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A WEARABLE SYSTEM FOR RESPIRATORY AND PACE MONITORING IN RUNNING ACTIVITY

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ABSTRACT

Wearable technology has dramatically transformed the tracking of physiological parameters, particularly in healthcare and athletic environments. While devices that monitor heart rate, step count, and calories are widely used, respiratory rate is often overlooked. However, respiratory rate plays a crucial role in understanding the body's physiological and biomechanical responses during physical exertion. This study investigates a wearable system designed to monitor respiratory rate and running-related parameters, aiming to fill the gap in performance analysis, especially for athletes. Respiratory rate is an important indicator of a person's physiological condition, reflecting the body's metabolic demands during physical activity. While heart rate is commonly utilized in sports science, respiratory data provides valuable insights into performance and fatigue. Traditional techniques for measuring respiration, such as spirometry and laboratory tests, offer high accuracy but are impractical for real-time or field-based monitoring. In contrast, wearable devices offer a practical, non-invasive alternative. This study evaluates a wearable system that consists of two elastic bands equipped with conductive textile sensors. These bands are designed to monitor respiratory activity and estimate running-related metrics during a field test. By applying frequency-domain analysis, the system aims to accurately estimate the average respiratory rate as well as other running metrics like pace and distance. These insights could improve the understanding of how respiratory patterns relate to fatigue and athletic performance. The wearable system is made up of two bands with conductive textile sensors placed at key anatomical sites: one on the upper thorax and the other around the umbilicus. This configuration allows the system to track both chest and abdominal movements during breathing. The sensors detect the strain caused by respiratory motion, enabling real-time monitoring of respiratory parameters. The test was conducted with a healthy young volunteer who ran about 9.5 km outdoors to simulate real-world conditions. The system captured data that reflected both respiratory and biomechanical activities during the run. Frequency-domain analysis was applied to the sensor data, focusing on two main

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areas: Respiratory Parameters: Estimating the average respiratory rate during the run.Running Parameters: Estimating the running distance and pace based on gait-related data from the sensors. The wearable system demonstrated its ability to accurately estimate both respiratory and running parameters during the field test.

I. INTRODUCTION

Wearable technology has significantly changed the way we monitor physiological parameters, enabling continuous, non-invasive tracking in various fields, particularly in healthcare and sports. While commonly measured metrics such as heart rate, step count, and calorie expenditure are well known, respiratory rate is often neglected, even though it plays a crucial role in assessing both metabolic health and athletic performance. As an important indicator of the body's ability to meet oxygen demands during physical exertion, respiratory rate is vital for evaluating performance, fatigue, and overall well-being. In the past, respiratory rate was measured using large, cumbersome devices like spirometers, which are not ideal for continuous monitoring during physical activities. Wearable technology, however, provides a more effective and efficient alternative, allowing for real-time tracking of respiratory parameters during exercise in natural, uncontrolled environments. This study investigates a wearable system designed to monitor both respiratory rate and running performance metrics simultaneously.

The system consists of two elastic bands with conductive textile sensors, tested during a 9.5 km run to calculate the average respiratory rate, along with running data such as pace and distance. By employing frequency-domain analysis, the system gathers real-time data on both respiratory and biomechanical parameters. This research aims to explore the relationship between respiratory patterns and running performance, contributing to a better understanding of fatigue and its impact on athletic performance, while offering a new method for tracking endurance sports.

The wearable system assessed in this study holds the potential to change how athletes and coaches evaluate and enhance performance. By providing valuable insights into the connection between physiological and biomechanical factors, the system can serve as a powerful tool for improving training and optimizing performance

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outcomes. In recent years, wearable devices have become essential for monitoring a wide variety of physiological metrics, facilitating continuous health and performance tracking. These devices are widely used in clinical and sports science fields, offering critical insights into the body's function during physical activity. While metrics like heart rate, step count, and calorie expenditure are commonly tracked, respiratory rate remains underutilized, despite its significance in evaluating athletic performance, especially in endurance sports where managing oxygen consumption and fatigue is essential. Respiratory rate is a key measure of the efficiency of both the cardiovascular and pulmonary systems, which are crucial during sustained physical activity. In endurance sports, athletes frequently push their limits, making it vital to understand the body's ventilator response in order to improve performance, aid recovery, and prevent overexertion. However, real-time tracking of respiratory rate during dynamic activities such as running has been challenging due to the limitations of traditional measurement methods. Conventional tools, such as spirometry and capnography, require specialized equipment and controlled settings, making them unsuitable for use during physical activities in uncontrolled environments.To overcome this challenge, wearable technologies have been developed to provide continuous, non-invasive tracking of physiological parameters. These devices are lightweight, unobtrusive, and offer portable solutions for monitoring both respiratory and biomechanical metrics during exercise. By integrating sensors that detect respiratory movements, these systems provide valuable data for better understanding an athlete's physiological condition, performance, and recovery. This study evaluates a novel wearable system that tracks both respiratory rate and running performance metrics throughout a running session. The system comprises two elastic bands with conductive textile sensors placed on the rib cage—one on the upper thorax and another around the umbilicus. These sensors detect respiratory motion and provide data for frequency-domain analysis, which estimates respiratory parameters (such as average respiratory rate) and running metrics (like pace and distance).

II.METHODOLOGY

A) System Architecture

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Fig1 .Block Diagram

The wearable system for tracking respiratory rate and pace during running consists of several essential components. At its core, the device incorporates sensors like a heart rate monitor, accelerometer, gyroscope, and respiratory sensor to measure important metrics such as heart rate, breathing rate, and running speed. The data is processed directly on the device, which then sends real-time updates to a mobile app or cloud platform via Bluetooth or Wi-Fi. The app provides users with visual feedback, trends, and notifications related to their respiratory and pace performance. Additionally, the system analyzes the data to identify patterns and generate health insights, helping users improve their running performance and monitor progress over time.

B) Proposed Raspberry pi

The Raspberry Pi Pico is an affordable microcontroller board created by the Raspberry Pi Foundation. Unlike full-fledged computers, microcontrollers are small and have limited storage and peripheral options, such as the absence of devices like monitors or keyboards. However, the Raspberry Pi Pico is equipped with General Purpose Input/Output (GPIO) pins, similar to the ones found on Raspberry Pi computers, allowing it to connect with and control a variety of electronic devices. Introduced in January 2021, the Raspberry Pi Pico is based on the RP2040 System on Chip (SoC), which is both cost-effective and highly efficient. The RP2040 SoC includes a dual-core ARM Cortex-M0+ processor that is well-known for its low power consumption. The Raspberry Pi Pico is compact, versatile, and performs efficiently, with the RP2040 chip as its core. It can be programmed using either Micro Python or C, providing a flexible platform for users of various experience levels. The board contains several important components, including the RP2040 microcontroller, debugging pins, flash memory, a boot selection button, a programmable LED, a USB port, and a power pin. The RP2040 microcontroller, custom-built by the Raspberry Pi Foundation, is a powerful and affordable processor. It features a dual-core ARM Cortex-M0+ processor running at 133 MHz, 264 KB of internal RAM, and supports

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up to 16 MB of flash memory. The microcontroller provides a wide range of input/output options, such as I2C, SPI, and GPIO. The Raspberry Pi Pico has 40 pins, including ground (GND) and power (Vcc) pins. These pins are grouped into categories such as Power, Ground, UART, GPIO, PWM, ADC, SPI, I2C, System Control, and Debugging. Unlike the Raspberry Pi computers, the GPIO pins on the Pico can serve multiple functions. For instance, the GP4 and GP5 pins can be set up for digital input/output, or as I2C1 (SDA and SCK) or UART1 (Rx and Tx), though only one function can be used at a time.

C) DESIGN PROCESS

The design of embedded systems follows a methodical, data-driven process that requires precise planning and execution. One of the core elements of this approach is the clear separation between functionality and architecture, which is crucial for moving from the initial concept to the final implementation. In recent years, hardware-software (HW/SW) co-design has gained significant attention, becoming a prominent focus in both academia and industry. This methodology aims to align the development of software and hardware components, addressing the integration challenges that have historically affected the electronics field. For large-scale embedded systems, it is essential to account for concurrency at all levels of abstraction, impacting both hardware and software components. To facilitate this, formal models and transformations are employed throughout the design cycle, ensuring efficient verification and synthesis. Simulation tools are vital for exploring design alternatives and confirming the functional and timing behavior of the system. Hardware can be simulated at different stages, including the electrical circuit, logic gate, or RTL level, often using languages like VHDL. In certain setups, software development tools are integrated with hardware simulators, while in other cases, software runs on the simulated hardware. This method is generally more suited for smaller parts of an embedded system. A practical example of this methodology is the design process using Intel's 80C188EB chip. To reduce complexity and manage the design more effectively, the process is typically divided into four main phases: specification, system synthesis, implementation synthesis, and performance evaluation of the prototype.

APPLICATIONS

Embedded systems are being

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increasingly incorporated into a wide range of consumer products, such as robotic toys, electronic pets, smart vehicles, and connected home appliances. Leading toy manufacturers have introduced interactive toys designed to create lasting relationships with users, like "Furby" and "AIBO." Furbies mimic a human-like life cycle, starting as babies and growing into adults. "AIBO," which stands for Artificial Intelligence Robot, is an advanced robotic dog with a variety of sophisticated features. In the automotive sector, embedded systems, commonly referred to as telematics systems, are integrated into vehicles to offer services like navigation, security, communication, and entertainment, typically powered by GPS and satellite technology. The use of embedded systems is also expanding in home appliances. For example, LG's DIOS refrigerator allows users to browse the internet, check emails, make video calls, and watch TV. IBM is also developing an air conditioner that can be controlled remotely via the internet. Given the widespread adoption of embedded systems across various industries.

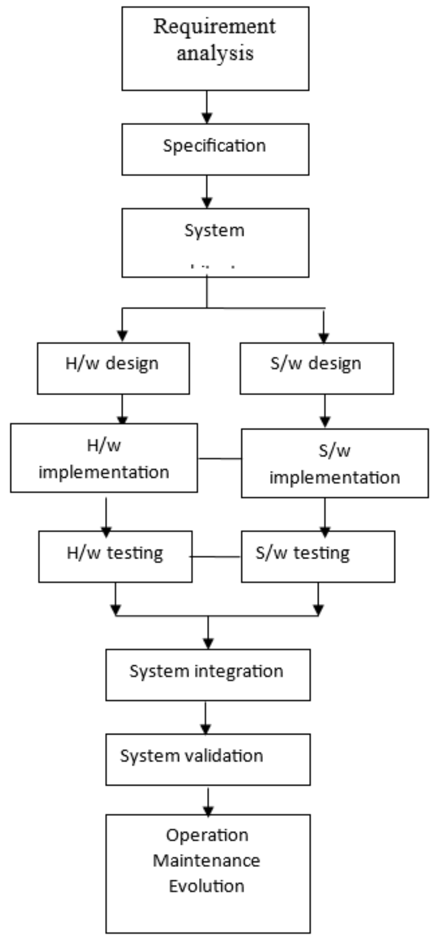

Fig 2. Embedded Development Life Cycle

III.CONCLUSION

In recent years, wearable technology has become increasingly popular in both sports science and healthcare, particularly for monitoring critical physiological factors such as respiratory rate, heart rate, and gait during physical activities. These technological advancements have facilitated more accurate and comprehensive tracking of athletes' performance and recovery. Wearables that use technologies like elastic bands and conductive textiles for respiratory monitoring have shown great potential in providing real-time data to improve the analysis of athletic performance. A key advantage of these devices is their ability to monitor respiratory metrics, which are often overlooked in traditional performance assessments. Respiratory rate is a vital indicator of an athlete's physical condition and endurance. By tracking respiratory rate alongside running metrics like pace and distance, athletes and coaches can obtain a more complete understanding of performance. These wearables capture both respiratory and biomechanical data, offering valuable insights that support informed decisions on training intensity, fatigue management, and recovery strategies. Studies reviewed in this research underscore the accuracy and reliability of wearable systems in estimating respiratory rate, running distance, and pace, especially when paired with other sensors such as accelerometers and gyroscopes. The integration of these sensors into wearable devices ensures that athletes can comfortably wear them during training and competitions without interfering with performance. Additionally, improvements in sensor technology, battery life, and data processing algorithms have enhanced the practicality of these systems for real-world use. Despite these advances, challenges persist in achieving maximum accuracy and reducing interference, particularly in dynamic environments where external factors can affect sensor performance. Sensor calibration and data interpretation remain key areas of ongoing research. The integration of machine learning and advanced signal processing techniques has the potential to further improve the precision and reliability of these systems, leading to better predictions of fatigue levels and performance outcomes. The future of wearable devices in sports science is promising, with potential applications extending beyond performance enhancement to include injury prevention and rehabilitation. Real-time monitoring of an athlete's physiological responses could lead to personalized training programs tailored to individual needs. Furthermore, these devices have significant clinical applications, where continuous monitoring of respiratory activity can assist in managing chronic conditions and improving patient care. In conclusion, wearable devices for tracking respiratory rate and performance represent a transformative development in sports science. These devices provide athletes with real-time data on their physiological parameters, allowing for optimized training, fatigue management, and performance enhancement. As technology continues to evolve, these devices are expected to become even more accurate, accessible, and integral to athletic training, potentially revolutionizing the way athletes approach both performance and recovery. The continued development of wearable systems for monitoring respiratory and biomechanical parameters has the potential to enhance not only sports performance but also the overall health and well-being of individuals engaged in physical activities.

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