Monitoring cyclist biometric signals using a wireless body sensor network based on LILYGO TTGO

Monitoreo de señales biométricas en ciclista mediante una red inalámbrica de sensores corporales basada en LILYGO TTGO

Monitoramento de sinais biométricos de ciclistas usando uma rede de sensores corporais sem fio baseada em LILYGO TTGO

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Abstract

Introduction: This article is the result of research project 22883.25-PD at the National Technological Institute of Mexico, conducted at the Instituto Tecnológico Superior de Irapuato in 2025. A cyclist's posture, pedaling technique, muscle strength, and revolutions per minute are crucial factors for the acquisition and processing of signals in dynamic analysis.

Problem: Traditional methods of acquiring biometric data are often direct and uncomfortable for the cyclist, causing inconvenience and stress that can negatively impact performance.

Objective: To analyze the development of a low-cost, compact system for monitoring a cyclist's pedaling performance using wireless communication and sensors such as the AD8832, AD8232, and MPU6050.

Methodology: The WBSN (Wireless Body Sensor Network) biometric monitoring system efficiently captures and processes analog data transmitted via Bluetooth during three pedaling stages (slow, normal, and fast). This process is complemented with imaging of joint articulation nodes.

Results: The biometric analysis enables real-time detection of postural deviations, oxygenation deficiencies, and variations in force applied across the three pedaling stages. Data are acquired wirelessly and in real time.

Conclusions: The system successfully implements the LilyGo Ttgo board to transmit biometric data—such as muscle activity, heart rate, and body posture—in real time, using the Bluetooth v2.4 protocol of the WBSN network.

Originality: The integration of new, compact, and low-cost technologies proves effective in monitoring analog biometric signals in cyclists, with the capability of retransmission via wireless networks.

Limitations: The system's working range could be extended by incorporating a radio frequency (RF) communication protocol.

Keywords: LilyGo Ttgo, Wireless body sensor network (WBSN), surface Electromyography (sEMG), Electrocardiographic (ECG).

Resumen

Introducción: El artículo es producto de la investigación *22883.25-PD Tecnológico Nacional de México*, desarrollada en el Instituto Tecnológico Superior de Irapuato en el año 2025. La postura, el movimiento de pedaleo, la fuerza muscular y las revoluciones por minuto de un ciclista son cruciales para la adquisición y el procesamiento de señales en el análisis dinámico.

Problema: Los métodos tradicionales adquieren datos biométricos de forma directa e incómoda para un ciclista, lo que genera molestias y estrés que afectan el rendimiento efectivo.

Objetivo: Analizar el desarrollo de un sistema compacto para monitorear el rendimiento del pedaleo de un ciclista empleando sensores de bajo costo como AD8832, AD8232 y MPU66050 mediante comunicación inalámbrica.

Metodología: El sistema de monitoreo biométrico WBSN recopila y procesa eficazmente los datos analógicos transmitidos vía Bluetooth en tres etapas de pedaleo (lenta, normal y rápida). El proceso se complementa con imágenes de los nodos de las articulaciones.

Resultados: El análisis biométrico identifica en tiempo real las alteraciones posturales, deficiencias en la oxigenación y variaciones en la fuerza aplicada en las tres etapas de pedaleo del ciclista. Los datos se adquieren de manera inalámbrica y en tiempo real.

Conclusiones: El sistema permite la implementación de la tarjeta LilyGo Ttgo como método de transmisión de datos biométricos (movimiento muscular, ritmo cardíaco y postura corporal) en tiempo real, basado en el protocolo Bluetooth v2.4 de red WBSN.

Originalidad: El uso de nuevas tecnologías compactas y de bajo costo demuestra efectividad para el monitoreo de señales biométricas analógicas del ciclista, con capacidad de retransmisión mediante redes inalámbricas.

Limitaciones: El sistema puede aumentar el rango de distancia de trabajo con el protocolo de comunicación de radiofrecuencia.

Palabras clave: LilyGo Ttgo, Red Inalámbrica de Sensores Corporales (WBSN), Electromiografía de Superficie (sEMG), Electrocardiograma (ECG).

Resumo

Introdução: Este artigo é produto do projeto de pesquisa 22883.25-PD, financiado pelo Instituto Tecnológico Nacional do México e desenvolvido no Instituto Superior Tecnológico de Irapuato em 2025. A postura, o movimento de pedalada, a força muscular e as rotações por minuto de um ciclista são cruciais para a aquisição e o processamento de sinais em análises dinâmicas.

Problema: Os métodos tradicionais adquirem dados biométricos de forma direta e inconveniente para os ciclistas, causando desconforto e estresse que impactam negativamente o desempenho.

Objetivo: Analisar o desenvolvimento de um sistema compacto para monitoramento do desempenho de pedalada de um ciclista utilizando sensores de baixo custo, como o AD8832, AD8232 e MPU66050, via comunicação sem fio.

Metodologia: O sistema de monitoramento biométrico WBSN coleta e processa de forma eficiente dados analógicos transmitidos via Bluetooth durante três estágios de pedalada (lenta, normal e rápida). Esse processo é complementado por imagens dos nós articulares.

Resultados: A análise biométrica identifica alterações posturais, deficiências de oxigenação e variações na força aplicada durante as três fases da pedalada do ciclista em tempo real. Os dados são adquiridos sem fio e em tempo real.

Conclusões: O sistema permite a implementação do cartão LilyGo Ttgo como método de transmissão de dados biométricos (movimento muscular, frequência cardíaca e postura corporal) em tempo real, com base no protocolo de rede Bluetooth v2.4 WBSN.

Originalidade: O uso de tecnologias novas, compactas e de baixo custo demonstra eficácia no monitoramento de sinais biométricos analógicos de ciclistas, com capacidade de retransmissão via redes sem fio.

Limitações: O alcance operacional do sistema pode ser ampliado com o protocolo de comunicação por radiofrequência.

Palavras-chave: LilyGo Ttgo, Rede de Sensores Corporais Sem Fio (WBSN), Eletromiografia de Superfície (EMGs), Eletrocardiograma (ECG).

I. INTRODUCTION

The biomechanics of cycling aims to determine the optimal body posture for ergonomic pedaling without negative consequences for the cyclist. Quesada analyzed the properties of the bicycle in direct correlation with fatigue resistance in cyclists across three back angle positions, highlighting the importance of correct adjustment of bicycle measurements relative to the cyclist’s height [1]. Swart, however, approaches the biomechanical study from the perspective of the bicycle's static kinematics—one of the traditional methods explored since the early days of the field [2]—focusing on the pedaling loads applied to specific pressure points of the body such as the hips, shoulders, elbows, and leg joints. This approach enables the identification of areas with the highest muscular tension during pedaling, pinpointing critical pressure zones where the risk of extreme fatigue and injury increases in relation to exhaustion time [3].

Although there is no direct correlation between cardiorespiratory response and cycling performance, muscle fatigue does result in higher energy consumption during the same pedaling routine. This is reflected in increased breathing rate and heart rate compared to a muscle in a relaxed state.

Kinematic and dynamic analysis methods used to calculate pressure points are generally approached separately due to the differing analytical techniques involved [1] [4] [5]. This results in a wide variety of devices capable of experimentally measuring the variables described in kinematic and dynamic models. However, the relationship between these variables and muscle fatigue or exhaustion time remains unclear [6]. Therefore, there is a need to integrate new analytical technologies that can provide a novel perspective—one that relates the dynamics of cycling to heart rate and muscle power readings, from rest to the point of exhaustion.

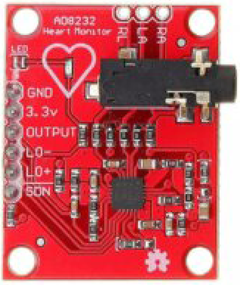
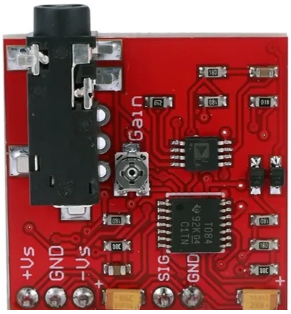
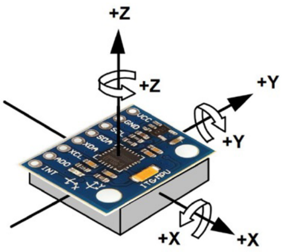
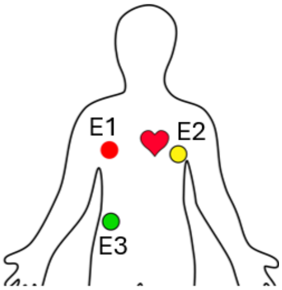
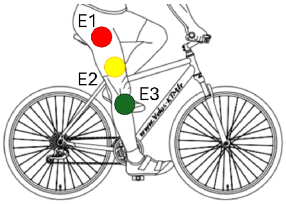
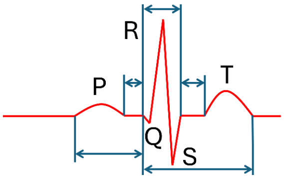
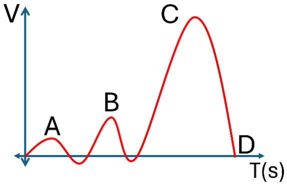
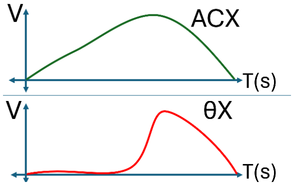
Research has demonstrated [14][15] the importance of developing biometric signal acquisition systems composed of non-invasive components capable of monitoring cycling performance. These systems offer a new methodology for data extraction using wireless protocols. The use of compact body sensors has had a significant impact on the methodology for biometric data analysis, particularly through biomechanics and real-time data extraction [13][16].

There is a wide range of biomedical instrumentation sensors focused on capturing signals relevant to this field [17][18]. One such signal is the electrocardiographic signal (ECG), illustrated in Table 1. ECG analysis involves the electrical pulses generated at the beginning, during, and after a heartbeat. Signal acquisition is based on the placement of electrodes along the torso—E_1 as the reference electrode, E_2 for sensing the ECG pulse, and E_3 as the ground electrode.

Electrode placement configurations vary depending on the characteristic points of the ECG waveform—P, Q, R, S, and T. Under normal operating conditions, these signals typically exhibit a voltage range below 50 mV. However, due to the skin-electrode interface, peak voltage values on the skin surface can rise to ±300 mV [7].

Another relevant signal is the surface electromyography (sEMG), also represented in Table 1. It captures the voltage differential on the skin surface over the muscle being studied. This non-invasive method records signals with a typical range of ±200 mV, based on electrode-skin contact [8]. The characteristic sEMG curve represents the muscular force required to perform mechanical work, often illustrated as a Gaussian distribution, with maximum voltage corresponding to peak muscle activation.

Table 1. Biometric instrumentation sensors AD8232, AD8832 and MPU6050.

ECG	**sEMG**	**Gyroscope**	
AD8232	AD8832	MPU6050	
		 	**Module**
 	 	 	**Localization**
 	 	 	**Signal**

Source: Own Work

It is important to mention that for the correct measurement of ECG and sEMG signals [19], the AD8232 module includes amplifiers and impedance couplers that increase the ECG signal from millivolt levels to a range of 0V to 5V, making it measurable by any ADC (Analog-to-Digital Converter). Conversely, the AD8832 module, as shown in Table 1, presents a decrease in reading sensitivity when detecting potential differences between electrodes due to the use of lower-cost high-pass filtering components, which results in lower resolution in voltage readings.

To read the sEMG signal, it is necessary to quantify muscle power based on the electrical load measured by the AD8232. Both the AD8232 and AD8832 sensors operate on the principle of differential voltage signal coupling and require a dual power supply (+V and -V). Their output is an analog voltage signal, with gain and offset defined by the modules, which must be read using an ADC converter [1].

To calculate heart rate, the peak-to-peak values of the EMG signal (∑V_pp) are summed over a given total measurement time (p_T). Using Equation 1, the heart rate is then expressed in beats per second. To convert this value to BPM (beats per minute), the result is multiplied by the constant γ, applying a reduction as shown in Equation 1.

$$LPM = \frac{\sum V_{pp}}{p_T} * \gamma \tag{1}$$

Additionally, the inertial gyroscope MPU6050 incorporates a MEMS (Micro-Electro-Mechanical System) that enables the conversion of linear motion into measurable electrical variations associated with a specific axis of movement, thereby allowing the extraction of acceleration data. It also enables the determination of the degree of rotational motion based on the Coriolis effect [10].

The cyclist's posture is a critical factor in pedaling analysis; specifically, back curvature enhances aerodynamic efficiency at high speeds. Therefore, it is essential to quantify the degree of inclination as pedaling speed increases. However, measuring acceleration and angular displacement over extended periods presents a challenge due to cumulative errors from successive readings, a phenomenon represented in Equation 2.

$$e_T = \sum e_{t-1} + e_t \tag{2}$$

To mitigate the accumulated error, a complementary filter is employed. In Equation 3, this filter contributes to the calculation of the angle (θ) by incorporating the previous angle (α), the angular displacement velocity (ω_g) and the accelerometer -based angle (β_{ac}) as a reference. This approach results in an angle estimation with enhanced smoothing and reduced noise.

$$\theta = C_1\left(\alpha + \omega_g dt\right) + C_2(\beta_{ac}) \tag{3}$$

The angular variation and its acceleration are taken with a proportionality factor with the constants C_1 and C_2, must be adjusted as a calibration method of the MPU6050 module for its correct operation as shown in Equation 4.

$$C_{1,2} = \left\{C_{1,2} \in \mathbb{R} \middle| C_1 + C_2 \neq 0 \cup C_1 + C_2 \leq 1 \right\} \tag{4}$$

Telecommunication systems with local access devices interconnected with long-distance servers reduce the time required for sending and receiving information [7]. In particular, the WAP Bluetooth module, used for biomechanics studies, is mounted on a stationary bicycle and allows efficient data transmission within a radius of a few meters. However, external factors can introduce noise into the acquired signal, as well as cause delays in data acquisition. Equation 5 describes the accumulated error as a function of the delay in data transmission and reception, where (t_R) is the total accumulated response time, (t_k) is the previous response time, and (Δ_k) the accumulated error.

$$t_R = \sum_{k=10\ ms}^{n} t_k * \Delta_k \tag{5}$$

The LilyGo Ttgo board shown in Figure 1 is a microcontroller based on the ESP32 model, with the same digital and analog I/O configuration and support for machine-to-machine (M2M) communication protocols such as SPI and I2C. It operates with two physical cores at an adjustable clock speed ranging from 80 to 240 MHz, enabling more efficient processing and multicore programming through threading. The board includes Wi-Fi, Bluetooth 2.4, and 915 MHz radio frequency capabilities, allowing it to process, transmit, and receive digital signals through multiple wireless communication protocols.

Dedhia developed an ECG signal transmission system [11] using the Bluetooth protocol, focusing more on the instrumentation of the reading circuit than on data transmission. Villalva [12] developed a biometric data instrumentation system using the AD8832 sensor in conjunction with Arduino Uno and Nano boards, incorporating an Ethernet module to enable Wi-Fi communication via a router.

Currently, monitoring the real-time activities of athletes presents a challenge for real-time data transmission. Independent modules are required for data transmission, focusing on the instrumentation, normalization, and representation of biomedical signals.

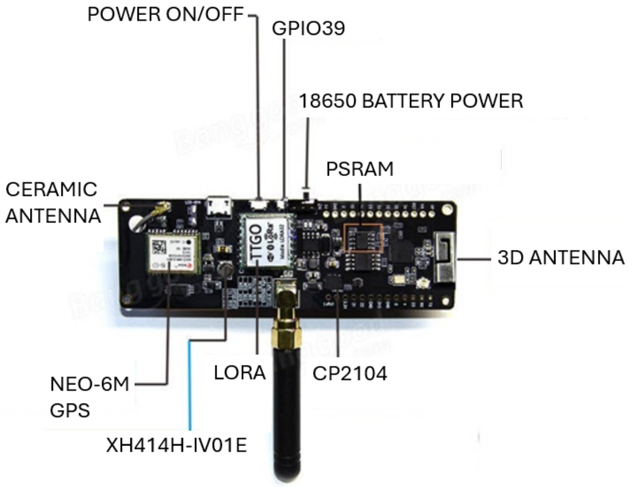


Figure 1. LilyGo Ttgo Card Pinout.
Source: Own Work

Nowadays, the systems used to monitor cyclists' physical performance are often expensive, invasive, or limited in their ability to provide real-time visualization [14]. These limitations hinder the dynamic analysis of key cycling variables, potentially affecting the accurate capture of posture, performance quality, and efficiency. As a result, corrective interventions to prevent injuries may not be effectively implemented. This issue highlights the need for an accessible, non-invasive technological solution capable of real-time data processing using practical and low-cost devices.

The objective of this study is to experimentally analyze a cyclist's performance during slow, normal, and fast pedaling stages using body sensor devices integrated into a wireless network [20]. The instrumentation includes practical sensors such as the AD8232 (for heart rate/ECG), AD8832 (for muscle activity/EMG), and MPU6050 (for back posture). Real-time graphical visualization is achieved through Bluetooth communication using the LilyGo Ttgo board programmed in MicroPython and interfaced with Visual Studio.

Research Question:

Can a wireless sensor network based on the LilyGo Ttgo and MicroPython provide an efficient and non-invasive system for real-time visualization of biometric data during a cyclist's pedaling?

Hypothesis:

The integration of low-cost biometric sensors within a wireless network, coupled with real-time graphical visualization, will enable the detection of performance patterns and the prevention of risk factors during cyclist training, without compromising physical performance.

2. MATERIALS AND METHODS

In Figure 2, the instrumentation system was designed using the biometric sensors AD8832 (for muscle strength), AD8232 (for heartbeat), and the inertial gyroscope MPU6050, all integrated into the LilyGo Ttgo board programmed with MicroPython. Signal extraction from the AD8832 and AD8232 modules is performed directly, with a smoothing filter applied based on the average signal to attenuate noise generated by the power supply and GND connection, due to their analog output nature. The MPU6050 inertial gyroscope, on the other hand, requires the I2C protocol for efficient data acquisition. For both the accelerometer and gyroscope components, a complementary filter was applied using the angular acceleration value on the Y-axis in combination with the gyroscope output, resulting in an attenuated and smoothed estimate of the absolute angle.

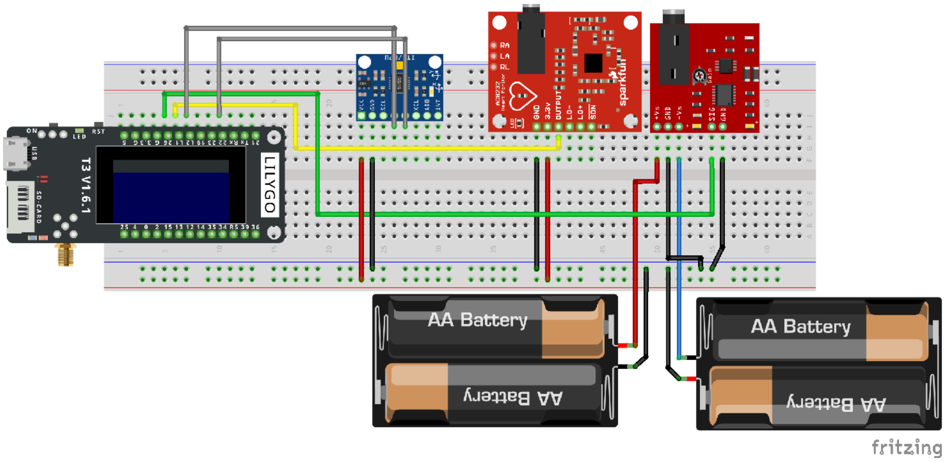


Figure 2. A schematic representation of the wireless body sensor network in LilyGo Ttgo.

Source: Own Work

In Figure 3, and taking Table 1 as a reference, the electrodes were positioned according to the type of signal to be instrumented:

1. **ECG signal**: For accurate signal extraction, the electrodes must be placed in specific areas of the chest. The positive reference electrode and the ground electrode should be positioned at opposite ends of the heart, while the sensing electrode should be placed over the area associated with the heart's surface.
2. **sEMG signal**: Unlike the ECG configuration, the sEMG signal requires a sequential placement of the electrodes over the target muscle. In this case, the outer electrodes serve as the positive reference and ground, while the middle electrode functions as the sensing electrode.

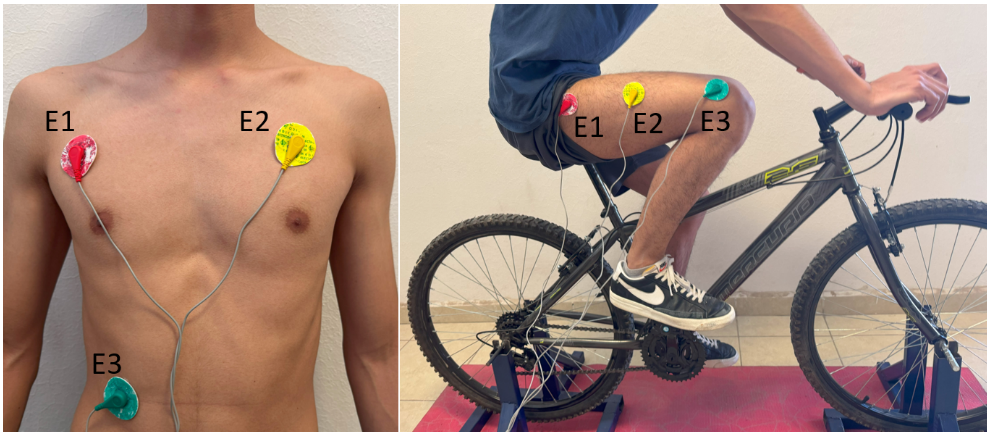


Figure 3. Electrode connection: ECG signal and sEMG signal.
Source: Own Work

The host device was an HP laptop running Windows 10, designated to receive the cyclist's biometric data transmitted by the LilyGo Ttgo board. This data was then retransmitted to other devices, referred to as users, through an application developed in the Visual Studio environment, as illustrated in Figure 4. As shown in Table 2, communication between the host and the LilyGo Ttgo board can be established using any of the integrated wireless protocols; however, Bluetooth was selected as the primary communication method for the interface.

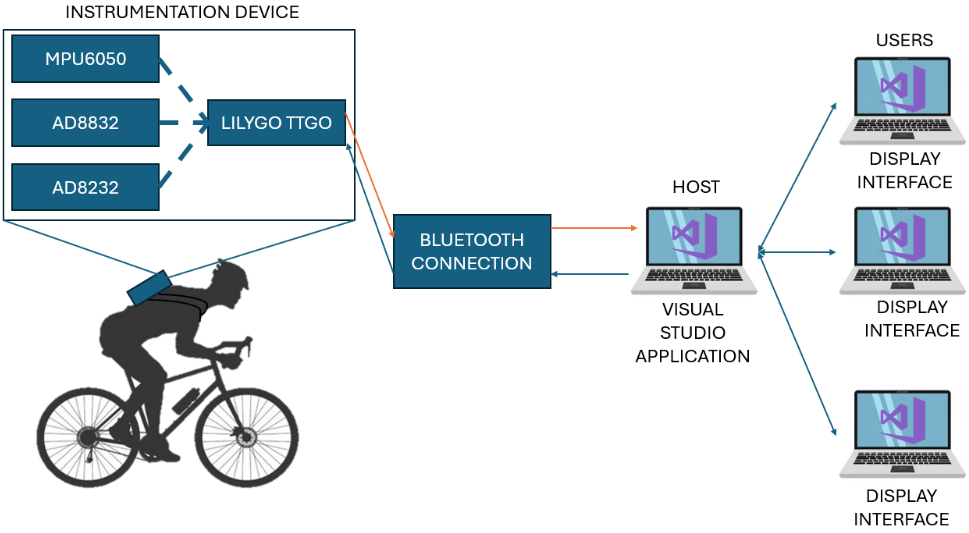


Figure 4. Wireless body sensor network diagram.

Source: Own Work

Table 2. Configuration of communication protocols.

Transmitting device	Receiving device	Communication Protocol	Speed *(baudios)*	Range *(m)*
LilyGo Ttgo	Host	Bluetooth	115200	8
AD8832	LilyGo Ttgo	-	-	-
AD8232	LilyGo Ttgo	-	-	-
MPU6050	LilyGo Ttgo	I2C	115200	-
Host	Users	Bluetooth /COM	Adjustable	8 a 12
User	-	Bluetooth/COM	Adjustable	8 a 12

The electronic circuit was assembled on a perforated board to minimize movement and signal interference between components during pedaling tests. Figure 5 displays the final configuration, including the power supplies. Visual Studio enables connectivity with multiple communication protocols compatible with the COM port. While the host system can support up to five physical devices simultaneously, this limitation can be overcome by integrating additional wireless protocols, depending on the computer's processing capacity.

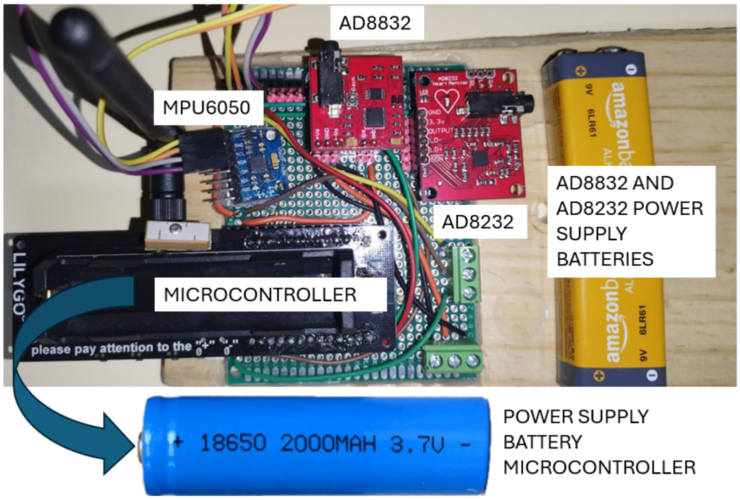


Figure 5. Electronic circuit assembly.
Source: Own Work

3. RESULTS

Figure 6 shows the system assembled on the cyclist mounted on an R26 mountain bike, with the LilyGo Ttgo circuit and board integrated into a harness worn by the cyclist during the execution of different pedaling levels. Additionally, a Stelar CW 750 video camera was mounted laterally on the bicycle to capture footage of each pedaling cycle. The recorded video is processed through an algorithm developed in the Python 3 environment, where it is plotted in real time. Specific signals are identified as nodes and associated with key points on the human body, as detailed in Table 3.

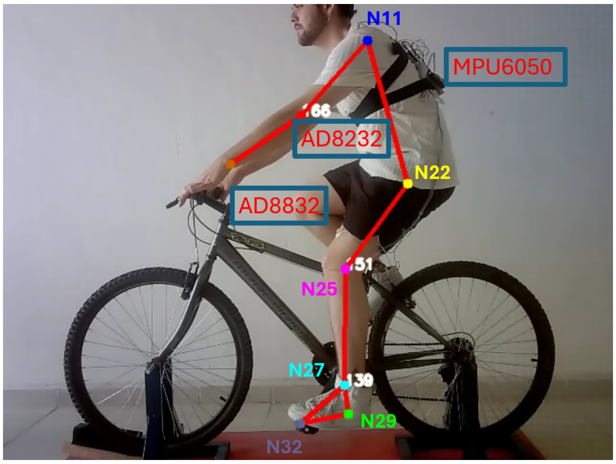


Figure 6. Harness setup with the sensor instrumentation circuit on the rider.
Source: Own Work

The samples were studied across three pedaling stages: slow, normal, and fast, each lasting 10 seconds. The characterization of the sensors is presented in Figure 7 and Table 1. A complementary filter was applied, and the AD8832 and AD8232 sensors were calibrated to operate within a range of 0–5 V to prevent damage to the internal ADC of the microcontroller.

Table 3. Configuration of human body nodes.

Node	Body Part	Node	Body Part	Node	Body Part
N11	Right arm	N25	Right knee	N29	Right heel
N22	Right hip	N27	Right ankle	N32	Right index toe

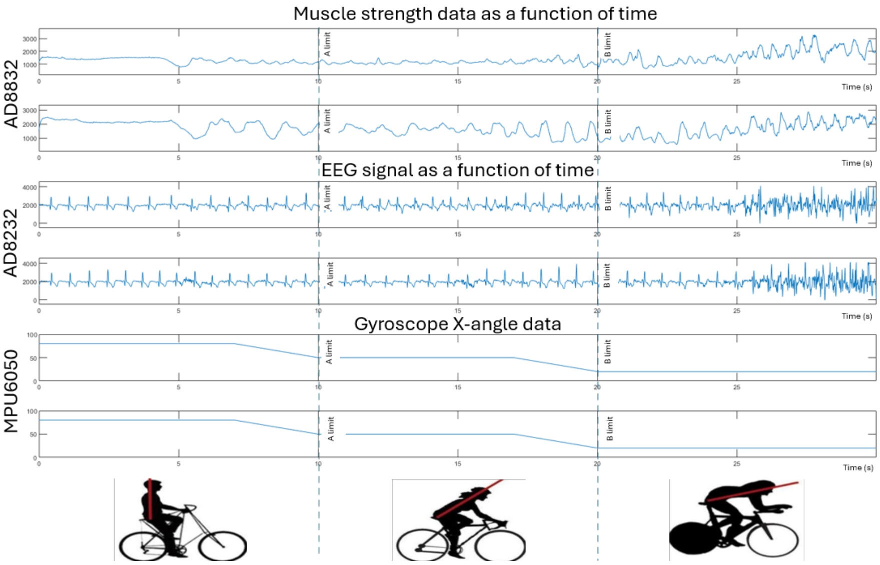


Figure 7. AD8832, AD8232 and MPU6050 sensor signal: low, normal and fast pedaling.
Source: Own Work

According to Table 4, the AD8832 sensor uses electrodes placed on the right quadriceps. The signal exhibits a sinusoidal, cyclic pattern corresponding to pedaling, reflecting the contractions of the upper thigh muscles, with the biceps femoris acting as the counterpart to the sinusoidal wave. In the slow pedaling phase, the signal displays smaller amplitude peaks compared to fast pedaling, demonstrating Newton’s second law: a greater force is required to achieve higher acceleration. Generating such force implies an increase in energy production, which in turn requires a higher oxygen flow to produce ATP (adenosine triphosphate), as reflected in the BPM.

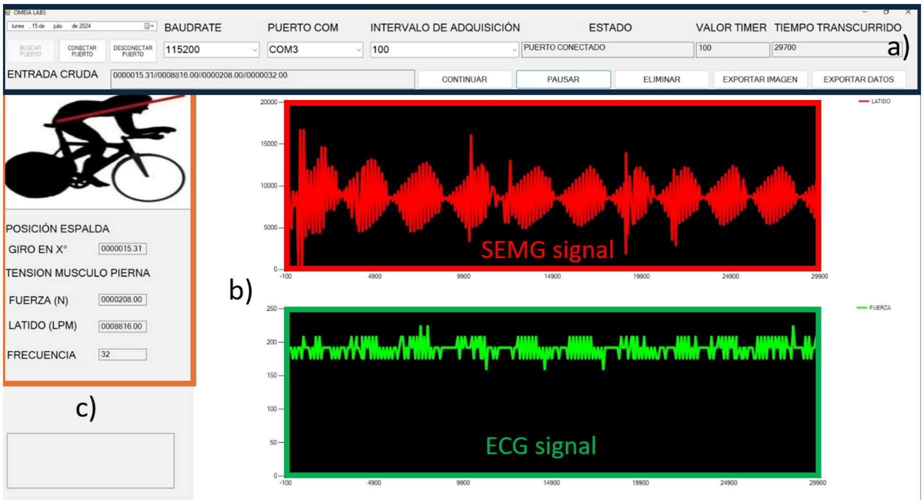
The AD8232 sensor captures the ECG signal, requiring electrode placement on the chest and upper abdomen of the cyclist. However, instrumentation error increases with pedaling intensity and speed, due to greater vibration affecting the electrodes from body movement. To mitigate this, the sensor modules are mounted on a chest harness, isolated from sweat and with improved cable distribution to reduce interference with pedaling.

The angular position of the back, associated with the Y (θ_y), is recorded during the pedaling cycles to analyze the cyclist's posture relative to the vertical. While the AD8832 and AD8232 sensors show increased error as pedaling speed rises, the MPU6050 sensor maintains the angular range within consistent parameters.

Table 4. Results acquired from the sensors throughout the pedaling stages.

Pedaling Stage	AD8832	AD8232	MPU6050
Slow	Muscle with constant tension with a variation associated to ± 0.6103 V with force throughout pedaling cycles.	Beats with constant frequency of 84 *BPM* with normal beating range associated with an adult: using Equation 1.	Angle ≈ 80°, with variation between slow and normal pedaling.
Normal	Muscles with greater variation in tension of ± 0.8544 V, constant cycles are observed with greater peak strength.	Beats of variable frequency of 96 *BPM* with an average increase in frequency as the cyclist accelerates.	Angle 60°, with a change between normal and fast pedaling.
Fast	Muscles with high cyclic tensions of ± 1.4648 V, the signal is cut off by the sensing limit in the ADC, a readjustment in the sensor amplification value is required	Significantly increase in error, the heart rate presents an unstable increase with an average of 138 *BPM*, it is necessary to adjust the distribution of the samples for a better visualization of the heart rate.	Angle ≈ 20°, the signal shows an increase in error at the measured angle.

The interface developed in Visual Studio, shown in Figure 8, displays the biometric signals from the Wireless Body Sensor Network (WBSN) transmitted by the LilyGo Ttgo board and received at the computer station.



lunes , 15 de julio de 2024

BAUDRATE: 115200

PUERTO COM: COM3

INTERVALO DE ADQUISICIÓN: 100

ESTADO: PUERTO CONECTADO

VALOR TIMER: 100

TIEMPO TRANSCURRIDO: 29700

ENTRADA CRUDA: 0000015.31//0008816.00//0000208.00//0000032.00

POSICIÓN ESPALDA

GIRO EN X°: 0000015.31

TENSION MUSCULO PIERNA

FUERZA (N): 0000208.00

LATIDO (LPM): 0008816.00

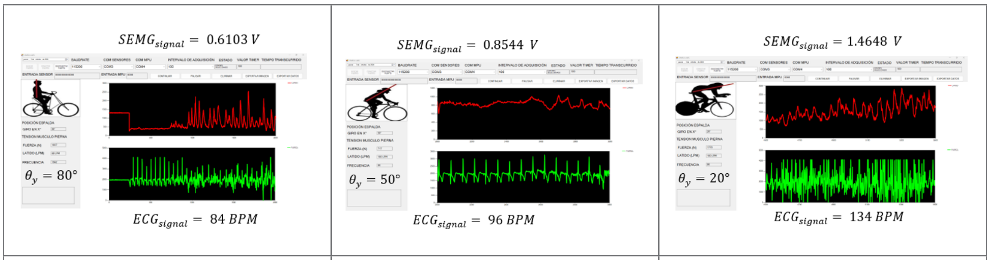
FRECUENCIA: 32

Figure 8. WBSN interface components: a) Configuration, b) Signal visualization and c) Data output.
Source: Own Work

4. DISCUSSION AND CONCLUSIONS

The use of a thoracic harness integrates the WBSN communication system into a biometric signal acquisition and processing unit with a total weight of 120 grams. This setup allows for proper pedaling by the cyclist without imposing a significant additional load that could affect performance during speed tests. With an implementation cost of less than 200 USD, the system offers a compact and cost-effective alternative for monitoring cyclist performance, with data retransmission capabilities at a maximum range of 8 meters—comparable to acquisition equipment costing approximately 900 USD. It provides equivalent functionalities in heart rate preprocessing and graphical visualization of muscle power (sEMG and EMG) during speed and exhaustion tests. Figure 9 shows the Python interface, where the three pedaling types at suggested 10-second intervals can be observed. The posture signals indicate the pedaling stage being evaluated, and the capture of the cyclist's torso inclination angle is represented by θ_y. The cadence for each pedaling type is classified in sequential posture angle ranges: slow speed 75° < θ_y < 90°, normal speed 45° < θ_y < 74°, and fast speed 20° < θ_y < 44°, respectively. The graphs display the body signals (sEMG in red and ECG in green), showing the sequence of study in relation to pedaling exercise time.

In conclusion:



Slow | Normal | Fast

Figure 9. Pedal Display Interface.
Source: Own Work

Slow. In the initial stage, the cyclist starts from rest at time t = 0 s. The signal associated with the magnitude of the force required to initiate motion presents an initial peak of 2.81 V. Once the pedaling speed stabilizes, muscle power decreases to 1.75 V. The AD8232 sensor registers a change in heart rate, stabilizing at 90 BPM. At t = 2 s, the pedaling speed becomes constant, and posture is maintained at 80° ± 5°, as detected by the accelerometer.

Normal. Speed stabilizes at t = 12 s as the cyclist overcomes the inertia of the resting state. The muscle signal increases to 1.5 V. Meanwhile, the BPM signal averages 100 BPM with a posture angle of 60° ± 15°.

Fast. The signal stabilizes at t = 22 s, where the pedaling rate causes notable perturbations, increasing BPM measurement error in the AD8232 sensor. The muscle force signal voltage rises, reaching saturation near the 5 V limit of the LilyGo Ttgo board's internal ADC. At this stage, the exerted force exceeds the threshold, and the accelerometer detects a back position inclination of up to 20° ± 35°.

However, the wireless body sensor network (WBSN) harness occasionally registers false states due to sensor contact on the control board, resulting in approximately 10% data loss and a bit-reception delay beginning at k = 10 ms. Although this delay does not significantly affect WBSN data acquisition, optimizing the data transmission method is necessary to ensure a reliable real-time response.

Future improvements propose the use of the Radio Frequency (RF) protocol integrated into the board to enhance communication range, and the adoption of an internet-based protocol to establish a network between the WBSN system and smart devices. This would allow data access from any internet-enabled device, forming an Internet of Things (IoT) system with lower power consumption, higher connectivity, and greater data transmission capacity—effectively eliminating response time errors and exponentially optimizing the performance of the wireless cardiac, muscle, and angular sensor system.

Communication protocols in sports measurement instruments are evolving toward wireless technologies, where real-time biometric data acquisition plays a critical role in improving physical conditioning and performance by dynamically identifying the cyclist's physical condition and environmental factors influencing their output. In this work, the implementation of the LilyGo Ttgo board enables the transmission of WBSN biometric data via Bluetooth, using advanced instrumentation and monitoring techniques that minimize pedaling interference—an effective alternative to conventional equipment for pedaling kinematic analysis. The use of compact sensors allows the harness to remain lightweight, thus avoiding additional fatigue or back strain for the cyclist during performance testing.

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