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A Paradigm Shift in Sports Science: The IOT-Enhanced Agility-Pad for Athletic Performance Evaluation

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ABSTRACT

This paper explores the development and implementation of an agility monitoring system, aiming to provide real-time assessment of an athlete's agility. The need for such technology to facilitate instant and remote agility assessment has become increasingly apparent in the field of sports science. Unfortunately, progress in this area has been relatively slow until the emergence of IoT (Internet of Things) technology, which presents a promising avenue for athlete agility monitoring through telemetering. The core of this innovative system consists of an agility pad and a real-time monitoring module, with communication facilitated by LabVIEW software. Our approach involves rigorous testing, including unit testing of the agility pad, which serves as an MQTT publisher, the server, which functions as an MQTT broker, and the monitoring module, acting as an MQTT subscriber. In addition to these technical aspects, this article showcases various outcomes of our research. These include the designs of two activity diagrams, a comprehensive conceptual framework for agility monitoring, the database structure, communication designs for the agility pad, a wiring schematic, a 3D model of the agility pad, and the corresponding wiring configuration. We have successfully constructed two sets of agility pads, each integrated with an MCU system (ESP8266) and a dedicated database architecture designed for agile monitoring. One significant achievement of our work is the identification of the optimal delay interval required on the agility pad to prevent data loss on the MQTT broker. Furthermore, we have effectively developed a mechanism for detecting and addressing abnormal data during each testing phase, which contributes to the robustness and reliability of the system. This paper not only highlights the innovative technology behind the IOT-Infused Agility-Pad but also underscores its potential to revolutionize the assessment of athletic performance, offering coaches and athletes real-time insights into agility progress.

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1. Introduction

Athletic performance assessment is a fundamental aspect of sports science, allowing coaches and athletes to gauge progress, make data-driven decisions, and optimize training regimens [1,2]. Among the various dimensions of athletic performance, agility stands out as a critical factor, influencing an athlete's ability to swiftly adapt to changing situations and outmanoeuvre opponents [3,4]. The ability to monitor an athlete's agility in real time has significant implications for training, coaching, and sports performance optimization [5,6].

The IoT, characterized by the interconnectedness of devices and the transmission of data over the internet [7,8], presents a groundbreaking opportunity for real-time sport science monitoring [9,10]. IoT technology enables the collection, transmission, and analysis of data from agility monitoring devices, opening doors to remote assessment and immediate feedback. Several IoT technologies have been applied in sports science such as Passos *et al.,* [11] identify and summarize recent studies that have used wearables and IoT technologies and discuss its applicability for fitness assessment. Ahmad *et al.,* [12] introduces the anxiety monitoring systems for sports athletes based on the IoT which accurately identifies athlete performance and the IoT technology can connect functions between sensors, microcontrollers, cloud systems, technological devices, and digital equipment for the targeted users. Karakaya *et al.,* [13] proposed a model that provides information and alerts to the technical team about the occurrence of the goal by using machine learning methods on an IoT-based infrastructure. They test system using discriminant analysis, k-nearest neighbour (KNN), naive bayes, support vector machine (SVM), decision tree and ensemble learning methods. Wang *et al.,* [14] propose an IoT framework for next-generation racket sports training and construct a wireless wearable sensing device (WSD) based on microelectromechanical systems motion sensors for recognize different badminton strokes and classify skill levels from different badminton players. Masuki *et al.,* [15] developed a device that is equipped with a triaxial accelerometer and a barometer to measure energy expenditure during interval walking training (IWT) in the field with inclines and developed an IoT system that enables users to receive instructions from trainers according to their walking records even if they live far away. Lian *et al.,* [16] developed an IoT wristband for basketball shooting analysis, which can provide quantitative shooting guidance for basketball players in a convenient and low-cost manner. Kim *et al.,* [17] proposed the application of IoT-based integrated management system to public sports facilities (PSF) to improve the utilization and management of PSF by analysing the actual state of PSF empirical. Zhao and You [18] proposed sports and daily training of athletes in rehabilitation therapy with wearable sports posture measurement system using IoT technology.

Traditionally, agility assessment has been a somewhat cumbersome and time-consuming process, relying on manual measurements and subjective observations [19,20]. The demand for innovative technology capable of instantly assessing an athlete's agility has grown steadily. Unfortunately, the development of such technology has been relatively slow. However, the advent of the Internet of Things (IoT) offers a promising solution to address this need by enabling remote and real-time agility monitoring through telemetering.

This paper presents a comprehensive exploration of our endeavour to advance agility monitoring technology with the creation of the "IOT-Infused Agility-Pad." Our system comprises an agility pad and a real-time monitoring module, with communication established through LabVIEW software. Through rigorous testing and development, we have not only created a functional system but also introduced several noteworthy outcomes. These include detailed designs, a conceptual framework, database architecture, and efficient communication protocols for the agility pad. We have also developed 3D models, wiring schematics, and configurations.

Crucially, we have successfully constructed two sets of agility pads, each equipped with a Microcontroller Unit (MCU) system, specifically the ESP8266, and a database architecture tailored for agile monitoring. One of the significant milestones of our research is the identification of the optimal delay interval on the agility pad to prevent data loss during transmission to the MQTT broker. Additionally, we have implemented mechanisms to detect and address abnormal data, enhancing the system's robustness and reliability.

In this paper, we present a comprehensive account of our journey to revolutionize athletic performance assessment by combining agility monitoring with IoT technology. We believe that our innovative "IOT-Infused Agility-Pad" not only offers an effective solution for real-time agility assessment but also has the potential to transform how athletes and coaches approach training and performance evaluation, ultimately enhancing athletic excellence.

2. Methodology

2.1 System Design and Architecture

The wiring diagram for the agility pad, depicted in Figure 1, illustrates a simplified layout that incorporates essential components including the ESP32 microcontroller unit (MCU), four push buttons, batteries, power switches, and LED indicators. The ESP32 MCU plays a central role in processing input data from four separate switch modules, each independently installed to relay user inputs to the MCU. The batteries serve as a dependable 3.3V DC voltage source, while the four parallel push buttons allow users to conveniently initiate specific functions. Power switches enable effective device control, and LED indicators provide real-time feedback on communication status with the server, ensuring efficient data processing and dependable user interaction.

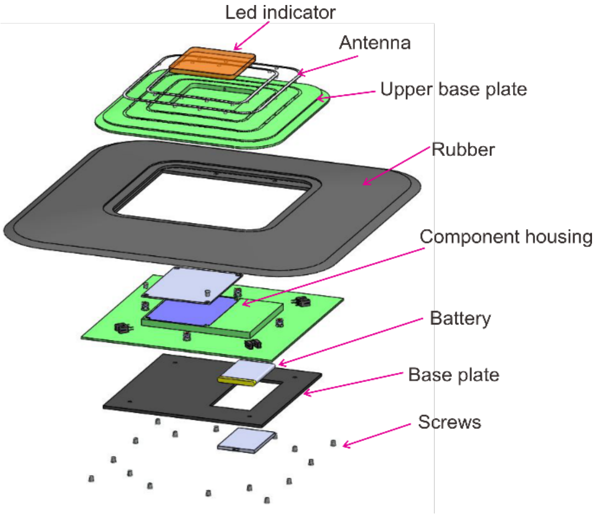


Fig. 1. Design of pad-agility architecture

2.2 Communication Protocol Implementation

Figure 2 represents the communication protocol of the agility system, an integral component of agility measurement technology. This system facilitates seamless communication between various devices, with human operators responsible for validating data collected by the server's logging device. The system comprises two primary components: the agility pad and the mobile device. The agility pad is equipped with an array of components, including tactile switches, a Microcontroller Unit (MCU), and a power source in the form of a battery. Communication between the agility pad and the mobile device is established through the IEEE802.11 protocol, with the mobile device serving as the central server.

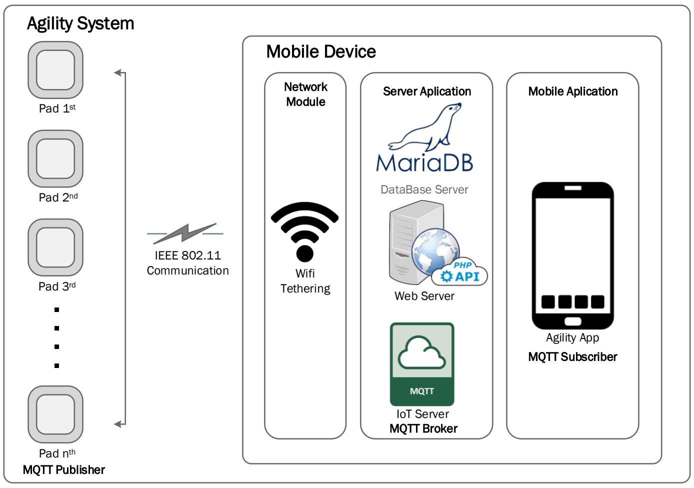


Fig. 2. Communication protocol of agility system

The server component of the system encompasses a network interface, an MQTT Broker, and an MQTT Subscriber, which runs a dedicated mobile application. This application is further divided into a server application, based on MariaDB, a web server, and an IoT server. The agility program, designed for the Android platform, operates as an MQTT Subscriber, responsible for the storage of data within a MariaDB database through a Restful API developed using PHP. Data transmission is executed in JSON format, encompassing critical information such as battery level and MAC address, with varying data sizes typically ranging between 45-47 bytes.

Within the system's framework, key actors include operators and administrators, as well as athletes. Operators are primarily responsible for the setup and analysis of data, ensuring the efficient functioning of the system. During testing scenarios, athletes interact with the agility pad, generating data that is subsequently transmitted to the server. The MAC Address serves as the unique identifier for each agility pad, while the battery status conveys essential information regarding its operational condition

2.3 Testing and Validation

In an agility system assessment, five athletes participated in a range of activities spanning from walking to sprinting, categorized by speed as follows: slow run (2.5-3.5 m/s), run (3.5-4.5 m/s), and fast run (>4.5 m/s). The operational concept of the agility pad, as depicted in Figure 3, encompasses the Human-Machine Interface (HMI) Sender, which acts as a publisher, the server, which functions as an MQTT broker, and the HMI Receiver, equipped with a monitoring module, serving as a subscriber. The agility system ensures precise data processing, capturing all data transmitted by the pad, regardless of delay intervals. This capability is a critical aspect for effectively representing an athlete's agility. Delay time can affect the results of an athlete's agility assessment because the more agile an athlete is, the smaller the delay time needs to be.

In this configuration, two agility pads are connected to the HMI Sender, each equipped with an ON/OFF switch. When an athlete steps on a pad, it transitions from OFF to ON, and this change in status is relayed to the monitoring module via the MQTT broker through an internet connection. Each cycle, which encompasses the ON-OFF-ON transition, includes a response time (RT). There are two types of response time: the internal response time (RT(Int)), which refers to the time taken for a pad to switch from ON to OFF and back to ON, and the external response time (RT(Ext)), which occurs when one pad transitions from ON to OFF, followed by another pad switching from OFF to ON. Experimental continuity is ensured with only two sets of agility pads because the external response time (RT(Ext)) between pad 1 and pad 2 will represent the external response time (RT(Ext)) between pad 2 and pad 3 and so on.

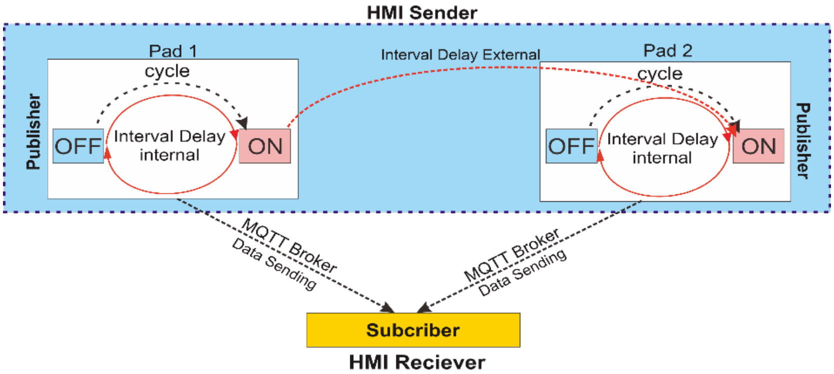


Fig. 3. Pad-agility operational principles

2.4 Integration Architecture and Data Analysis

The test was centred on measuring the duration of data transmission from the pad to the monitoring module, monitored through the components of the HMI Sender and HMI Receiver. RT (Response Time) pulses were utilized in two distinct approaches: one with delay intervals less than one second (ranging from 0.1 to 0.9 seconds) and another with intervals equal to or exceeding one second (ranging from 1 to 10 seconds). These pulses were generated by the MCU within the pad. Each interval was subjected to ten repetitions, resulting in a dataset comprising 999 data points. ΔTx represents the time difference between data reception (Tr) and data transmission (Ts). An optimal scenario would have ΔTx≤RT(Int) or ΔTx≤RT(Ext), signifying minimal delay, whereas larger ΔTx values indicate potential system bottlenecks or delays induced by queuing, emphasizing the need to determine the minimum ΔTx for efficient data transmission.

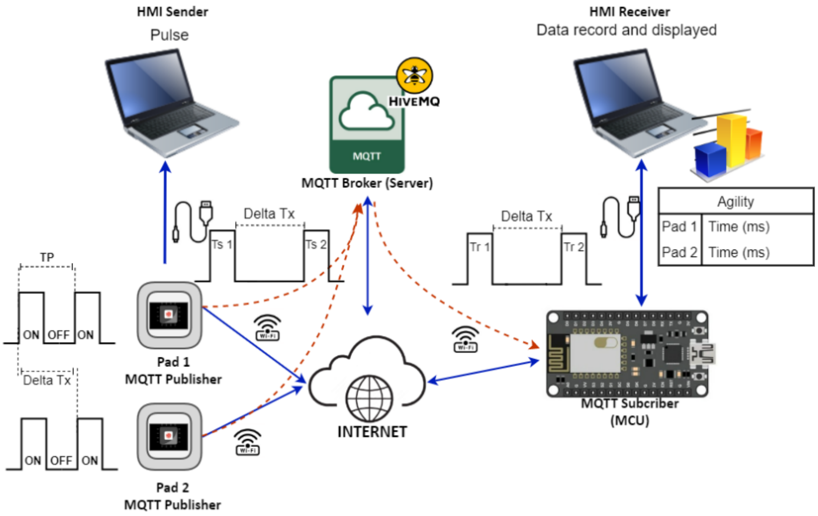


Fig. 4. Pad-agility system based on the IoT

The system architecture (as depicted in Figure 4) comprises the HMI Sender and HMI Receiver, responsible for tracking data transmission time (Ts) and reception time (Tr) on the monitoring module. The pad executes a pulse program with delay intervals ranging from 0.1 to 10 seconds, with each interval being tested separately. Internal delay is calculated from Tr within the monitoring module, with each interval undergoing ten repetitions, thus generating 10 data samples for the subsequent calculation of ΔTx using Eq. (1).

$$\Delta T_x = T_r - T_s \tag{1}$$

$$TP_s \approx TP_r \tag{2}$$

$$\Delta T_x \leq TP_r \tag{3}$$

$$\Delta T_x \leq TP_s \tag{4}$$

$$\varphi \in \Delta T_x \tag{5}$$

$$\psi = \varphi > \Delta T_x \tag{6}$$

$$\Upsilon = \frac{\psi}{\Delta T_x} \tag{7}$$

The agility monitoring system heavily relies on internet communication to expeditiously process timestamp data from the pad. The primary objective is to minimize the time difference (ΔTx) between the timestamps sent by the pad (Tr) and those received by the monitoring module (Ts), as computed using Eq. (1). Ideally, the time for sending data (TPr) should closely align with the time for receiving data (TPs), as expressed in Eq. (2). The Eq. (3) and Eq. (4) underscore that ΔTx should be smaller than TPs and TPr, respectively, indicating optimal performance where all pad data is processed and promptly displayed on the monitoring module. Conversely, a higher ΔTx value suggests potential data loss.

The Eq. (5) elucidates that abnormal data (φ) is an integral component of the ΔTx value, while Eq. (6) outlines the method for computing the number of anomalies (ψ) by comparing φ to ΔTx or the average time difference between data reception (Tr) and data transmission (Ts). The anomaly index (ϒ) is computed using Eq. (7), and ϒ is derived by dividing the count of anomalous data (ψ) by ΔTx.

3. Results and Discussion

3.1 Hardware Validation

This paper presents a pivotal process design for an IoT-based agility pad, as illustrated in Figure 5. The agility sensor system, commonly referred to as the 'pad,' is distinctly segregated from the server system. It incorporates integral components, most notably the compact ESP8266 Microcontroller Unit (MCU), which operates within the 2.4GHz communication frequency range and utilizes the IEEE 802.11 Wi-Fi protocol [21,22]. The ESP8266's diminutive form factor and its multifaceted operational modes render it highly suitable for deployment in agility assessment and energy monitoring systems.

The data flow mechanism entails the activation of mechanical switches, which in turn initiate the analogue-to-digital conversion (ADC) process. Subsequently [23], the MCU undertakes data processing and orchestrates wireless data transmission to the server [24]. Mobile devices are endowed with the capability to establish a Wi-Fi connection with the server [25], enabling them to access monitoring data and effectuate adjustments to the pad's configurations.

A simplifying activity diagram characterizes the system and features three principal actors: the administrator/tester, the coach tester, and the athlete. In this framework, the administrator undertakes the pivotal role of determining the test approach, the tester exercises control over the sequence of operations, and the athlete actor serves as a representative entity for the subject of evaluation.

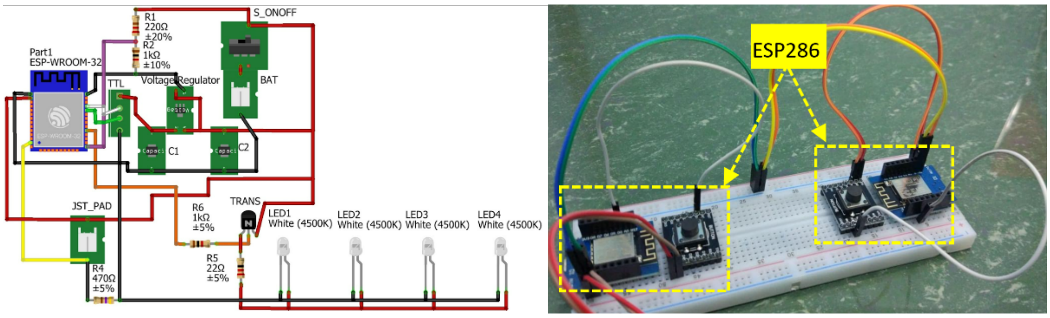


Fig. 5. Pad Agility wiring design

The database architecture of the IoT-based agility measurement system is composed of seven tables, including three master tables (athlete, master-pad, test-scheme) and four transactional tables (athlete-test, test-log, test-pad, test-agility). The administrative actor selects athletes from the 'athlete' table and records test data in the 'test-log' database. The 'test-pad' database is dedicated to storing server coordination results and the statuses of the agility pads, while the 'test-agility' table provides a concise summary of altitude agility values for each test scheme.

The mechanical wiring configuration of the agility pad device is thoughtfully depicted in Figure 5, portraying a straightforward switch design for agility pad testing. Employing two such pads, press intervals were deliberately manipulated to establish seamless machine-to-machine communication. Figure 6 serves to present the resultant dataset, reflecting anticipated outcomes and serving as a testament to the successful data transmission that transpired between the two pads.

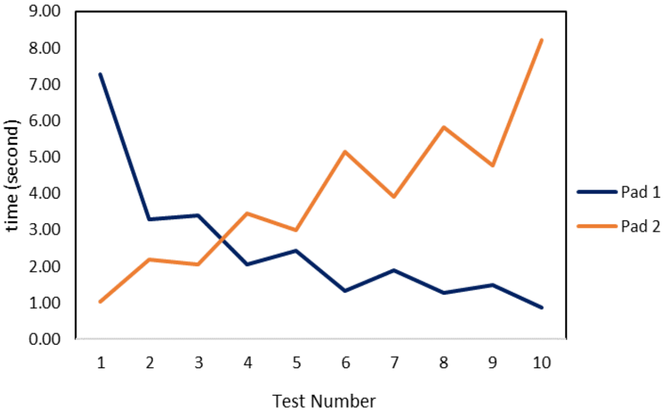
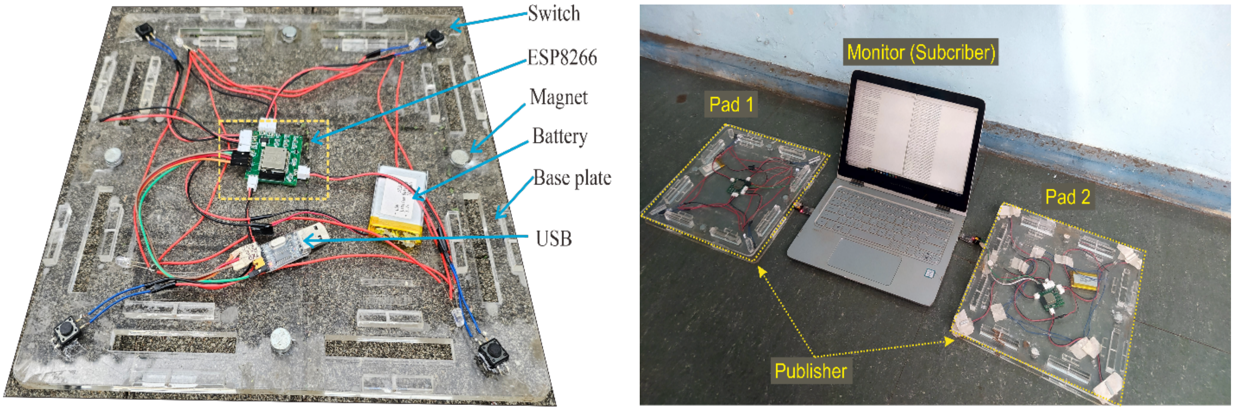


Fig. 6. Monitoring of two pad agilities

3.2 Validation Pad-Agility System

Figure 7 illustrates the agility pad communication test, designed with the purpose of assessing the quality of machine-to-machine communication between the agility pad, the server, and the monitoring module. The primary objective of this test is to ensure the precise transmission of data from the agility pad to the monitoring module while concurrently detecting any potential data anomalies. Conducted within a controlled environment, the test involved the systematic and randomized activation of the pad's push button.



(a) (b)

Fig. 7. Prototype setup (a) component layout. (b) communication test

Figure 8 presents a series of distinct time periods (TP) ranging from 1 second to 10 seconds. Following ten repetitions of the test, discernible variations in ΔTx values within each measurement set become apparent. By implementing Eq. (6), it becomes possible to quantify the count of anomalous data points (\psi) in each measurement. The six data points manifest ΔTx values that diverge from the anticipated pattern, potentially attributed to network quality interferences or hardware-related factors. The index characterizing anomalous data (Y) is subsequently computed using Eq. (7), where ψ equals 6, signifying the existence of anomalous data points among a total of $\Delta Tx = 100$ data points, representing a 6% anomaly rate within the comprehensive dataset.

The comprehensive test spanning TP intervals from 1 second to 10 seconds yielded commendable results. Over the course of ten repetitions, fluctuations in ΔTx values were noted, with the minimum recorded ΔTx at 246 milliseconds and the maximum at 267 milliseconds. Figure 8 additionally depicts a discernible upward trend in the average ΔTx values and highlights a higher incidence of anomalous data points at TP intervals of 1 second, 2 seconds, 4 seconds, 6 seconds, and 8 seconds. It is noteworthy that while TP durations on individual agility pads may not exhibit a direct correlation with the quality of machine communication, the existence of these anomalous data points should be duly acknowledged, as they have the potential to influence the information presented on the agility monitor module.

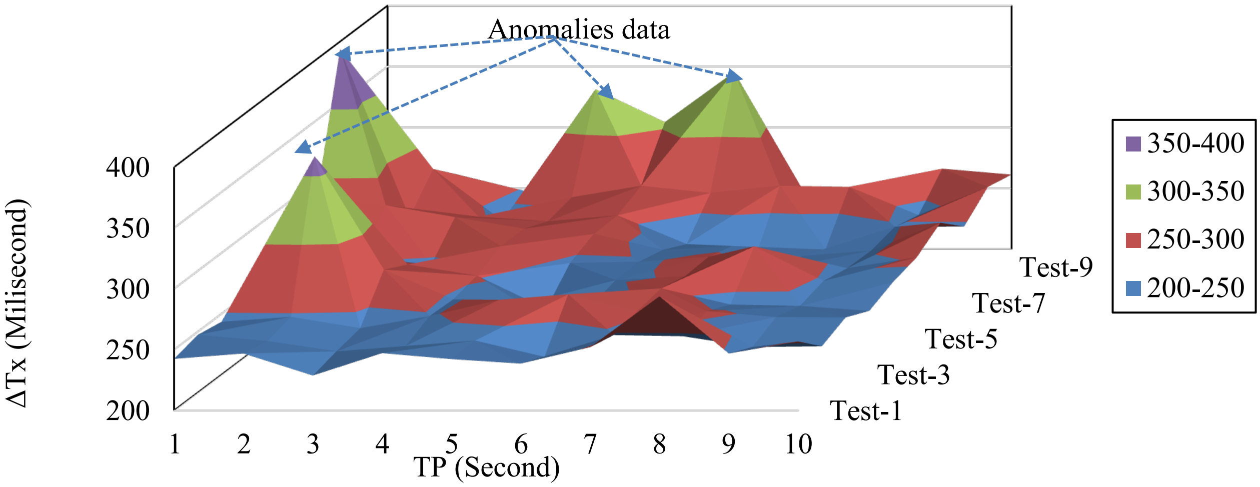


Fig. 8. Data Transfer Speed: Agility Pad to Server (1s - 10s)

Based on the Figure 8, it can be reasonably concluded that within the TP range spanning from 1 second to 10 seconds on the agility pad, the ON→OFF→ON switch behaviour occurs in both internal and external intervals. Consequently, the ΔTx values do not align seamlessly with the TP, suggesting the plausible occurrence of packet loss within either the server system (MQTT broker) or the monitoring system (MQTT subscriber).

In summary, tests encompassing TP durations ranging from 0.1 to 1 second have yielded favourable results, characterized by variations in ΔTx values observed over ten repeated iterations. The average ΔTx values, across all tests, exhibited a range spanning from a minimum of 239.64 milliseconds to a maximum of 319.25 milliseconds. Figure 9 illustrates an ascending trend in the average ΔTx values, with a pronounced occurrence of anomalous data points during the 7th test iteration and at specific TP values, notably, 0.1 seconds, 0.6 seconds, 0.7 seconds, and 0.8 seconds. While TP durations on individual agility pads do not directly influence communication quality, it is imperative to acknowledge that the presence of anomalous data points bears the potential to influence the information presented on the agility monitoring module.

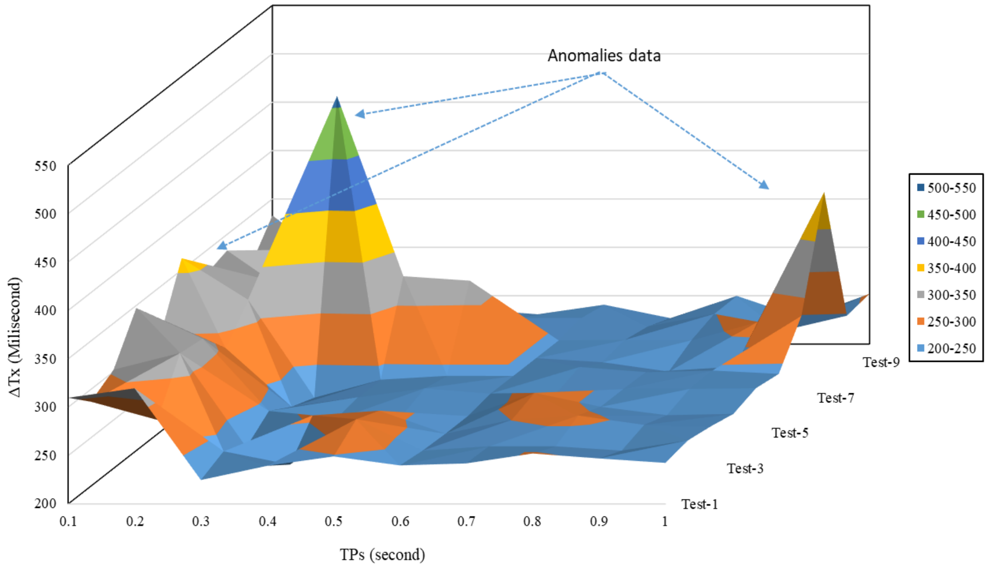


Fig. 9. Data transmission speed from pad-agility to server with (TP=0.1s-10s)

In conclusion, within the TP range of 1 to 10 seconds on the agility pad, the switch consistently adheres to an ON→OFF→ON pattern, ensuring that both the broker system and the subscriber system can process all incoming data without incurring any packet loss.

3.3 Pad-Agility Testing

The agility system underwent a comprehensive testing regimen involving a cohort of five athletes, with an average age of approximately 23 years and weights ranging between 58 and 62 kilograms. The battery of tests encompassed a spectrum of activities, including leisurely walking, brisk walking, slow running, moderate running, and fast running. These evaluations were conducted using two agility pads and a singular monitoring module. Each athlete was tasked with executing 40-foot taps on the agility pads, and this procedure was repeated ten times to ensure the precision and accuracy of the results.

Our communication setup adheres to the established conventional framework for agility communication. Distinguishing itself from the FiTRONiC Test of Agility System, our system adopts a wireless communication approach, offering enhanced flexibility in the placement of the agility pads, if a reliable internet connection is accessible.

Figure 10 provides a visual representation of an athlete engaged in agility pad testing. The process commences with the server's activation of the agility pads, positioning them appropriately on the floor. Subsequently, the athlete proceeds to step on each pad individually, each time varying their speed. Throughout the testing procedure, meticulous monitoring of the condition of the agility pads is maintained, enabling the collection of specific agility data that corresponds to each pad, with data retrieval being carried out directly from the athlete.

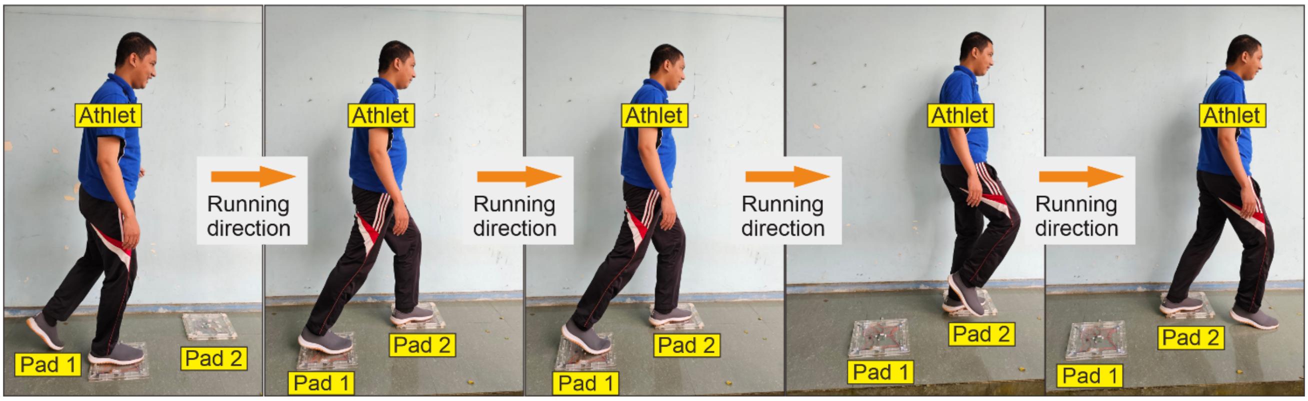
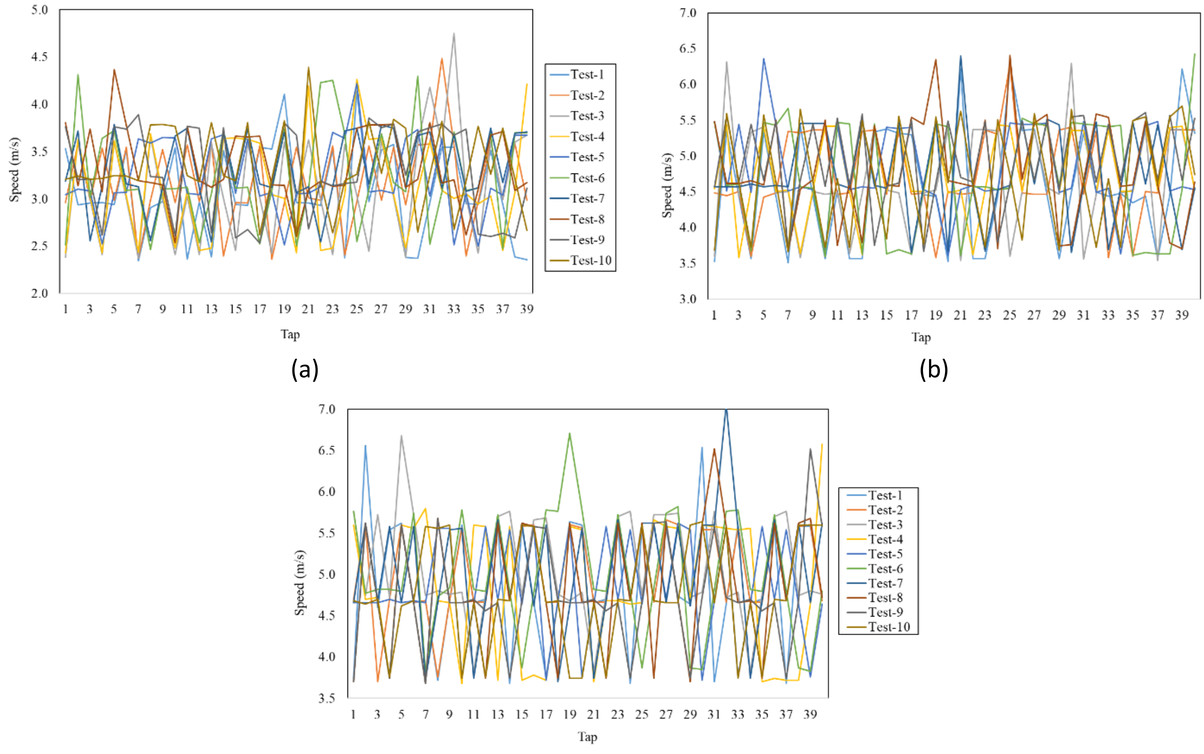


Fig. 10. Agility Pad Testing with Varied Athletic Activities

In Figure 11(a), the results pertaining to leisurely walking are presented, revealing consistent albeit not profoundly significant changes in speed. The observed speeds range from 1.1 m/s to 2.2 m/s, with an average speed of 1.44 m/s. Transitioning to Figure 11(b), the graph delineates speed dynamics during fast walking. In contrast to leisurely walking, this graph portrays a broader spectrum of speed variations, indicating greater irregularities and heightened pace. The speed range for this test extends from 1.6 m/s to 3.2 m/s, with an average speed of 2.16 m/s.

Figure 11(c) offers insights into the speed characteristics associated with slow running. It showcases dynamic speed changes like those observed during fast walking, albeit at varying intensity levels. The speed range for this test spans from 2.5 m/s to 4.7 m/s, with an average speed of 3.23 m/s. In Figure 11(d), the speed graph pertains to running activities, mirroring dynamic alterations and irregularities akin to those in slow running. Notably, the distinguishing factor lies in the higher average speed, which ranges between 3.5 m/s and 6.5 m/s, with an average speed of 4.76 m/s. Conclusively, Figure 11(e) illustrates the speed graph during sprinting, featuring dynamic changes and irregularities like running. The prominent difference here lies in the further elevated average speed, spanning from 3.7 m/s to 7 m/s, with an average speed of 4.94 m/s.



(a)

(b)

(c)

Fig. 11. Agility Pad Testing with Varied Athletic Activities

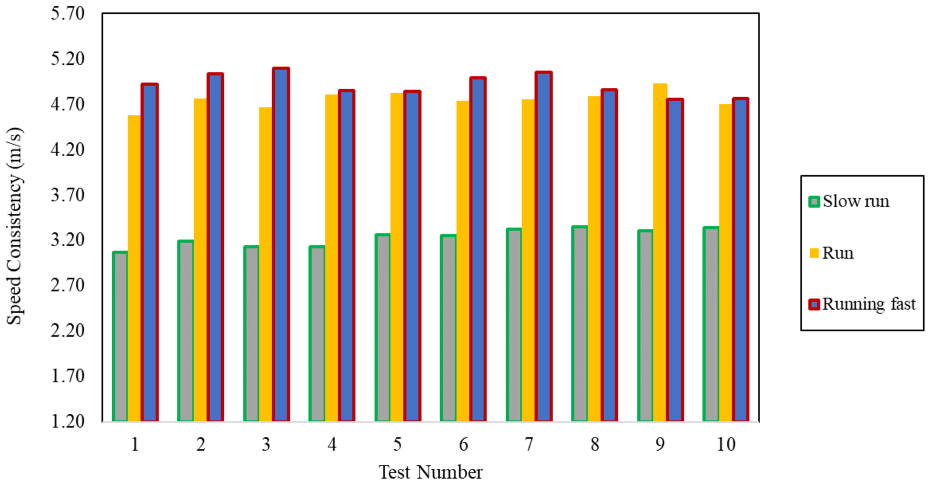


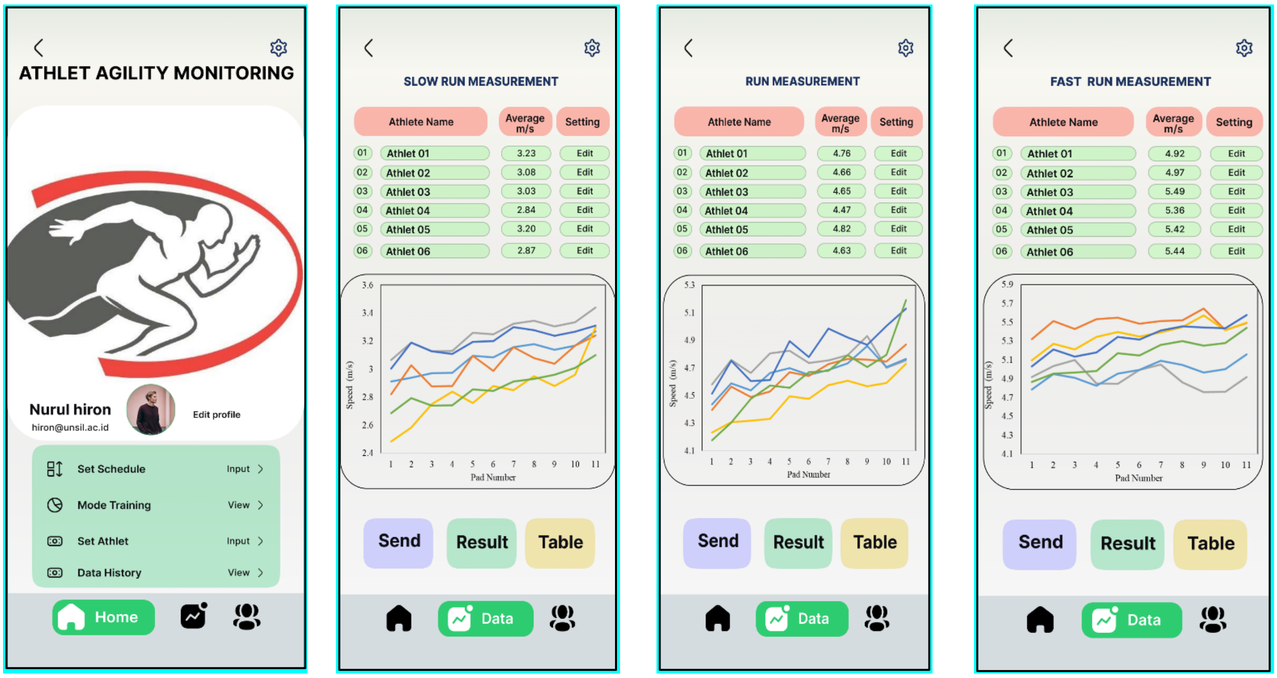
Fig. 12. Agility speed consistency test

The results obtained consistently demonstrate a trend towards ascending values. It is essential to consider the potential influence of fatigue induced by multiple test repetitions, which may lead to diminished speed and introduce some variability in an athlete's performance. To comprehensively evaluate an athlete's capabilities, it is crucial to ascertain the upper limit of achievable speed consistency on the agility pad. However, it is noteworthy that this study encompasses only ten trials, and as such, may not fully encapsulate the effects of fatigue. Nonetheless, the insights gleaned from the agility monitoring system suggest that the overall performance in agility remains notably commendable. The agility speed consistency test can be seen in Figure 12.

In the context of fast walking, this inconsistency in performance becomes more conspicuous, reflected by an average speed of 4.75 m/s. In the instance of slow running, the analysis reveals dynamic speed fluctuations and an increasing degree of variability, resulting in an average speed of 4.75 m/s. Similarly, the test for slow running displays dynamic speed variations and a progressive level of inconsistency, with an average speed of 4.92 m/s.

3.4 IoT Platform

The testing of the mobile-based IoT platform is comprehensively depicted in Figure 13. This evaluation encompassed six athletes and involved the execution of three distinct types of activities, specifically, slow running, running, and fast running. The outcomes of the agility application testing affirm the effective presentation of essential functionalities within the home menu display (Figure 13(a)). Additionally, the list of athletes is meticulously organized based on their respective athlete numbers. Notably, the application adeptly captures the rate of running activities, and successfully portrays the average speed of each athlete along with the corresponding speed graph (Figure 13(b)). Similarly, the application seamlessly captures the data for the slow running activity, consistently displaying the average speed data for each athlete and presenting the corresponding speed graph with precision (Figure 13(c)). Furthermore, the application adeptly captures the data for fast running activities, effectively showcasing the average speed data of each athlete and presenting the corresponding speed graph accurately (Figure 13(d)). In conclusion, the results of the testing of the mobile-based agility application underline the application's proficiency in rendering both graphical and numerical data for each athlete. Moreover, the stored historical data is readily accessible and effectively retrievable through the application.



ATHLET AGILITY MONITORING

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SLOW RUN MEASUREMENT

	Athlete Name	Average m/s	Setting
01	Athlet 01	3.23	Edit
02	Athlet 02	3.08	Edit
03	Athlet 03	3.03	Edit
04	Athlet 04	2.84	Edit
05	Athlet 05	3.20	Edit
06	Athlet 06	2.87	Edit

RUN MEASUREMENT

	Athlete Name	Average m/s	Setting
01	Athlet 01	4.76	Edit
02	Athlet 02	4.66	Edit
03	Athlet 03	4.65	Edit
04	Athlet 04	4.47	Edit
05	Athlet 05	4.82	Edit
06	Athlet 06	4.63	Edit

FAST RUN MEASUREMENT

	Athlete Name	Average m/s	Setting
01	Athlet 01	4.92	Edit
02	Athlet 02	4.97	Edit
03	Athlet 03	5.49	Edit
04	Athlet 04	5.36	Edit
05	Athlet 05	5.42	Edit
06	Athlet 06	5.44	Edit

(a) (b) (c) (d)

Fig. 13. Agility Mobile base Application

4. Conclusions

This article has presented a comprehensive athlete agility monitoring system, comprising the essential components of the agility pad (serving as an MQTT publisher), the server (functioning as an MQTT broker), and the monitoring module (acting as an MQTT subscriber), all seamlessly integrated with the ESP8266 microcontroller for efficient communication. The system has demonstrated excellence in database design, ensuring optimal data storage and retrieval capabilities, while the user-friendly 3D-modeled design of the agility pad enhances its functionality. Rigorous testing has established robust machine communication, leading to the determination of a critical 240ms minimum delay interval, which in turn optimizes data transmission and effectively mitigates latency concerns.

Moreover, the system's ability to identify and address anomalous data has significantly contributed to enhancing the measurement accuracy and overall reliability of the system. The agility pad prototype underwent rigorous testing involving five athletes engaged in various activities, successfully demonstrating its capacity for accurate and effective monitoring of athlete performance. In summary, this article underscores the successful development of an advanced athlete agility monitoring system, which leverages cutting-edge technology, meticulous database design, and stringent testing protocols. These findings hold substantial implications for sports professionals and athletes who are keen on optimizing their performance through precise agility assessment.

Finally, the development of mobile-based applications integrated with an IoT platform for athlete agility measurement has also been a success. The test results affirm the application's proficiency in presenting numerical data and graphical representations for each athlete. Furthermore, the application offers historical data, which can be instrumental for trainers and coaches in making informed decisions to enhance athlete performance and training strategies. This multi-faceted approach offers a holistic solution for agility assessment and monitoring, benefitting both athletes and their support teams.

Acknowledgement

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