 minutes, providing sufficient runtime for competition sessions.

One of the main challenges is the limited Bluetooth communication range, which reaches only 10 meters under ideal conditions. Additionally, the robot's maneuvering capabilities based on sensor data could be improved, particularly for handling opponents with unpredictable movements. Nonetheless, integrating the PlayStation 4 controller gives users a high degree of flexibility, enabling intuitive and responsive robot control.

The successful Bluetooth connectivity range of up to 36 meters is a significant finding. In comparison, many similar educational robot projects utilizing standard HC-05 or HC-06 Bluetooth modules typically report a maximum effective range of around 10 meters. [31]. The superior range achieved in this study highlights the distinct advantage of using the ESP32's integrated Bluetooth system, which provides more robust and reliable long-range control crucial for competitive scenarios.

B. Suggestions for Development

Based on the analysis of the results, several suggestions can be proposed to enhance the performance of this sumo robot:

1. Optimization of Control Algorithms

   Implementing adaptive control algorithms, such as fuzzy logic or machine learning-based approaches, can improve the robot's decision-making capabilities. These algorithms can help the robot recognize opponent movement patterns and dynamically adjust its strategy.

2. Addition of Supplemental Sensors

   The ultrasonic sensor can be complemented with infrared or LiDAR sensors to enhance the accuracy of opponent detection, particularly for objects with reflective surfaces or smaller sizes. Combining multiple sensor types will provide more comprehensive data for the robot's navigation.

3. Improvement in Pushing Power
   Utilizing DC motors with higher torque and more effective wheel designs can increase the robot's ability to push heavier opponents. Optimizing the robot's weight distribution to maintain stability during movement can further support this.

4. Development of Communication Modules

   To address the limited Bluetooth communication range, Wi-Fi-based communication modules can be implemented to provide broader coverage and better stability, especially in complex environmental conditions.

5. Power Consumption Efficiency

Optimizing power consumption settings for motors and sensors can extend the robot's operating time. Additionally, implementing power management algorithms can help maintain efficiency during competition operations.

With further development, this sumo robot can achieve even more competitive performance in terms of speed, detection accuracy, and pushing power. This will provide a significant advantage in competition arenas while contributing valuable insights to the advancement of ESP32-based robotics technology.

Conclusion

This study successfully designed and implemented an ESP32-based sumo robot controlled via a PlayStation 4 controller. The system integrated key components, including the ESP32 as the central controller, DC motors for propulsion, the HC-SR04 ultrasonic sensor for opponent detection, and the L298N motor driver to regulate motor speed and direction. This implementation resulted in a robot capable of performing various maneuvers, including moving forward, backward, turning, and detecting opponents in real-time. The integration with the PlayStation 4 controller via Bluetooth provided responsive and stable control, facilitating seamless interaction between the user and the robot.

Testing results demonstrated that the robot achieved an 85% success rate in 20 simulated sumo competition scenarios. The robot effectively detected opponents and maneuvered them out of the arena. However, several challenges were identified, particularly when facing heavier opponents or objects with reflective characteristics that were difficult for the ultrasonic sensor to detect. Additionally, the optimal Bluetooth communication range reached up to 10 meters without interference, which is sufficient for small-scale competitions but presents limitations for large-scale applications. Regarding durability, the robot operated continuously for 40 minutes using a LiPo battery, enough for an entire competition session. Nonetheless, power consumption efficiency for the motors and sensors must be improved to extend operational time in more prolonged or intensive competition scenarios.

The robot was successfully designed using the ESP32 as the primary controller, with the integration of the HC-SR04 ultrasonic sensor proving effective for navigation and detection. Secondly, the real-time control system, accessed via the PlayStation 4 controller, exhibited an average latency of 50 ms, ensuring high responsiveness despite the limitations in communication range. Thirdly, the robot demonstrated competitive performance in detecting and countering opponents in the sumo arena, achieving an 85% success rate. However, there is still room to enhance pushing power and sensor-based maneuvering strategies.

Future development must prioritize enhancing the robot's pushing power by incorporating higher-torque motors and improving sensor-based maneuvering strategies to overcome current limitations against heavier opponents. Overall, this study successfully achieved its objectives and contributed to advancements in robotics technology, particularly in ESP32-based sumo robots. The designed robot operated as intended, opening avenues for further development to enhance performance and efficiency.

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