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IoT Device with LED Lights for Physical Ability Training

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1. Abstract

The aim of this project was to develop a prototype for physical ability training through reaction time measurement. The prototype consists of a master device built on an ESP32 card and a slave device on an Arduino Nano card. The use of an ESP32 allows IoT connectivity since a local web server is generated into the device via HTTP commands. This server works as a user graphical interface for the operation and visualization of the obtained data. The master/slave communication was wireless using a 2.4 GHz radio frequency antenna, while the reaction time was determined by the difference between the activation of an LED light and the positioning of the hand on infrared sensors, allowing the stimulation of eye-hand coordination. The prototype was compared against a traditional method of video analysis by frames (Kinovea software) yielding an error of only 6% against 10% of the traditional method. Finally, the prototype was manufactured with low-cost elements and components, which paves the way for future research in sports science.

2. Summary

The objective of this project was to develop a prototype for the training of physical abilities through the measurement of reaction times. The prototype is composed of a master device integrated on an ESP32 board and a slave device on an Arduino Nano board. The use of the ESP32 enables IoT connectivity by generating a local web server on the device via HTTP commands. This server functions as a graphical user interface for operation and visualization of the obtained data. Master/slave communication was wireless through 2.4 GHz radio frequency antennas, while the reaction time was determined by the difference between the activation of an LED light and the positioning of the hand over infrared sensors, which allowed for the stimulation of eye-hand coordination. The prototype was compared against a traditional frame-by-frame video analysis method (Kinovea software), yielding an error of only 6% compared to 10% for the traditional method. Finally, the prototype was manufactured with low-cost elements and components, paving the way for future research in sports science.

3. Introduction

Physical fitness is considered "as the weighted sum of all important physical or conditional capacities, and although it is genetically determined, environmental factors and especially physical exercise influence it" [1], that is, physical fitness can be improved with training. Authors such as Jiménez et al [2], indicate that physical fitness includes conditional capacities which are mainly based on the energetic processes that occur during exercise such as endurance, power, strength, speed and flexibility. This is why nowadays people dedicate part of their time to developing or reinforcing physical capacities through the practice of physical activity. However, little has been studied about the training of mental skills, which involve real situations in the development of daily activity, be it a game or a common practice of physical activity. The training of mental skills enhances cognitive functions, improving the skills of anticipation and interpretation of stimuli, obtaining a better performance in physical capacities [3]. Recently, the World Congress of Sports Psychology (ISSP) in Seville shed light on lines of research that seek to determine optimal levels of physical fitness for cognitive development, as well as to link cognitive functioning and physical activity [4]. Training with lighting devices, such as light-emitting diodes (LEDs), plays an important role in the development of physical abilities, allowing, for example, the stimulation of eye-hand coordination. Currently, several companies are developing and marketing wireless LED lighting systems for sports training, such as FITLIGHT®, BLAZEPOD, or Led Trainer. A study conducted in Genoa (Italy) states that a 6-week visual training program using devices like the Fit Light Trainer can improve reaction time and motor performance on the court, especially in young tennis players under 10 years of age [5]. Likewise, [6] sought to establish test-retest reliability in an LED device such as the Fit Light Trainer TM, evaluating reaction time in a healthy, unfamiliar population. Noting that devices such as the Fit Light Trainer TM provide reliable measures of reaction time in a healthy population, and furthermore, evaluation with this type of device could be considered a practical standard for assessing choice reaction times. Similarly, Levy A de Oliveira, [7] used the BlazePodTM device to monitor performance changes during cognitive training and evaluate the effects of a training intervention. Additionally, at the Argentine Congress of Embedded Systems [8], the development process of an electronic device, based on sensors and LEDs, used for cognitive training of athletes is described. a new version of the software. However, although there are some commercial alternatives, these devices are difficult to access for health researchers, in addition to being closed devices. Therefore, with the development of this work, an open-source, reprogrammable LED IoT device was created. This device allows researchers and health educators to create specific training programs aimed at improving people's performance and physical abilities, as well as recording reaction times to eye-hand responses.

3. Materials and Methods

Initially, through a review of the state of the art, similar products on the international market were identified. These products operate through mobile applications and feature wireless communication. As mentioned above, there are three major competitors in the market, all of which share the use of RGB LEDs and connect to mobile applications. Therefore, the development of a prototype consisting of a master device and two slave devices was proposed, although the number of slave devices is expandable. The Master device sends light activation orders to the slaves, in addition to serving as a host for the Internet connection, while the slave device will be responsible for measuring the reaction times (time between the switch-on order and the positioning of the hand on the sensor). An ESP32 board was used for the Master because it has an integrated Wi-Fi antenna, in addition to having great operating power and being low-cost. For the slaves, an Arduino Nano was chosen. For wireless communication between devices, nRF24L01 antennas were used, which have a range of 1 m to 1000 m (with an external antenna), low power consumption, and easy integration with microcontrollers such as ATMEGA. This antenna allows fast and economical two-way communication between devices. For hand detection, an infrared sensor was used. Finally, a Neopixel LED ring was used, and for the power subcircuit, a LiPo battery, a TP4056 charge controller, and an XL6009 DC-DC booster were used to raise the battery voltage from 3.7 to 6 V, the minimum voltage for autonomous operation of the Arduino. All components are shown in Figure 1. The schematic design of each device was created using the free Fritzing software and is presented in Figure 2 for the Master device and in Figure 3 for the Slave device.

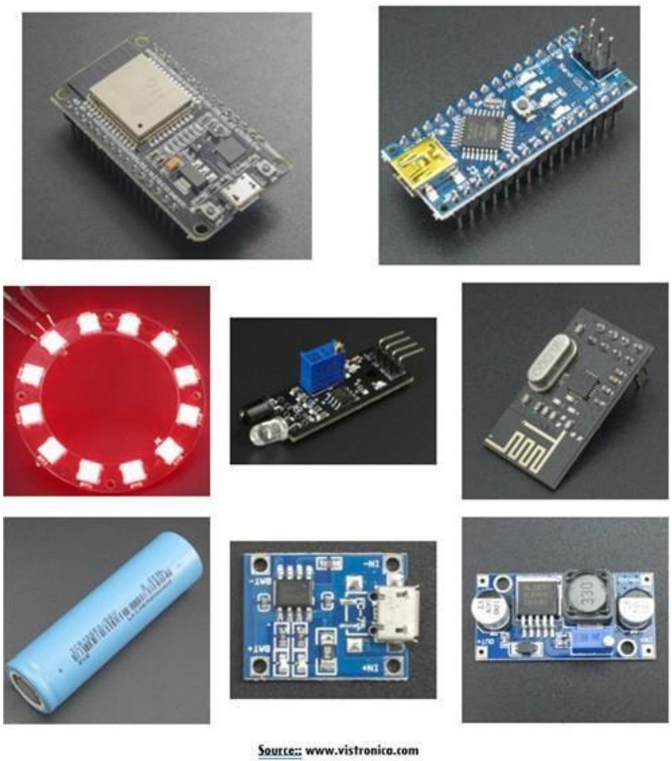


Figure 1: Components used in the construction of the prototype: (From left to right and top to bottom) ESP32, Arduino NANO, LED ring, IR module, RF antenna, LiPo battery, TP4056 battery charging module, XL6009 voltage booster.

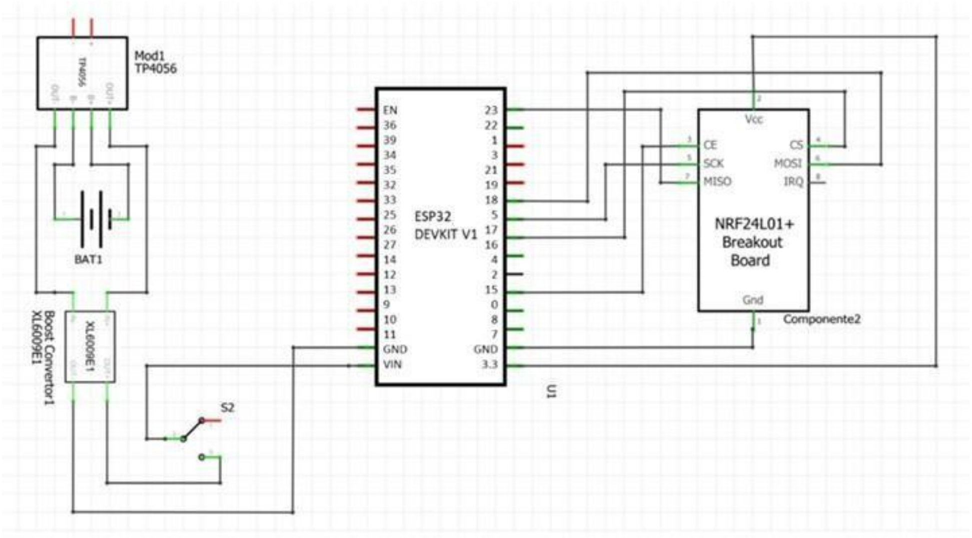
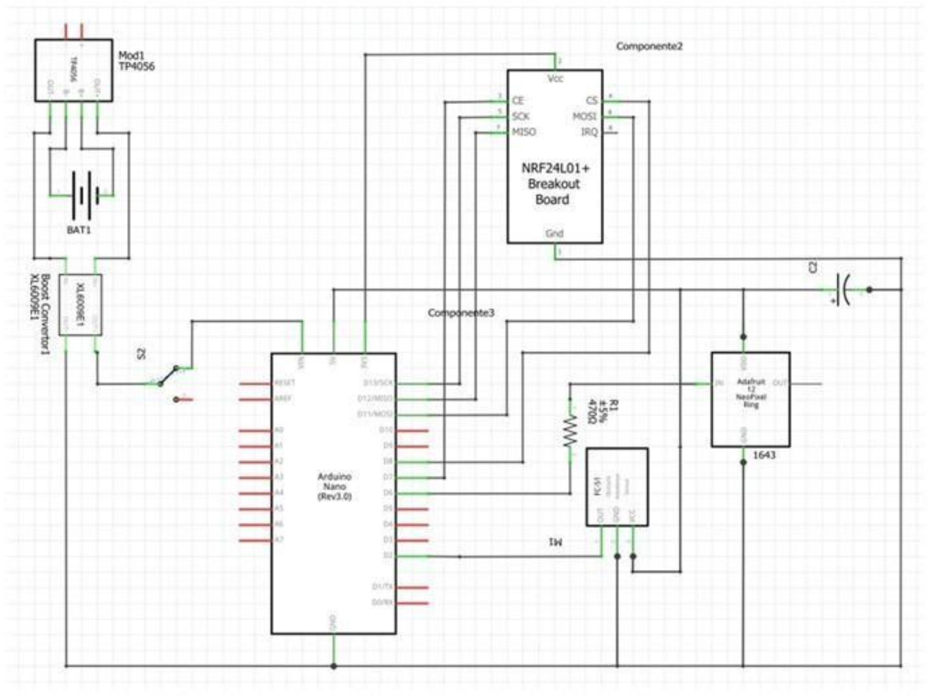


Figure 2: Diseño esquemático del dispositivo Maestro.



Source: Authors own creation.

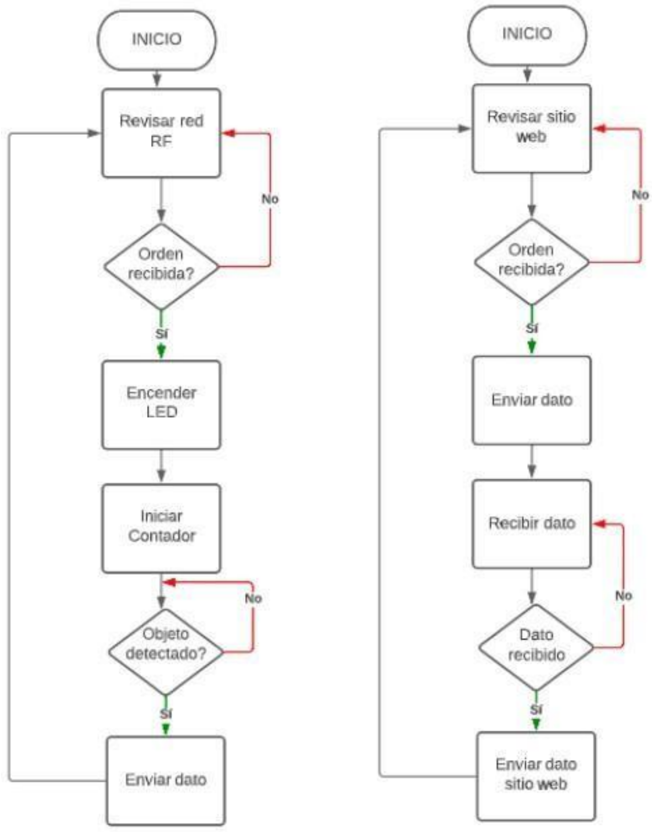
Figure 3: Diseño esquemático del dispositivo Esclavo.

3.1. Source: Authors Own Creation.

For the development of the algorithm, it was taken into account that the infrared sensor generates a rising or falling edge (depending on the configuration) when a device is positioned in front of it. This edge can be used with the Arduino as an external event to activate certain specific routines. In this case, the duration between the RGB ring's activation and the detection of the edge in the infrared sensor signal would correspond to the operator's reaction time. Thus, within the Arduino code logic, the time between the LED ring's activation and the hand's positioning in front of the infrared sensor must be accounted for. The ring will only turn on upon a specific command received by the RF antenna and sent by the master device. When an object is detected after the LED ring activates, the slave device must send this time to the master device. To better understand the operating dynamics, a flowchart was created, which is shown in Figure 4.

3.2. Source: Authors Own Creation.

To build a fully functional algorithm, it was first divided into different routines: RGB LED ring configuration, RF communication, and interrupts with the IR sensor. Once each routine was tested, they were integrated into a single code.



Source: Authors own creation.

Figura 4: Diagrama de flujo de la programación de los dispositivos ESCLAVO (izquierda) y MAESTRO (derecha).

3.3. RGB LED Ring Control

This routine consisted of the operation of the RGB LED ring. Thanks to the neo pixel library (<Adafruit Neo Pixel. h>), it is possible to assign a specific color to each of the 12 LEDs that make up the ring. Each color must be created using a 1x3 array corresponding to the RGB component values (red, green, and blue). This value must be an integer between 0 and 255. The ring is controlled by a digital pin. The ring is initialized using the. Begin () and. Clear () commands. The ring is then lit with the desired color using the. Color (), set Pixel Color () and .show () commands.

3.4. Radio Frequency Communication

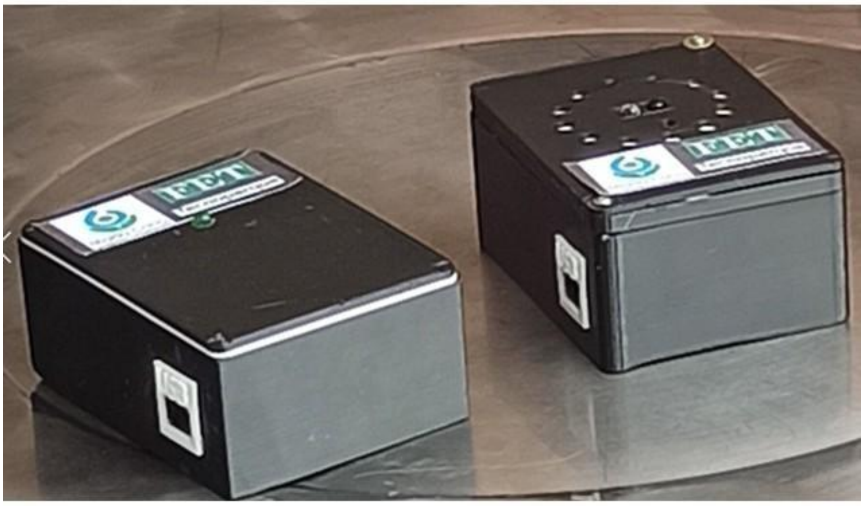
It was decided to use radio frequency communication using NRF24L01 antennas with the RF24.h and RF24Network.h libraries. These libraries allow the creation of a bidirectional network of devices with NRF24 antennas. Each device within the network will be assigned a unique identification number (address) (based on octal). Thus, if there is dual communication, the master will have address “00” and the slave will have address “01.” As in almost all Arduino libraries, the. Begin () command assigned to the “radio” object allows for antenna initialization. If this operation fails, the code will get stuck in the “while” loop. The same applies to the network object. Additionally, during the initialization process, it is essential to define the communication channel, i.e., the band through which the antennas will be connected. To do this, use the. Set Channel (100) command, whose initial parameter must be the same for all devices. Subsequently, the main code execution begins. For the receiver or slave, the first procedure is to check if data has been or is being sent using the network. Available () command. If communication exists, the data is read and stored in a variable (payload) using the network. Read (header, &payload, 1) command. To confirm receipt of the data, a second procedure was defined, where the slave device sends data to the master device using the network. Write (header_2, &payload, 1) command, where header indicates the address of the master device. This operation will be executed until the master device confirms receipt of the data.

3.5. IR Interrupt

Finally, the interrupt routine was executed. An interrupt, in microprocessor language terms, is an internal or external event that can occur only at certain times. These events are used to execute certain routines that require an input unknown to the programmer. Although interrupt routines vary, in this case, the state change of an Arduino digital pin (PIN 2) was used. The microcontroller will constantly check if the pin’s state changed within a time window, which allows for noise reduction and therefore the false detection of external events. The output of the infrared module was connected to the digital pin. For the master device, code was developed to activate the slave devices through an action on a local website. This website also allows data to be viewed and subsequently saved in a .CSV file. For this purpose, the <WiFi.h> libraries and the HTTP protocol were used, complemented by the RF communication previously described. Using a Wi-Fi connection allowed the master device to connect to a modem and subsequently access the internet. A local web server was then created with a fixed IP address, and the website was then created using HTTP commands. Finally, the prototype was evaluated using Kinovea software, which allows photographic analysis of hand movements. The frames between the light being turned on and the hand being positioned on the device were analyzed. This allowed the error between the device's measurement times to be determined.

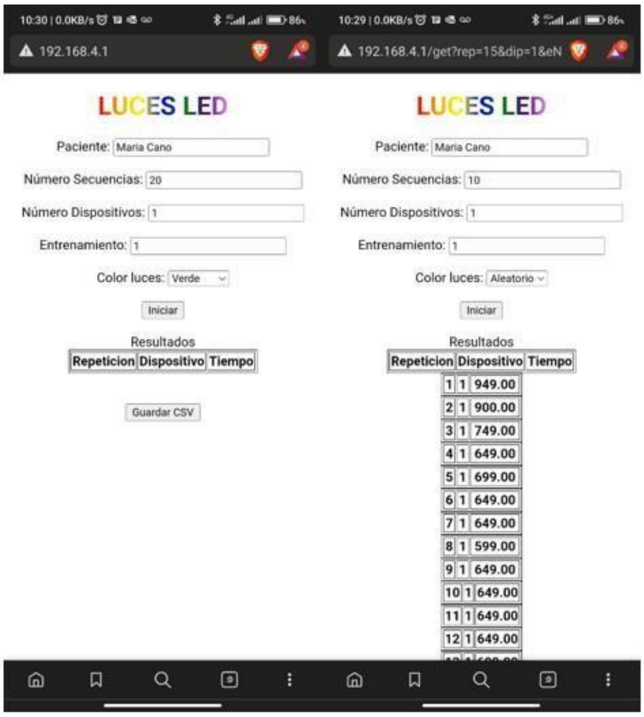
4. Results

Following the previously described methodology, the devices were manufactured, and the operating algorithms for each type of device were developed (available upon request from the authors). Figure 5 Source: Authors own creation. Using HTTP commands, a web page was built on a local server stored on the ESP32. The resulting website is shown in Figure 6. By pressing the Start button, the activation command is sent to the slave device, which turns on the LED ring and begins timing the activation time, which will stop when the hand is positioned over the IR sensor. Once the time is computed, it is sent back to the master device, which will publish it on the website. This operation will be repeated according to the value entered in the "Number of sequences" field. If two or more devices are active, they will be activated randomly, one at a time.



Source: Authors own creation.

Figure 5: Prototipos desarrollados: (Izquierda) Maestro, y (Derecha) Esclavo.

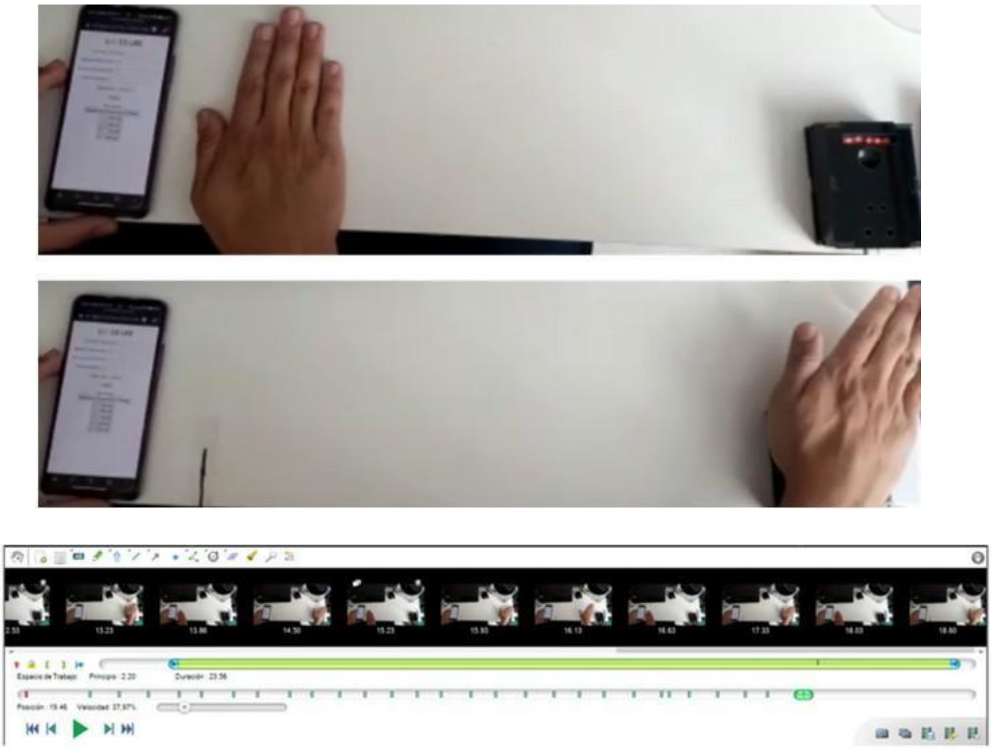


Source: Authors own creation.

Figure 6: Sitio web en servidor local antes y después de terminado el ejercicio.

4.1. Source: Authors Own Creation.

To determine the prototype’s validity, a 12-repetition exercise was performed on one device. The validation exercise consisted of moving the hand from a reference point to a device positioned 50 cm away. This exercise was recorded and analyzed frame by frame using Kinovea software. The dynamics of the exercise are presented in Figure 7. Reaction times were extracted from the exercise using the two methods mentioned above. Time was measured from the activation of the light to the positioning of the hand on the device; the results are shown in Table 1.



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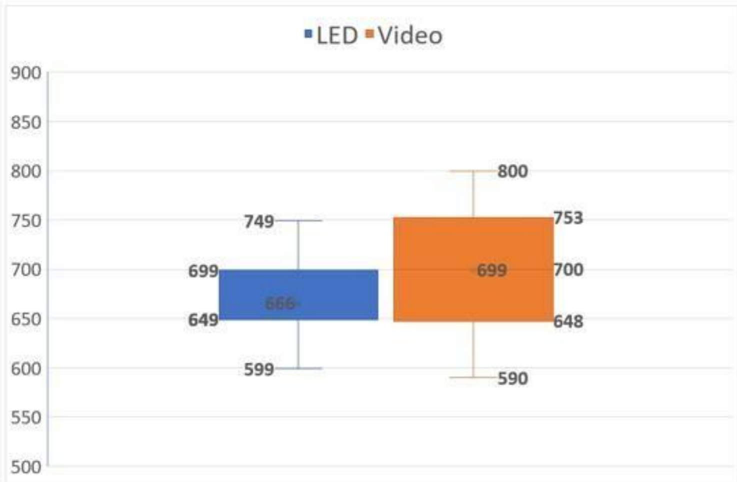

Figure 7: Fotogramas extraídos con el software Kinovea. La imagen de abajo muestra la secuencia de análisis del video.

Table 1: Tiempos de reaccion.

	1	2	3	4	5	6	7	8	9	10	11	12
LED	749	649	699	649	649	599	649	649	649	649	699	699
Video	730	760	800	800	700	670	600	590	700	640	700	700

Source: Authors own creation.

4.2. Source: Authors own creation.

A comparison was then made between the times obtained by the prototype and the times extracted from the video. It was found that the average reaction time according to the device was 666 ms with a deviation of 39 ms, while according to the video analysis the average and deviation were 699 and 68 ms, respectively. The distribution of the data obtained is presented in the following box plot. As can be seen, the greatest difference was for the maximum value determined by each method, which was higher in the case of the frame analysis. This is due to human error when selecting the final frame for each repetition, while the device has a response speed determined by the microprocessor, allowing for greater accuracy. As for the minimum value (best time), these are almost the same for both methods, being 599 ms for the prototype and 590 for the Kinovea. This analysis determined the device error, which was 6%. This is within the experimental error range and is attributed to operator-related factors such as fatigue during exercise or lack of concentration. While for the Kinovea measurement, the error was 10%, a value at the limit of experimental error, due to the aforementioned factors plus human error induced when selecting the appropriate frame.

5. Conclusions

This study shows the development of a prototype for training physical abilities by measuring the reaction time between the activation of an LED ring and the positioning of the hand on it. It was determined that when compared to image analysis software, the prototype showed measurement times with an error of 20%. The prototype integrated different communication protocols such as RF and WiFi, allowing for wireless communication and reaction time monitoring in an IoT system. The web server allows the researcher or coach greater control over exercise data. The development of a low-cost and easily accessible prototype for training physical abilities is demonstrated, allowing for the development of specific training programs designed to improve motor and cognitive abilities.

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