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An IoT-enabled Portable System for Field-based Endurance Run Testing

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***Abstract*—Nowadays, aerobic capacity tests are recurrently used to determine the maximum oxygen consumption (VO2max) of an individual. The VO2max expresses the maximum aerobic capacity and is considered the best cardio-respiratory fitness index. A widely used test in a school context for this purpose is the PACER (Progressive Aerobic Cardiovascular Endurance Run) test, which consists of a shuttle race at a stage of 20 meters under a certain pace that is increased over time. When performed in a school context, where several individuals perform the test at the same time, some problems arise that may affect the reliability of the test. Problems such as human error, in measurements and lap counting, or lack of perception of the rhythm for the tested individual can affect the reliability of the results obtained. It is also difficult to repeat the test indefinitely, since it requires more than one test for the results to have the desired credibility. This research activity involves the development and validation of an electronic digital prototype for setting the pace of the PACER test. This apparatus will need to be portable for using in all possible settings (field and laboratory); price affordable; will have the possibility to be used in other paced tests; it will be controlled via a digital App (Smartphone) and will allow collecting inline data.**

***Index Terms*—Endurance Run, Fitness Assessment, Internet-of-Things, IoT, IoT in Sports, Cyber-Physical Systems**

I. Introduction

Due to the technological advances we have been experiencing in the last decades, besides other areas such as agriculture and industry, sports has also benefited from these advances. The implementation of technological resources has brought countless benefits to sports, mainly in the measurement and analysis of indicators of physical and mental health of human beings. Besides medical tests, there are other techniques for obtaining these indicators, such as aerobic capacity tests. Aerobic capacity tests are recurrently used to determine the maximum oxygen consumption, V_{O_2}max, of an individual. The V_{O_2}max expresses the maximum aerobic capacity and is considered the best cardio-respiratory fitness index. There are many aerobic capacity tests that can be used to obtain this index. A widely used test to estimate an athlete's aerobic capacity is the *Progressive Aerobic Cardiovascular Endurance Run* (PACER) test. The PACER test is a 15 or 20-meter multi-stage run test that relies on an auditory stimulus to set a pace that is increased throughout each stage. In figure 1 an example of a lap is shown. A lap is considered to be the distance covered from the start of the stage to its end, at which point the runner should reverse the direction of the movement. Each stage has a preset pace (speed in km/h) and a preset number of laps. When all the laps of a certain stage have been concluded, a beep is given to inform the runners of such an event. This lets them know that the pace has increased and that the number of laps may have changed (note that the number of laps can change from stage to stage). When the athlete fails to finish the stage before the sound signal twice, the test ends. Depending on the number of stages performed, it is possible to calculate the maximum aerobic capacity of the athlete, along with other data such as age, height, weight and gender.

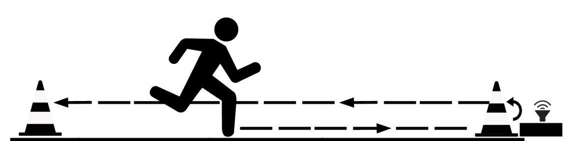

Fig. 1. Classic PACER test implementation using Beep test

Although the PACER test is an effective way to obtain maximal aerobic capacity, there are some problems in its execution. In its classic implementation, the PACER test is based on an audio CD with auditory stimuli that informs runners of the increase of pace, as well as the instant at which they should start running in each lap. Because this information is transmitted by auditory stimuli, the runner cannot get a correct perception of the speed at which he has to run in order to complete the lap before the beep. With this, two situations can occur: the runner ends the stage with some time to spare (this means that he ran at a higher pace than intended) or does not finish the stage on time (by trying to manage the effort). Therefore, the lack of perception of the pace at which you have to run can result in mismanagement of physical effort, which can influence the results obtained from the test. In addition, the results are recorded manually on a sheet of paper, which contains the number of stages and laps existing in each of these stages. Although it seems like a simple solution, when the test is performed with more than one person at a time, recording all the results can become a complicated task. Furthermore, performing the test repeatedly in order to get more reliable results is not an ideal solution for the person recording the results. Each run would involve a new sheet of paper, and the organization of the results is not optimal when multiple runs of the test are done. For these reasons, manually recording the results is not a scalable solution. Still in the classic implementation, not all types of audiences can perform the test independently, as is the case with hearing-impaired people. Since the signals are audible, people with this type of problem would not be able to perform this test.

This paper presents the design and implementation of a prototype capable of executing the PACER test, as well as other aerobic capacity/endurance run tests. The system takes advantage of a microcontroller unit (MCU) to control a light and sound signaling, as well as the communications through the Bluetooth Low Energy (BLE) protocol with a mobile app where the main interaction with the user is performed.

This paper is organized as follows: section II contains an overview of technology used in sports, a brief study on the PACER test and related works in this topic and in section III we propose the architecture of the apparatus and operation mode.

II. State of art

With the constant growth and innovation of technology applied to other areas, sports have also begun to benefit from various studies. The information currently present around this area has allowed sports to move to another level, both competitively and leisurely. With this, new technologies began to be applied to sports in general, leading to the development of prototypes embedded with sensors (data acquisition), processing units (data processing), and communication blocks (data transfer). Many of the prototypes made are wearables for sports enthusiasts and athletes to wear during their activities. A systematic review [1] of wearables and Internet-of-Thing (IoT) summarizes recent studies that have used such technologies for fitness assessment. Among the 20 studies covered, the most common was the wristband, but many other wearables were developed, such as gloves, t-shirts, watches, etc. None of these studies developed a prototype for the PACER test or any other endurance run test.

The PACER test is known worldwide and there are hundreds of articles published on this subject. In some of these articles, we tried to understand more about this test and what technologies are used for its implementation.

A. PACER test

1) Realiability and Validity: Since this work aims to implement the PACER test in a school context, it is important to understand how accurate, reliable and valid this test can be. Authors in [2] conducted a study on the validity and reliability of the results obtained in the test for obtaining the maximum volume of oxygen and concluded that the 20-meter version of the PACER test showed positive results in the criteria mentioned above, both in children and adults. The authors in [3] obtained identical results with a slight difference in the results obtained in adults.

2) PACER with children: Several studies on youth and children have stated that the PACER test is a reliable way to test maximum aerobic capacity, taking into consideration the effort made by them and the motivation to perform the test [4] [5] [6] [7] [8].

3) PACER methods: In a school context, the space required for the test can be a conditioning factor. Authors in [9] concluded that both versions of the test (15 and 20 meters) provide similar results, and they recommend the 20-meter version. When comparing the results obtained between a treadmill test and the PACER test, authors in [10] say that the results were quite similar although for young males there was a slight difference in the treadmill test, but nothing relevant. When comparing the different equations commonly used to obtain the maximum aerobic capacity, Gao et al. in [11] carried out a study in which they compared four equations, concluding that, in children, all present the same results when used to estimate the maximum VO2. Thus, in this work, we adopted Eq.1:

$$VO2_{Max} = 3.46\times(L+TL/(L\times0.4325+7.0048))+12.2 \quad (1)$$

where L represents the stage number and TL represents the total laps performed.

In [12], Lightburne has observed a minimal improvement in accuracy when adding the BMI (Body Mass Index) as a predictor, having concluded that the model with PACER and age as predictors has a high level of utility for physical fitness testing of young people.

B. Technologies used

1) RFID: Radiofrequency identification is a very common technology nowadays. Applied to sports, this technology has brought some significant advantages such as the mitigation of human error. The article [13] is about a device that was developed to autonomously measure the laps in the PACER test. For this, antennas are placed at the ends of the stage

TABLE I
COMPARISON OF PRODUCTS IN SECTION II-C ACCORDING TO PRIORITIZED CRITERIA

Product	Low-cost	Portable	Reliable	Configurable	Price
FitnessGram CD	✓	✓	-	-	20$
PACER for Schools	✓	✓	✓	-	Free
Beam Trainer Package	-	✓	✓	✓	1500$
RFID-based PACER	✓	✓	✓	-	-
Our product	✓	✓	✓	✓	$\sim$100$

so that when the athlete reaches each one of them, a reader captures the identification of the athlete and checks if he complies with the stipulated time. In this article, references were made to other examples where this technology was used, such as in marathons, soccer or even in gyms where a bracelet allowed a machine to read the user's data and configure a specific test previously stipulated.

2) Bluetooth Low Energy (BLE): Bluetooth Low Energy is a low power wireless technology that is widely used in the Internet of Things (IoT). This protocol is designed to allow networked devices to transmit bursts of data consuming a small amount of energy, allowing devices under the power of a coin cell battery to run for an order of magnitude of years. Although this protocol has numerous advantages, when used for large data transmissions the low-power criterion tends to fade. Another important criterion to take into account is security and although the protocol itself already provides some protection measures, in a network of exposed sensors may not be enough [14]. Applied to the fitness area, multiple cardiac monitoring devices use this prototype to communicate the values read and visualized in real-time in a mobile device. An example of this is the study done in [15], where the authors besides introducing, explaining and comparing with the classic Bluetooth, also developed a prototype of heart rate monitoring in real-time.

C. Related Products

To complete this state of the art, a survey of applications and products similar to what is intended to be developed has been made and are presented in the sections below, as well as compared in table I. The criteria defined in the table represent the ones established for this project, which are defined as:

- Low-cost: Since the project is being developed for use in a school context, the most prioritized criterion is to be low cost, so that it can be easily acquired by any school;
- Portable: being light and easy to carry device it can be used anywhere;
- Reliable: measurements are accurate allowing to obtain credible results and close to the real value;
- Configurable: not only allows the PACER test but also the customization of other aerobic capacity exercises so that the use of the device is not restricted for a particular purpose.

1) FitnessGram PACER: The FitnessGram PACER test is a program created by The Cooper Institute to measure the maximum aerobic capacity of a student. It contains the audio that will guide students through the test along with other resources such as score sheets and instructions. All measurements have to be made manually and can be inserted later in software provided. To implement the test, besides the audio CD that will create the auditory stimuli, other accessories are needed to delimit the test area. The student cannot have an effective perception of the rhythm that is imposed and the measurement of results, when the test is performed in groups, may have unwanted inaccuracies.

2) PACER for Schools: Pacer for Schools is a mobile application that can be acquired for free from an application store like PlayStore. It allows the implementation of the PACER test using hearing stimuli (beeps). Also, it is possible to observe the elapsed time, imposed speed, distance travelled and the current stage in the interface. However, only one user can run the test at a time, as the free version does not allow for use in groups. In the Pro version, there is the test functionality in groups, with the possibility to save and export the results individually and still visualize the comparison of the group in graphs. However, despite the mitigation of human error, the lack of notion of the imposed pace still exists.

3) Beam Trainer Package: The Beam Trainer Package is the most complete product among all those mentioned above. It contains a system of infra-red sensors that count the times in a very precise way. Accompanied by a mobile application, the system can be previously configured depending on the number of sensors used or the type of test to be implemented. Although it is configurable, this product was designed to be used mostly in sprint or round-trip tests. In the application, there is an option to implement the PACER test, where the human error is mitigated because the system contains the sensors that allow controlling the time but yet the lack of awareness of the pace imposed remains present. Besides, it is only possible to perform the test individually because the product focuses on tests of speed and not resistance.

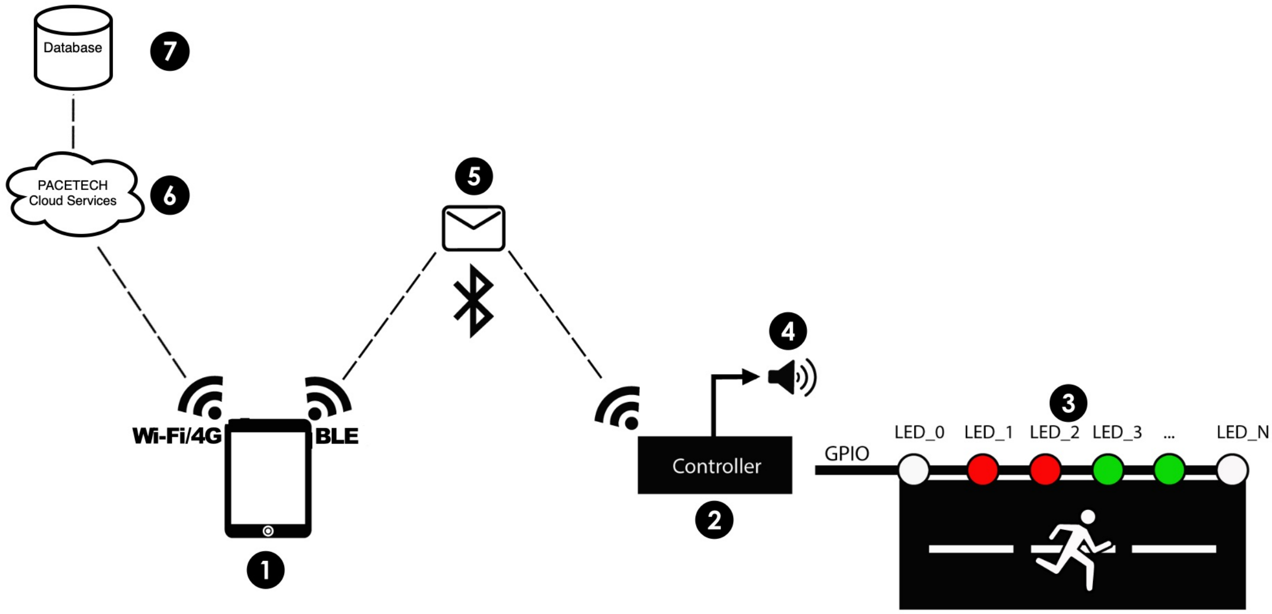

Fig. 2. Conceptual model consisting of two parts: one is the mobile application as the control interface; the other is the peripheral controller that signals the progress of the test.

III. System Architecture

In this section, the specification of the prototype to be developed is presented. The model specification was based on a solution to mitigate the problems encountered when implementing the classic PACER test, along with a questionnaire given to several physical education students and professionals. First, in subsection III-A, the conceptual model and its constituents are described. Then, in subsection III-B a description is made of how the system should work, in other words, how the interaction between the user and the interface is intended and how the system will respond to the request made in the interface.

A. Conceptual Model

This prototype was designed to contain an Android mobile application and an ESP-32 that will be the microcontroller (MCU) of the system. As shown in the figure 2 the conceptual model consists of 7 parts: android device (1), controller(2), light and sound system (3 and 4), an instruction(5), cloud services(6) and a database in the cloud(7). The mobile application running in the android device is where the user can configure the parameters stipulated for the performance as well as enter some information (weight, age, etc.) regarding who will perform the test. The controller is the unit responsible not only for the light and sound systems, but also for hosting the Bluetooth Low Energy server. The light and sound systems are the system outputs that give the student/athlete instructions on how to proceed during the test. The communication between the mobile application and the embedded system is made via radiofrequency, using the BLE protocol. The configuration message is based on an ad Hoc protocol and consists of instructions that the microcontroller is prepared to handle. Besides the communication with the controller, the mobile application also sends data to a cloud where information is stored in a database. In order to reach the cloud, the application uses Wi-Fi or 4G to connect itself to the Internet.

The user shall insert the name, age and gender of the person that will perform the test. With this information, the mobile app can calculate results, attending to the total number of laps that the runner could finish successfully. The number of laps is obtained from the MCU through the communication protocol. Besides inserting data, the user can end the test for a specific runner if he fails to finish the stage on time. So far, it was not found any product or prototype destined to perform aerobic capacity or endurance run tests similar to the one presented. Our prototype is capable of giving the runner the speed he should run through light signaling. No other systems with this kind of functionality have been found.

B. Operation Mode

All operations are centralized in the mobile application. There are two choices available when the user wants to perform a test: the PACER test or a customized test. When the customized one is chosen, the user can manipulate speed for each lap and the amount of laps for each stage. Selecting the PACER test will automatically adjust the test settings accordingly. In both ways, the user must insert individuals to take the test, along with some data about them (age and gender). After the insertion, the microcontroller is ready to execute the test, waiting for the application signal. When signaled, the microcontroller starts the peripherals (LED strip and column) according to the test settings for each level or stage. The sounds produced by the speaker are used to announce the end of the stage, an increase in the imposed speed or the end of the test. The light system will switch on each of the lights according to where the runner should be in order to finish the stage successfully, as shown in figure 2. In the PACER test, as long as the runner keeps ahead of the first green LED, he will finish the stage successfully. The process is repeated indefinitely until the student is not able to finish the stage successfully or by indication of the mobile application. After the test is over, the microcontroller sends to the application some relevant data for computing results that are later displayed on the smartphone screen. When the information is received in the mobile application, the user can save results, test-related data for a specific individual or group or customized tests settings on the cloud in order to make data available across different devices.

IV. Prototype

As a result of the conceptual model, a prototype was developed with almost all the pretended features. The prototype developed is capable of reproducing the PACER test and save results for individuals, although they are saved locally on the android device. The MCU used for the controller was an Espressif® ESP-32 with a Tensilica 32-bit dual-core CPU Xtensa LX6, 4MB of flash memory and 520 KB of SRAM. A 20-meter LED strip and a 13 mm audio jack are connected to the MCU. The LED strip contains 600 addressable LEDs, but only 30 of them are powered on at the same time. The audio jack permits that an external speaker can be connected to the MCU, allowing the user to control the volume according to the place where the test is executed.

Fig. 3 presents in a block diagram the controller system. Both outputs are controlled through Pulse Width Modulation. In order to not limit the user's information on the system status to the mobile application, we inserted an RGB LED that shows a different color according to the actual system state. The controller and all the components attached are powered by an AC/DC power source that outputs a voltage of 5V and a current of 8A.

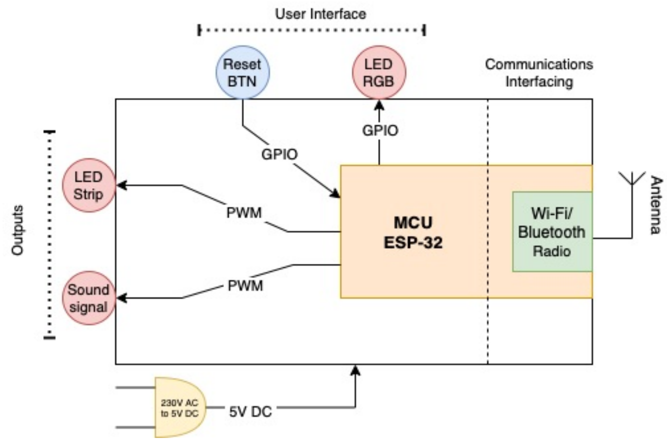

Fig. 3. Controller architecture regarding inputs, outputs and user and communications interface

Fig. 4. Prototype on operation. The controller is ready and waiting for an instruction from the Android device.

V. Conclusion

The work carried out focused on the state of the art and technologies used in the PACER test, as well as the idealization of the prototype developed. From the state-of-art study, we conclude that the PACER test presents reliable and accurate results in measuring the maximum aerobic capacity of an individual and that is suitable for application to a young audience. However, we looked for negative aspects of the classic implementation of the PACER test and found some issues that can be fixed with a digital solution. The lack of perception of the imposed rhythm can take to a worse effort management by the runner, leading to inaccurate results. Also, when performing the test with many individuals or multiple times, registering the results can become a hard task. With this, our purposed prototype will bring the possibility of mitigating human error through the automatic measurement of laps and stages performed; will give the runner the notion of the pace at which it should run so that the effort is balanced throughout the test, allowing results closer to the real value.

Future work includes the design and development of an experimental validation procedure to assess the prototype variability and reliability for the implementation of the pacer test. The experiments will be performed with undifferentiated children with ages between 10 and 15 years.

Acknowledgments

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