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Design of Time Out Devices for Amateur Volleyball Games Using ESP32 Microcontroller

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ABSTRACT

This study developed a wireless time-out device for amateur volleyball games using ESP32 microcontrollers and ESP-NOW communication. The device aims to improve the efficiency and accuracy of time-out requests, eliminating delays from traditional manual signaling. Functional and field tests confirmed seamless coach-referee communication, ensuring prompt time-out processing. Performance evaluations covered TFT display readability, push button responsiveness, and communication stability across distances. The TFT screen offered clear visibility at night but had readability issues under direct sunlight, indicating a need for brightness optimization. Distance tests showed reliable ESP-NOW communication within 20-100 meters; however, signal degradation and packet loss occurred beyond this range. These findings highlight the importance of optimizing system placement and display readability for diverse match conditions.

Keywords: *ESP32, sports technology, time-out device, volleyball, wireless communication*

Introduction

In the modern era, sports have evolved beyond physical competition, integrating technology to enhance performance, fairness, and overall experience for players, officials, and spectators. Innovations in sports technology have led to significant improvements in game efficiency, data analytics, athlete training, and officiating accuracy [1]. From advanced tracking systems that monitor player movement [2] to digital scoreboards [3], technological advancements continue to shape the way sports are played and managed. Another key innovation is the use of smart communication devices that enable real-time interaction between coaches, referees, and players [4]. These systems improve decision-making and strategic planning by providing immediate access to game data and facilitating seamless communication on the field.

In volleyball, one crucial aspect of game management is the time-out process, which allows coaches to briefly pause the game for strategic discussions and player adjustments [5]. However, traditional time-out request methods, relying on manual signals such as verbal calls or hand gestures, are often inefficient and prone to misinterpretation, leading to unnecessary game delays [6]. The fast-paced nature of volleyball means referees may not always immediately notice a coach's request, causing delayed responses that impact game momentum. Additionally, in noisy or high-pressure environments, verbal requests can be misheard or overlooked, and hand signals may not always be clearly visible [7]. This inconsistency can result in unfair play and hinder strategic team adjustments. Furthermore, the absence of an automated system increases the risk of human error, where referees might mistakenly acknowledge or deny a time-out request , potentially influencing match outcomes and leading to disputes [8]. Such errors could influence match outcomes and lead to disputes between teams and officials.

Current technological interventions in volleyball, such as digital scoring and referee communication tools, have improved various aspects of game management. However, a noticeable gap remains in the implementation of a reliable, wireless time-out system that ensures accuracy, speed, and ease of use. Existing solutions to improve referee-coach communication include electronic whistles, LED-based signals, and automated scoreboard integration. While these tools have enhanced some aspects of game management, they possess notable weaknesses. For instance, LED-based signals still demand visual attention from referees, and electronic whistles do not fully address time-out request delays. Moreover, many existing systems often require complex installations and expensive infrastructure , limiting their accessibility for amateur and community-level volleyball games.

Addressing this problem offers significant benefits, including reducing game disruptions, improving referee-coach coordination, and ensuring fairer match conditions [9]. A reliable time-out system can also contribute to better strategic planning for teams, allowing them to optimize time-out usage effectively [10]. Furthermore, the introduction of wireless communication for time-out management lays a foundation for further technological advancements in sports officiating.

This study contributes to the field by designing and implementing a wireless time-out device using ESP32 microcontrollers and ESP-NOW communication. Unlike existing methods and current technological interventions that rely on visual or auditory signals prone to misinterpretation (like electronic whistles or LED-based signals), this system provides a direct, low-latency, and reliable communication pathway between coaches and referees. The proposed solution is cost-effective, easy to deploy, and does not require complex infrastructure. By ensuring real-time, accurate, and seamless time-out requests, this research improves game management and fairness while paving the way for broader technological integration in sports officiating. Despite these benefits, future challenges include ensuring the scalability of the solution across different levels of competition and maintaining affordability for widespread adoption. Battery life, interference with other wireless devices, and regulatory approvals for official use in professional leagues must also be considered.

Research Methods

Tools and Materials

The tools and materials used in this study are essential for designing and implementing the time-out device system. The tools include an electric drill, a laptop for programming and testing, a screwdriver for assembling components, a cutter knife for precise modifications, and a soldering iron for connecting electronic components. Additionally, the materials used consist of a buzzer for audio alerts, three junction boxes to house the components, jumper wires for electrical connections, and three ESP32 microcontrollers for wireless communication. A printed circuit board (PCB) is utilized to organize and connect components, while three ON/OFF switches control device power. A Thin Film Transistor (TFT) display is used for visual outputs, and sufficient soldering tin ensures stable connections. Furthermore, two push buttons serve as input controls, and a reset button is included to restart the system when necessary.

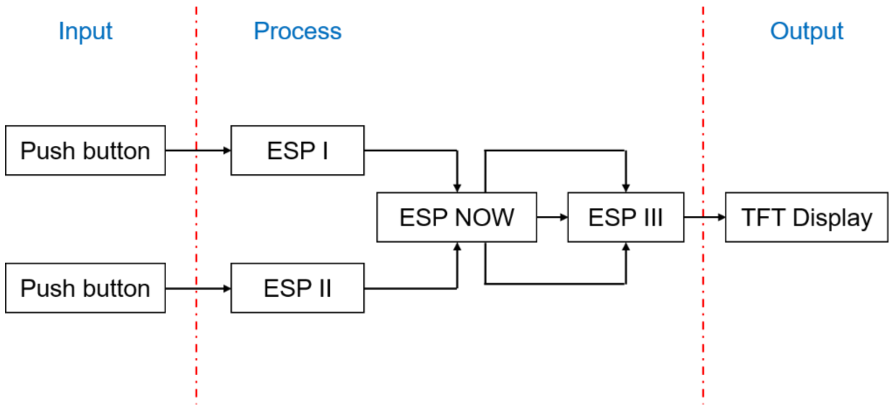


Figure 1. Block diagram of the wireless time-out system.

System Design

The system design consists of key components, including the ESP32 microcontroller as the central controller, a push button for triggering the time-out, a buzzer for alert notifications, and a Thin Film Transistor (TFT) display for text and numerical information, as shown in Figure 1. This diagram illustrates the fundamental architecture of the time-out device, showcasing its central components and their interconnections. The system design centers around the ESP32 microcontroller as the primary controller for both sender and receiver units. Each unit integrates a push button for initiating time-out requests, a buzzer for alert notifications, and a Thin Film Transistor (TFT) display for visual information. The figure highlights how the two sender devices (designated as ESP I and ESP II) communicate wirelessly via ESP-NOW protocol with the single receiver device (ESP III), enabling seamless time-out management.

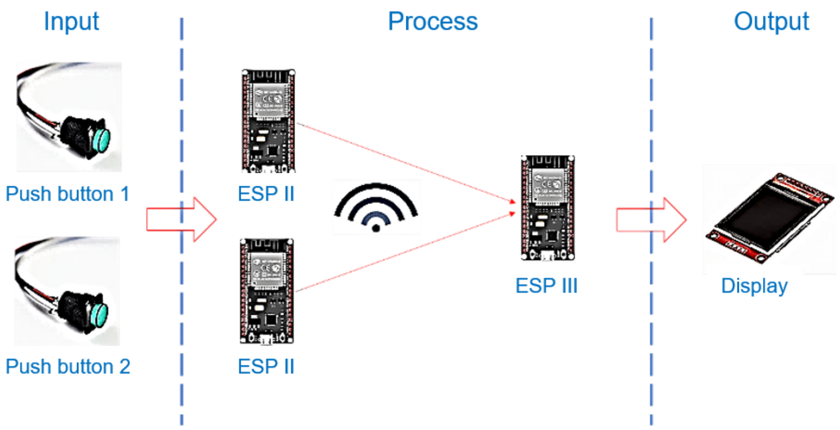
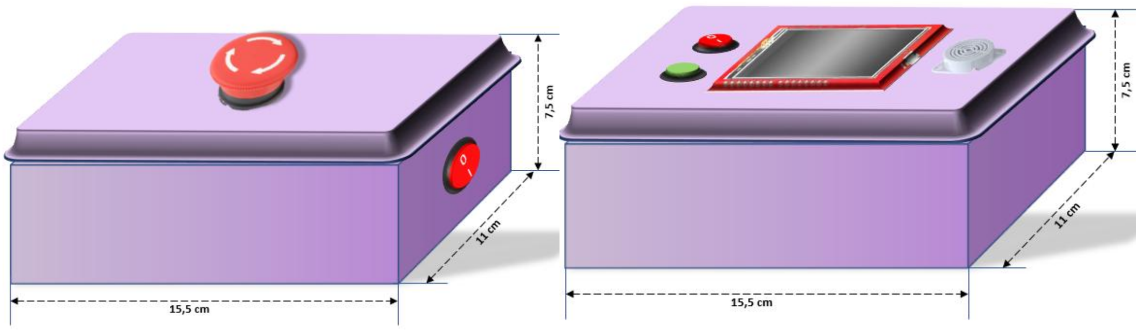


Figure 2. Overall system configuration and communication flow.

The overall system configuration is clarified in Figure 2, where the receiver unit then processes the request and displays the time-out notification on the TFT display, while the buzzer emits an audible alert to notify the referee. This figure clarifies the deployment and operational setup of the wireless time-out system within a volleyball game environment. The sender devices are strategically installed on the team benches, each equipped with a push button, allowing coaches to instantly request time-outs. Upon a button press, the ESP-NOW protocol facilitates a low-latency wireless transmission of the request to the receiver unit, which is positioned at the referee's station. The receiver unit then processes this incoming request, displaying a clear time-out notification on its TFT display, while a distinct audible alert from the buzzer notifies the referee, ensuring prompt action. The sender and receiver devices have distinct designs, as illustrated in Figure 3(a) and Figure 2(b). This figure illustrates the distinct physical designs and integrated components of the system's key units. As shown in Figure 3(a), the sender device, designed for placement on the player bench, comprises an ESP32 microcontroller, a push button for initiating time-out requests, and an ON/OFF switch for power control. Conversely, Figure 3(b) depicts the receiver device, intended for the referee's station, which integrates an ESP32 microcontroller, a TFT display for visual notifications, a reset button for clearing requests, a buzzer for auditory feedback, and an ON/OFF switch for overall system control. These detailed design specifications ensure an efficient, user-friendly, and reliable time-out request system that can be seamlessly integrated into amateur volleyball games.



(a) (b)

Figure 3. Physical design and component layout of the sender and receiver devices.

Functional Testing

The functional test of the time-out device in volleyball games was conducted to ensure all components functioned as expected and met user requirements. This testing process included evaluating each component individually to confirm their operational reliability. The TFT display was tested to verify its ability to present clear and readable information under various lighting conditions. The push button's response time was assessed for timely activation of time-out requests. Additionally, the buzzer was examined for sound clarity and appropriate volume levels to alert referees effectively. Through functional testing, the system was fine-tuned for optimal performance, making it dependable for real-game scenarios.

Field Testing

Field testing determined the real-world effectiveness of the time-out device during volleyball matches. The device was introduced to players and coaches, installed in a volleyball court environment, and tested for ease of use and response accuracy. The sender unit was placed on team benches, while the receiver unit was positioned near the referee to observe how well time-out requests were transmitted and received. This phase aimed to confirm the device's operation under typical game conditions and its ability to provide immediate feedback. Field testing also helped identify potential issues such as signal interference, visibility concerns under bright sunlight, and response time efficiency. The results showed that the device improved game efficiency by ensuring clear and fast communication between coaches and referees, enhancing strategic decision-making and minimizing disruptions.

Results and Discussion

TFT LCD Testing

The TFT display evaluation demonstrated reliable performance across all measured parameters, making it a crucial component of the time-out device. The screen's responsiveness ensured minimal delay in displaying time-out requests, which is essential for maintaining smooth game flow. Under controlled lighting conditions, the resolution test confirmed that the TFT display could present text and numerical data clearly without pixelation or distortion.

Figure 4. TFT Display testing

However, field testing under varying environmental conditions revealed that direct sunlight significantly impacted the visibility of the screen, a common issue also reported in previous studies on outdoor display technology. This aligns with findings by [11] which indicated that excessive ambient light reduces display contrast, making information harder to read. In contrast, night-time tests showed optimal readability, as the screen brightness was sufficient for clear visibility without additional illumination.

As shown in Figure 4, the TFT display was able to provide clear textual output in indoor and low-light conditions, ensuring that referees and players could easily interpret the information during the game. Despite the observed limitations in direct sunlight, the Thin Film Transistor (TFT) display was specifically chosen for this project due to its optimal balance of cost-effectiveness and performance for an amateur-level device. Compared to alternative display technologies, such as LED or e-paper displays, TFT screens offer a compelling solution given the project's design constraints and target audience. While LED screens provide superior visibility in high-brightness environments, their significantly higher power consumption makes them less practical for a battery-operated device intended for portability and extended use. Conversely, e-paper displays offer excellent readability in direct sunlight but are characterized by slower refresh rates, which could introduce unacceptable delays for real-time game updates crucial for time-out management. Therefore, the TFT display presented the most suitable compromise, providing clear visual feedback under most game conditions (especially indoors and at night) at a manageable cost, aligning with the project's goal of a practical and accessible solution for amateur volleyball games. The results of this study suggest that future improvements could involve integrating an adaptive brightness control mechanism or using an anti-reflective screen coating to enhance outdoor readability. Implementing these enhancements would align with recommendations from previous research and improve the device’s overall usability in various match conditions.

Table 1. RSSI Signal strength classification

Signal Strength (dBm)	Category
> -70 dBm	Very Good
-70 dBm to -85 dBm	Good
-86 dBm to -100 dBm	Moderate
< -100 dBm	Poor

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(a)

(b)

(c)

(d)

Figure 5 Stages of the push button test process and time-out display.

Push Button Test and Time-Out Duration Testing

This figure illustrates the four key operational stages observed during the push button functionality test. Specifically, Figure 5(a) depicts the initial state "when the button is pressed," indicating the user's action to initiate a time-out. Figure 5(b) then shows the immediate "time-out request" being sent and confirmed, highlighting the system's quick response. Subsequently, Figure 5(c) illustrates the active "time-out duration" countdown displayed on the TFT screen, providing real-time feedback. Finally, Figure 5(d) presents the "display after time out" expires, showing the updated status and readiness for subsequent game events. This comprehensive test process ensures the device's responsiveness and accurate visual feedback for time-out management.

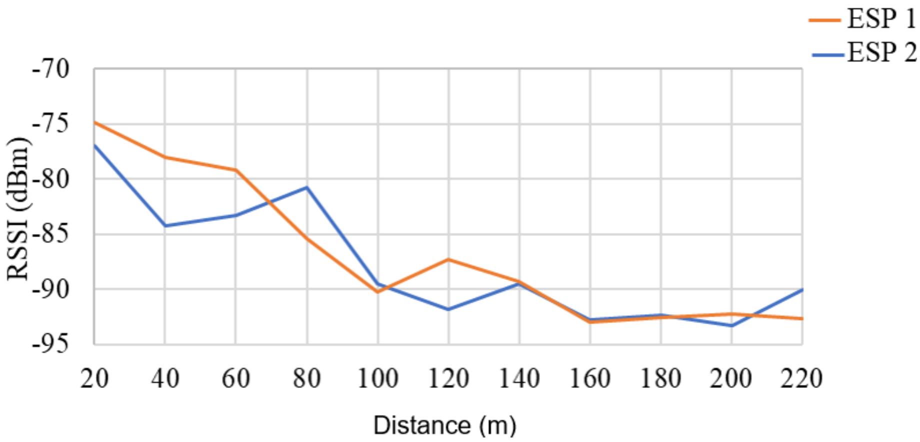

Figure 6 Gradual decline of Received Signal Strength Indicator (RSSI) values over distance.

The gradual decline of received signal strength indicator (RSSI) values over distance in Figure 6, represents the signal performance of the ESP-NOW communication as the distance between the sender and receiver devices increases. As depicted, the RSSI values show a clear and consistent decline as the operational range extends, indicating the weakening of the wireless signal. This gradual degradation directly impacts the stability and reliability of communication over longer distances. Understanding this relationship is crucial for optimizing device placement to maintain robust signal integrity during volleyball games.[12], [13].

The ESP32 microcontroller ensures real-time monitoring and enforcement, while the TFT display offers immediate feedback [14], helping referees and coaching staff manage the game seamlessly. The results of the time-out duration testing confirm that the system functions reliably, providing accurate countdowns and compliance with official regulations, further enhancing the efficiency of the time-out process in volleyball matches.

The push button test evaluates the component's sensitivity, response time, and durability under different conditions. The test ensures that the button activates reliably without excessive force and that there is no noticeable delay between pressing the button and sending the time-out request. Additionally, the push button's durability was tested through repeated use simulations to determine its resilience during extended gameplay.

The ergonomic placement of the push button was also examined to ensure it can be easily accessed by coaching staff without accidental activation. Table 2 presents a summary of push button performance metrics, including response time, activation force, and durability. The results confirm that the push button is responsive, durable, and functions effectively in high-pressure game situations, making it a reliable part of the time-out device system.

```
17:49:33.845 ->
17:49:36.070 -> Packet received from: 48:e7:29:ad:14:9c
17:49:36.070 -> 1, -92
17:49:36.070 ->
17:49:38.822 -> Packet received from: 58:bf:25:82:1b:90
17:49:38.869 -> 2, -87
17:49:38.869 ->
17:49:41.074 -> Packet received from: 48:e7:29:ad:14:9c
17:49:41.074 -> 1, -90
17:49:41.074 ->
17:49:43.840 -> Packet received from: 58:bf:25:82:1b:90
17:49:43.840 -> 2, -89
17:49:43.840 ->
17:49:46.050 -> Packet received from: 48:e7:29:ad:14:9c
17:49:46.050 -> 1, -94
17:49:46.050 ->
```

Figure 7 Instances of unsent data packets during communication tests.

Figure 7 shows the instances of unsent data packets during communication tests. This figure highlights specific occurrences where data packets failed to transmit successfully between the sender and receiver devices. Analyzing these instances provides critical insights into the communication reliability and potential areas of signal loss, such as interference or exceeding effective range. Understanding these patterns of unsent data is essential for identifying limitations and proposing improvements to the device's wireless transmission stability under various environmental conditions.

Figure 8 Strategic placement of the sender device (Coach Unit) on a volleyball court.

Figure 8 illustrates the typical placement of the sender device, specifically designed for coaches on the team bench. This positioning is crucial for ensuring optimal line-of-sight and minimizing potential signal obstructions, thereby maximizing the reliability and range of ESP-NOW communication with the referee's receiver unit. Effective placement directly influences the consistent and immediate transmission of time-out requests, which is vital for seamless game flow and strategic coaching decisions. The results of the distance test demonstrate that ESP-NOW communication performs reliably within a range of 20 to 100 meters, with a gradual decline in signal strength beyond this threshold. As shown in Figure 6, the RSSI value decreases consistently from 20 to 100 meters, while at distances between 120 and 200 meters, the signal remains relatively stable but weaker. The highest signal strength was recorded at 20 meters, with RSSI values ranging from -74 dBm to -77 dBm, classifying it within the 'Good' category. However, as the distance increases from 100 to 200 meters, the RSSI values drop into the 'Moderate' category, ranging between -90 dBm and -92 dBm.

The classification of RSSI values follows the TIPHON standard [15], as presented in Table 1, which categorizes signal strength into four levels: Very Good, Good, Moderate, and Poor. These classifications provide a useful benchmark for evaluating the effectiveness of ESP-NOW communication in different distance ranges. Comparing these results with previous studies on ESP-NOW communication, the observed decline in RSSI values aligns with findings that suggest a noticeable performance drop as transmission distance increases. Studies on wireless communication stability indicate that signal attenuation over long distances is influenced by environmental interference, obstacles, and device orientation. While ESP-NOW is known for its efficiency in low-power, short-range communication, its effectiveness is significantly reduced beyond 100 meters due to signal degradation and increased packet loss.

Beyond 100 meters, packet loss was observed, meaning that some data failed to transmit successfully [16], [17], as illustrated in Figure 7. This suggests that while ESP-NOW maintains a connection over extended distances, its reliability diminishes as the signal weakens, resulting in intermittent data loss [18]. Such limitations emphasize the importance of optimizing deployment strategies for ESP-NOW-based systems to ensure seamless and uninterrupted data exchange.

From a practical standpoint, these findings highlight that ESP-NOW is best suited for applications requiring stable communication within a controlled distance. For deployments exceeding 100 meters, additional techniques such as signal amplification, relay nodes, or alternative wireless protocols should be considered to enhance range and reliability. Further optimization, such as adaptive transmission power control, could also be explored to dynamically adjust signal strength based on real-time environmental conditions, improving system efficiency in various match settings.

Field Test

The field test results demonstrated that the time-out device effectively supports real-time communication between coaches and referees, enhancing the efficiency of game management. The interaction between the sender and receiver devices was seamless, ensuring that time-out requests were promptly processed without delays. The placement of the sender and receiver devices played a significant role in optimizing communication flow during the match.

Environmental factors significantly influenced the device's usability, particularly regarding TFT screen visibility. The morning shift tests revealed visibility issues due to direct sunlight exposure, which made reading the display challenging. For instance, at luminance levels exceeding 10,000 lux, the screen's legibility was noticeably compromised. This aligns with findings from prior research on outdoor electronic displays, which indicate that excessive brightness can reduce screen contrast and legibility. Conversely, during the night shift, the screen was optimally visible, reinforcing the need for improved brightness control or anti-glare screen coatings for daytime usage.

Figure 9 demonstrates the real-time countdown mechanism displayed on the referee's TFT screen during an active time-out. The visual elements within Figure 9 illustrate how the system accurately tracks and displays the remaining time, ensuring strict adherence to match regulations. This clear and consistent countdown timer allows coaches to efficiently strategize within the allotted 30-second time frame, a key factor in maintaining competitive balance during matches. The precision of this time tracking, as depicted, provides officials and coaching staff with critical real-time updates, validating the practical benefits observed in this study for effective game management.

Figure 9 Visual representation of the time-out duration countdown process.

Comparing these findings to previous research on referee communication technology, this system offers a more streamlined and cost-effective solution than traditional whistle- or hand-signal-based methods. The integration of wireless technology eliminates human interpretation errors, aligning with advancements in digital officiating systems used in professional leagues.

Despite its success, future improvements should focus on increasing the display's adaptability to outdoor lighting conditions. Potential enhancements include automatic brightness adjustment or alternative display technologies such as e-paper, which has been shown to perform well in high-ambient-light environments. Additionally, further field tests in various weather conditions could provide more insights into the device's robustness and long-term reliability. Overall, the field test confirmed that the proposed time-out device improves match officiating efficiency, reduces communication errors, and enhances strategic decision-making. These results contribute to the growing body of research on sports technology by demonstrating the practical applications of wireless communication in game management.

Comparison with Alternative Wireless Protocols

While Wi-Fi and Bluetooth are common wireless communication protocols, ESP-NOW was specifically chosen for this time-out device due to its distinct advantages in this application. Wi-Fi, though offering broad connectivity, typically involves higher latency and greater power consumption due to its infrastructure-based nature (requiring a router or access point) and more complex negotiation processes. Bluetooth, while suitable for short-range point-to-point communication, often has lower data rates and can be less robust for the immediate, critical transmissions required in time-out requests over varying distances on a volleyball court. In contrast, ESP-NOW operates as a connectionless communication protocol, enabling rapid, peer-to-peer data exchange with extremely low latency and minimal overhead. This direct communication mechanism ensures that time-out requests are sent and received almost instantaneously, without the need for network setup or constant connection maintenance, making it more efficient and reliable for time-sensitive sports officiating compared to the inherent delays and complexities of Wi-Fi or the range limitations of typical Bluetooth implementations.

Conclusion

The functional and field tests of the wireless time-out device demonstrated its significant technical benefits, including a low-cost implementation and simple setup, which effectively facilitates communication between coaches and referees, ensuring accurate and timely time-out requests. The results highlighted the importance of environmental factors, such as direct sunlight exposure, which affected the visibility of the TFT display. This suggests that future improvements should focus on implementing adaptive brightness control or more robust anti-glare screen coatings for better readability under various lighting conditions. Additionally, the distance test reaffirmed that ESP-NOW communication remains highly stable and reliable within a range of 20-100 meters, with some data loss observed beyond this effective distance. Enhancing the transmission range through signal amplification or exploring alternative, more resilient communication protocols could further improve device performance. Future developments may also explore integrating additional features such as real-time game analytics, dedicated mobile app connectivity for coaches to directly log time-out requests or view statistics, or expanding compatibility with other sports to broaden the application of this technology. By continuously refining its capabilities and addressing these identified areas, this device has the potential to set a new standard for efficient time-out management in both amateur and professional sports.

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