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TEMA:

SISTEMA DE CRONOMETRAJE DE ALTA PRECISIÓN Y BAJO COSTO, PARA MEDIR EL RENDIMIENTO DEPORTIVO DE LOS INTEGRANTES DEL CLUB DE TRIATLÓN DE LA UNIVERSIDAD TÉCNICA DEL NORTE.

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High-Speed, Low-Cost Timing System To Measure The Sport Performance Of Triathlon Club Members At Universidad Tecnica del Norte.

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Abstract. *There are different devices used for the timing of a sport and are available in the market, the problem is that its cost is very high. The present project presents the design and implementation of a timing system which will greatly aid in measuring the athletic performance of the triathletes belonging to the triathlon club of Universidad Técnica del Norte.*

With the help of different elements of information technology, it is possible to develop a communication system that allows the processing of data obtained by the equipment, in this way has the possibility to measure the physical performance of the athletes by analyzing the themselves.

The implementation of free software and hardware in the project allowed the development of a low cost system compared to devices of equal denomination present in the world market.

This system can be subjected to all the conditions that can be presented during the development of a training of the UTN triathlon club which tests the performance of the sensors to use, resulting in a reliable timing system in relation to the data provided by the same.

Keywords

Timing system; Sports performance; Wireless communications; Radiofrequency identification; Free software and hardware.

1. Introduction

The various technological advances in data collection and their influence in the development of high performance sports based on monitoring or progress of sports performance, especially those that define their competitors victorious for the accuracy of the time taking during the development of the triathlon discipline, has made the techniques used evolve rapidly.

During the development of a triathlon competition it is very important to take partial time according to the disciplines played including the time spent in transitions which makes up the final time of each participant.

Therefore, a certain number of judges in charge of different tasks must be included, who must take into account: attending to the judge who dictates the number of each athlete and registering in legible handwriting, mark the timer to be registered, not lose in view of the number of each athlete.

The use of all these resources within the triathlon club of the UTN makes the taking of times during a competition or training, to define the performance of each athlete in all its routes or scenarios of the discipline, is imprecise due to human error, response time of the reflexes or the speed that each athlete takes.

Therefore, a method can be developed to help correct these errors during the development of this discipline with the help of a wireless sensor network which is totally reliable and accurate for data collection.

2. Materials and Methods.

2.1 Triathlon.

Triathlon is an Olympic sport activity which involves three individual sports specialties: swimming, cycling and athletics. In such a way that the triathlete has the possibility to experience the three disciplines in order and without interruption between a test and the next one is to say the stopwatch does not stop during the time of the competition, reason why it is possible to establish that it is one of the more demanding sports that you can practice.

All statutes, rules and modalities that can be developed in a triathlon competition are dependent on the International Triathlon [1].

Transitions.

It can be called transition to the space reached between a sport or another, that is, the moment in which it changes of modality or segment. In this space there is an area of change or transition area, assembly line and dismantling, where previously all the necessary material will be located to be able to comply with the discipline of triathlon, described in figure 1. Within this area you can appreciate a place designated by the competition judge so that you can only occupy this space and not invade the space of another athlete.

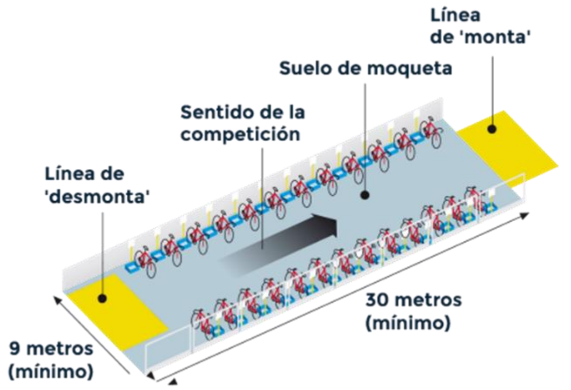

Figure 1. Zone of transition.
Source: http://www.marca.com/juegos-olimpicos/triatlon/todo-sobre.html.

Through the analysis of ITU Competition Rules [1], in relation to the development of a triathlon and its transitions, the following can be described:

Transition from swimming to cycling (T1): once the swimming course is finished, you should go as fast as possible to the location of the bicycle, which will be located in the previously assigned transition area.

It is a time when you can spend a lot or a little time depending on the skill of the athlete, must place the cycling shoes and helmet as it is of mandatory use whenever you are in contact with the bike. From the mark established by the race judges, the bike can be assembled and the cycling segment begins.

Transition from cycling to athletics (T2): at the end of the cycling course, before reaching the transition area, judges must place a line from foot to ground. The reason for this line is not to cross it while it is on the bicycle, so it is necessary to dismount beforehand and to cross with the bike in hand trying to avoid accidents, to later go to the place previously assigned to place the bicycle in the support and to do the changes needed for the athletics course as fast as possible.

2.2 Timing and Results.

The time of every athlete in a discipline is that which is taken into account from the time of departure to the end of the competition, cave emphasize that the time used in the transitions is part of the sum of the total time. The results should be according to ORIS standards [1].

The accuracy of the operation of a mechanical watch depends on the type of movement used, the personal habits of the user regarding the use of the watch and variations in the ambient temperature. Oris watches are checked and adjusted in the workshop so that the daily operation variation is within a tolerance range of - 5 to + 20 seconds per day.

Stopwatches are adjusted and revised in tighter tolerance intervals. A Swiss watch can qualify as a stopwatch only if its Swiss watch movement has successfully passed a control in accordance with the NIHS 95 -11 / ISO 3159 standards of the Official Swiss Control of Chronometers (COSC), an independent Swiss observatory. [2].

2.3 Timing systems.

The total time of each athlete is between the beginning of the competition until the goal line is crossed, taking into account the time spent in the transitions. In the development of a triathlon competition there are two types of timing systems which provide data in relation to the time of competition of each athlete.

- Manual.
- Automated(chip).

Manual timing system.

This type of system uses as the main resource the visual and auditory perception of the people in charge of recording and dictate the data of each athlete.

In triathlon, triathlon cross, aquathlon and quadricathlon competitions, it is recommended to mark the athletes as a minimum requirement in the left arm and in the front of the left thigh and always in vertical reading as shown in figure 2 [3].

Figure 2. Marking of athletes; right and wrong
Source: International Triathlon Union - Rules, 2015 [3]

In addition, it is compulsory to wear on your uniform, unmodified, all bibs and identification elements provided by the organizer and approved by the Technical Delegate as shown in figure 3.

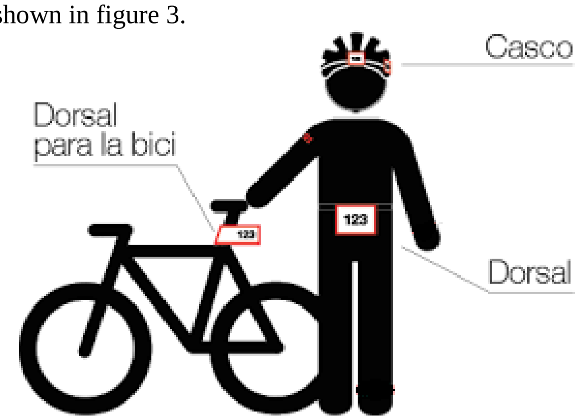

Figure 3. Dorsales y elementos de identificación usados en triatlón
Source: http://www.triatlomarina.com/ts2014/gava/infocarrera.html

Timing system with chip.

The manual timing system with many complexities including human error for data recording, is why the development of new technologies has made popular the use of chips to time races of all kinds.

This chip is very comfortable and imperceptible to the athlete during the competition which is marked by a unique identification code, has no batteries and is activated upon contact with a magnetic field. During the development of a competition, antennas must be placed which, when crossed, receive the information stored on the chip which includes the athlete's identification number [4].

The use of this chip allows to know the exact moment in which the athlete crosses the starting line and end of race, which helps to know the partial and total times. All this system allows to speed up the processing of data and the obtaining of reliable data for all the people involved in the use of this system.

When talking about timing systems with a chip, two concepts must be clearly understood to understand the operation of them and their equipment, as well as advantages and disadvantages of each one, so we proceed to describe the following terms:

Passive chip system.

This system consists of two elements: Reading mats the width of these carpets is between 2 and 4 meters and are placed in points of interest for a clock to perform its function and detect if the corridor the floor, The chip that is carried by each athlete in his ankle has the same information of the number that carries each athlete; in this way you can issue the code and race time.

The transponder or chip is passive until it moves inside a magnetic field, generated by the carpets. Here, the feed coil produces an electric current that feeds the chip. The transponder then transmits its individual identification number to a receiving antenna. The entire procedure takes approximately 60 milliseconds and is repeated continuously [5].

Active chip system.

The transponder or chip has a power source, which is used to power the circuit of the microchip and to transmit the signal to the reader. This helps active tags to be read over large distances compared to passive tags as they contain their own power source, active tags are also able to respond to lower-level signals compared to passive tags.

What it does is that the chip, when crossing the control point, transmits the chip code to the equipment that will collect that data, with an accuracy of 0.01 seconds up to a speed of 100km / h and 3000 catches per minute up to 100 meters of width [3].

2.4 RFID (Radio Frequency IDentification).

Radio frequency identification or RFID is the term used to describe the technology of remote identification of people, animals or things without the need for physical or visual contact through the use of radio waves. In order to perform this identification an RFID tag is necessary which inside has a micro chip attached to an antenna that together provide identification information to a reader capable of interpreting the data stored in an RFID tag, as shown in the figure Four.

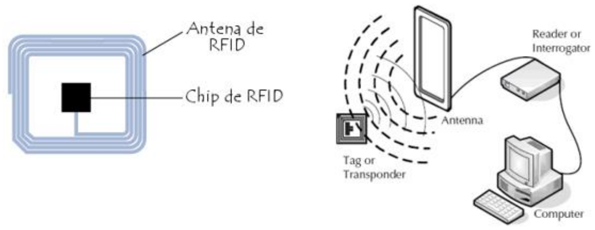

Figure 4. RFID Tag and Communication System
Source: http://www.pymescentral.com/tarjetas-pvc/rfid/

An RFID system has different active elements, which make possible the development of an identification system, so proceed to describe the elements that make up a radio frequency identification system:

RFID Tag: It can also be called tag, kip or transponder and can be inserted or attached to a person, animal or thing which would carry information about it by means of an EPC (Electronic product code) code, reason why it is composed mainly by a micro chip and an antenna.

The EPC is a standardized 96-bit numerical code [6], providing unique identification of the RFID tag. The code does not provide information specific to the object it labels.

Reader or interrogator: It is responsible for transmitting sufficient energy to the label and reading the data sent to it, which consists of a radio frequency module, a control unit and an antenna to probe the tags by means of radiofrequency waves.

The reader is programmed to operate in three modes:

- Interrogating periodically, to detect new presences of labels.
- Questioning in a timely manner, when the presence of a new tag is detected.
- Interrogating its area of coverage continuously, so it is expected the presence of multiple labels continuously.

Radiofrequency module: It consists of a transmitter that generates a radiofrequency signal and a reader that receives the data sent by the labels, and their functions are:

- Generate the radiofrequency signal to activate the transponder and provide it with energy.
- Modulate the transmission of the signal to send the data to the transponder.
- Receiving and demodulating the signals sent by the transponder.

Control unit: It performs the following functions:

- Manage access to the medium: activate the tags, authenticate and authorize the transmission, manage the reading process.
- Communicate with the information system.
- Encode and decode transponder data.

Antenna: It is the medium that allows communication between the reader and the transponder, its design depends on the type of application to be developed due to the frequency of operation so it is an aspect to consider when choosing an antenna due to its coverage area, as it should be large enough to detect labels, but not too small to avoid non-valid readings that can affect and confuse the system.

Host or Controller: It is the one that develops the RFID application, is able to receive information from one or more readers and communicates to the information system according to the master slave principle, which implies that all activities carried out by the reader and the transponder are initiated by the software application, since if the reader receives an order of this application must establish a communication with the transponders which leads the reader to exercise the function of master and slave tags.

The host or controller aims to manage and process the data received by the reader, so the software must be very robust to handle the multiple readings that RFID systems perform, coordinate times and flows of information, manage different events, introduce system updates when required [7].

2.5 Operating frequencies.

The micro chips that are inside the RFID tag can be classified according to their energy source, whether active or passive, as explained above. The frequency bands in which the RFID systems work are 125 or 134 KHz for low frequency and 13.56 MHz for high frequency, [8].

International regulation describes that RFID equipment must work in the ISM ("Industrial, Scientific and Medical") frequency band for UHF, as specified for Wifi, Bluetooth technologies. [6], this is a big problem that is generated worldwide, since in this band of frequencies work some devices that generate noise with the systems of RFID and vice versa.

2.6 Applications of RFID systems

The frequency at which the RFID systems work establishes the propagation characteristics of the electromagnetic field and thus the transmission of data:

transmission speed, maximum reading distance, coupling, sensitivity of materials; all this makes RFID systems to be used in different commercial applications, as can be seen in Table 1.

FREQUENCY OF WORK FOR RFID SYSTEMS

FREQUENCY OF WORK	USUAL APPLICATIONS
LF: 135 KHz	Access control.
	Identification of animals.
	Anti-theft control of cars.
HF: 13.56 MHz	Access control.
	Libraries and documentation control.
	Payment in means of transport.
	Control of luggage in airplanes.
UHF:860-960 MHz	Supply chains.
	Traceability of valuables.
	Anti-counterfeit control.
	Automation of inventory tasks.
	Toll payment on motorways.
Microondas:	Payment of tolls on motorways.
2.4 GHz, 5.8 GHz	Vehicle tracking.

Table 1. Frequency of work for rfid systems
Source: LIBERA, 2010 [6].

2.7 Wireless Communications WPAN

Wireless communications refers to communications that may be made between electronic devices or persons exchanging information using the electromagnetic spectrum as a transmission vehicle.

WPAN networks is a technology that aims to establish communication between devices without any cable and that may be little separated, is usually limited to the space of a room, as shown in Figure 21. The most used technologies in a WPAN are: Bluetooth, DECT, IrDa, NFC and Zigbee.

3. Diseño.

The design of the kronometraje system is based on the V methodology of software development, since it presents a suitable procedure for the implementation of the elements of software and hardware to use, which leads to a correct design of the timing system with help of an in-depth analysis of the current situation around the taking of times in a triathlon competition.

3.1 Analysis of the current situation of chip timing systems.

Timing systems using RFID identification are the most reliable for use in mass sports activities or events around the world so their use can be seen in such important competitions as those organized by the international triathlon union [3], including the former Olympic venues so its use has become popular, as these are fully automatic systems of timing that can be used in almost any sport that has a finish line.

3.2 UTN triathlon Club.

The technical university of the north contributes to the integral development and improvement of the quality of life of the university community and of society in general of Zone 1, through the formulation of policies, plans, programs and projects oriented to the development of the sport to university level and training, promoting the practice of physical activity, counseling and training in the sports area, with the organization of internal and external sporting events, efficiently and sustainably managing resources and sports scenarios with great social, ethical and humanistic responsibility, framed in compliance with the institutional objectives and the National Plan for Good Living. [9]

Thanks to the management of the Technical University of North and since 2012 is in constant activity to this day the triathlon club, with the aim of leaving in the name of the university house with the help of their athletes in competitions at national level, which are presented year after year, most of which are made up of university students and Jorge Pulles as coach.

3.3 System requirements..

In order to perform the analysis of system requirements, it is necessary to evaluate different requirements that lead to the system to develop the best performance during the development of its functions based on the ANSI / IEEE 830 standard [10]. During the description of the system requirements some abbreviated terms and acronyms described in table 2 will be used.

ABBREVIATED TERMS AND ACRONYMS USED DURING THE ANALYSIS OF REQUIREMENTS

Acronyms and abbreviations	Description
UTN	Universidad Técnica del Norte
PC	Computador Personal
StSR	System Stakeholders Requirements

SySR	System Functional Requirements
SRSH	System Architecture Requirements

Table 2. Abbreviated terms and acronyms used.
Source: Authorship.

Therefore, Table 3 is presented and has the prefix SySR that refers to the Functional Requirements of the system, which describes the initial requirements of the system in order to better visualize all the parameters to be considered for the design of the system. timing system.

SySR						
Functional Requirements						
#		**Priority**			**Relationship**	**Verification**
		High	**Medium**	**Low**		
Operational Requirements						
SySR 1	The system nodes must have wireless connection without any interference and a considerable distance.	■	□	□		
SySR 2	The system should not hinder the sports activity to be performed.	□	■	□		
SySR 3	The system must be accurate in the timing.	■	□	□		
SySR 4	Data visualization and easy interpretation.	□	■	□		
Usage requirements						
SySR 5	The system must be constantly powered by electric current for proper operation during a workout.	■	□	□		
SySR 6	Mobility of Nodes	□	■	□		
Interfaces Requirement						
SySR 7	Communication through the serial port.	■	□	□		
SySR 8	Easy-to-use software application.	□	■	□		
Modes / Status Requirements						
SySR 9	The whole system must be in constant operation during the sporting activity to be performed.	□	■	□		
Physical Requirements						
SySR 10	Take into account the location of the system and that it does not present problems of operation.	■	□	□		

ts

Usage requiremen

Table 3. Functional Requirements
Source: Authorship.

The requirements presented above were raised according to the analysis of the current situation of the triathlon club UTN.

Table 4 is presented and has the prefix SRSH that refers to the System Architecture Requirements, which describes the software and hardware requirements of the system. This analysis will greatly help the choice of Software and Hardware to use in the system.

SRSH
Architectural Requirements.

#		Priority			Relationship	Verificatior
		High	Medium	Low		
	Logical Requirements					
SRSH 1	Digital Inputs and Outputs	X				
SRSH 2	Communication between several nodes	X				
	Design Requirements					
SRSH 3	Implementation of a low cost system	X				
SRSH 4	Implement hardware and software that is freely distributed.	X				
	Software Requirements					
SRSH 5	Free software is required, compatible with the operating system of the PC on which the system operates.	X				
SRSH 6	The programming software must be compatible with the development board of choice.		X			
SRSH 7	It is necessary that the programming software can export the application to be developed to another PC without the need for that software installed.	X				
SRSH 8	The application to be developed should not be difficult to manipulate.		X			
SRSH 9	Difficulty of the software development environment.		X			
SRSH 10	C ++ based programming language		X			
SRSH 11	Use available resources on the PC	X				
	Hardware Requirements					
SRSH 9	Must be able to develop an identification system.	X				
SRSH 10	Able to process data at high speed in relation to the test environment and the reconnection of data.	X				
SRSH 11	It is of high priority to use a processor, capable of handling all the data that can be obtained during data collection.	X				
SRSH 12	Wireless communication between different devices.	X				
SRSH 13	Pin availability for connection of various peripherals.	X				
	Electrical Requirements					
SRSH 14	The system should not rely on batteries due to the time of operation.	X				

Table 4. Architectural Requirements.
Source: Authorship.

These requirements must be taken into account, as they are the basis for the development of the timing system, whose main objective is the accuracy in timing. So all the elements anchored to the development board, must be compatible with each other to ensure a correct work of each of the functionalities that are immersed within the system.

All development of a project has as a necessity the participation of a Stakeholder or individuals who will benefit from the development of the same, described in table 5 that has a StSR prefix that refers to the Requirements of Stakeholders, who will evaluate the system at the end of its implementation, with the objective of validating conclusions corresponding to the development of the project.

StSR						
Stakeholders Requirements						
#		**Priority**			**Relationship**	**Verificatior**
		High	**Medium**	**Low**		
Operational Requirements						
StSR 1	It is necessary for the participation of the triathlon club of the UTN for the development of the system.	■	□	□		
User Requirements						
StSR 2	The results obtained by the system must be digital.	■	□	□		
StSR 3	The identification chip should be comfortable to wear for athletes.	□	■	□		
StSR 4	The data obtained must be clear and precise.	■	□	□		
StSR 5	The data obtained must be stored in a safe place.	■	□	□		

Stakeholders List		
	Triathlon Club of the Universidad Técnica del norte	Members of the Club Coach of the Club
	Ing Jaime Michilena. Msc.	Director
	Ing Omar Oña.	Codirector
	Franklin Farinango.	Student

Table 5. Stakeholders Requirements.
Source: Authorship.

3.4 Hardware Choice.

The need to implement a timing system in the triathlon club of the Technical University of North, entails using some type of development platform capable of processing the data obtained according to the system requirements set out above. Table 22 evaluates the development boards available for data processing, taking into account the hardware requirements given in Table 6.

Choice of development boards for data processing.					
Hardware	*Requirements*				*Total Rating*
	SRSH 9	SRSH 10	SRSH 11	SRSH 13	
Arduino Uno	1	1	0	0	2
Raspberry Pi	1	1	1	0	3
Arduino Mega 2560	1	1	1	1	4
1 - Meets					
0 – Not Complying					
choice: Arduino Mega 2560.					

Table 6. Choice of development boards for data processing.
Source: Authorship.

On the basis of Table 6 already discussed above with regard to the development platforms available for use, which can greatly assist in data processing and that meets system requirements, we opt for the use of Arduino Mega 2560 .

Due to the geographical location where the platforms will be located, it would not be convenient to use a wired connection, so the best option is to use a personal area wireless communication system and can cover the particular needs of low cost sensor networks and consumption, requiring minimal power and at the same time allowing the reliable transport of data between remote devices. Table 7 shows the wireless communications that depending on the assessment based on the requirements raised can be chosen one for its implementation.

Choosing Hardware for Wireless Communication.						
Hardware	***Requirements***					***Total Rating***
	SySR 1	SySR 6	SySR 7	SRSH 1	SRSH 12	
Bluetooth	0	1	1	0	1	3
Xbee S1	1	1	1	1	1	5
Wifi	0	1	1	1	1	4
Infrarojo	0	1	1	0	0	2
1 - Meets						
0 – Not Complying						
choice: Xbee S1.						

Table 6. Choosing Hardware for Wireless Communication.
Source: Authorship

There are several Hardware components with which you can design a wireless communication system as well as those described in Table 15 and through the analysis of system requirements the best option is chosen, which in this case will be the spindle of a ZigBee communication system specifically of Xbee S1 hardware, since its use is based on personal area wireless communications.

The use of an RFID (Radio Frequency Identification) system is the most advisable method of identification to achieve the objectives planned in this project, since its popularity in the development of sports that demand the precision in the taking of times has been increasing [3] and thanks to the use of the Arduino platform minimize the search possibilities for the sensors to be used, because these elements and the platform must be compatible, so that together they present the best performance during the performance of the system to be developed and especially that leads to lower costs, table 7 shows the different devices compatible with the development board that according to the assessment based on the requirements of the system will be chosen by only one.

Choosing Hardware for an RFID System.							
Hardware	***Requerimientos***						
	Sy SR 2	SR SH 3	Sy SR 6	SR SH 9	SR SH 12	St SR 4	***Total Rating***
RFID-NFC SL060	1	0	1	1	1	1	5
RFID-RC522	1	1	1	1	1	1	6
Pn532 Nfc Rfid	1	0	0	1	1	1	4
RFID 125Khz RDM6300	1	0	1	1	1	1	5
1 - Meets							
0 – Not Complying							
choice: RFID-RC522							

Table 7. Choosing Hardware for an RFID System.
Source: Authorship.

The development of an RDIF system, greatly helps the development of the project and thanks to the analysis presented above it is possible to determine which RFID module is suitable for use considering that it meets the requirements of the system, that is why the module is chosen RIFD-RC522.

3.5 Block diagram of the system.

The following diagram shown in Figure 5 helps to better understand the design specifications of the system, and the internal functions that each of them must perform within it.

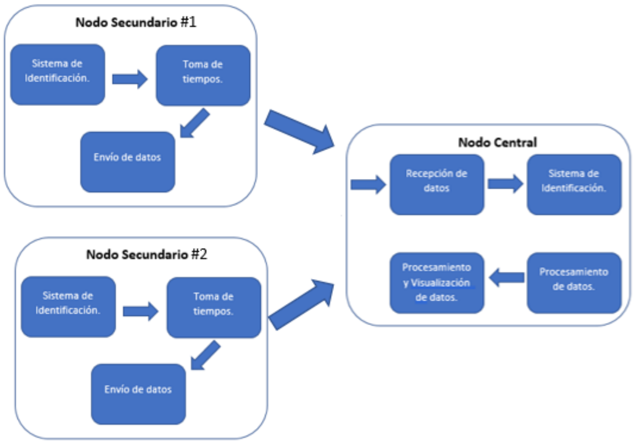

Figure 5. Diagrama de bloques del Sistema.
Source: Authorship.

Block diagram of the secondary nodes.

It may be considered that the secondary node one is a reflection of the secondary node two, these nodes are formed mainly by the Arduino MEGA development platform, the secondary nodes have the task of identifying, taking and sending all the data to the central node with the help of a wireless communication system.

The obtained data are the times used by the athletes in the different segments that must be realized in a triathlon including the transitions, and they are obtained thanks to the system of RFID and the programming in the platform of development. Figure 6 shows the interconnection of all the systems present in the node in more detail.

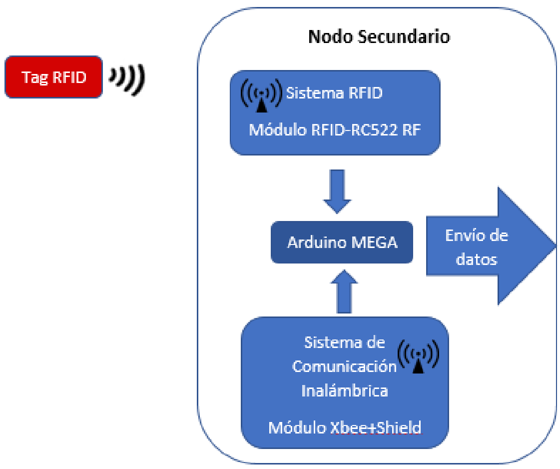

Figure 6. Block diagram of the secondary nodes.

Source: Authorship.

Flowchart secondary nodes.

An intuitive way of understanding how the secondary node and its subsystems work logically is with the aid of a flowchart. So it starts by checking whether the node is on or not, and followed with the RFID system plus a permanent census which identifies whether there is an RFID tag present or not within its reading range.

This process of census, consists of a cycle that yes yes registers the identification number of the RFID tag and initiates an individual upward timer in relation to other tags present, according to the programming in the Arduino plate and this will end when this programmed , otherwise it will continue to analyze if there is a present tag.

Once the process of identifying the start and end of the timer has been completed according to the corresponding tag, the communication system is in charge of sending the collected data to the central node for processing.
The above described in relation to the operation of the secondary nodes is shown in figure 7, which describes all the logical processes to be performed.

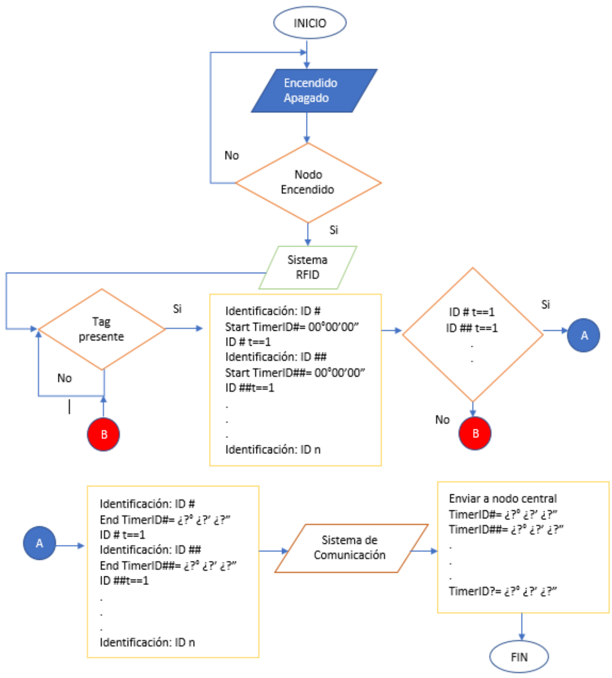

Figure 7. Flowchart secondary nodes.
Source: Authorship

Diagram of blocks of the Central node.

The central node is in charge of maintaining a previous register of all the handles that have an RFID device which will be previously validated in the programming of the platform Arduino.

The central node, in addition to receiving the times taken by the secondary nodes, will sum up all of these data through the use of a software application developed in Processing, to finally show them in a hierarchical way from a smaller to a larger one with the aid of a sheet of calculation in Excel. Figure 8 shows the interconnection of all processes present in the node in more detail.

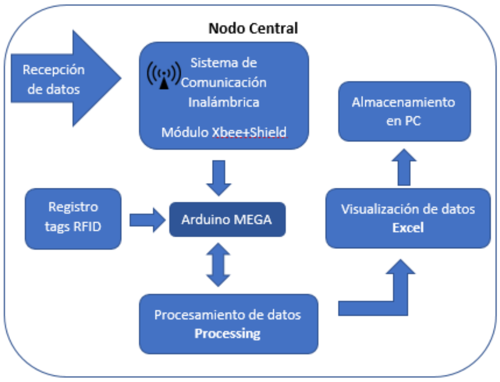

Figure 8. Diagram of blocks of the Central node.
Source: Authorship

Diagram of central node flow.

As in the secondary node, a flow diagram is presented to better understand the internal operation of the central node and all the processes involved in its operation.

The node begins with the reception of data thanks to the communication system which leads to perform data processing, which consists of taking all the data obtained from each RFID tag and making a summation of the timers corresponding to the programming performed on the board developmental.

In the end all this data will be exported to an Excel sheet so that it can be displayed in hierarchical order and later stored in the PC in which the system works and terminate the process that must be performed by the project timing system. Figure 9 shows the logical processes present in the central node.

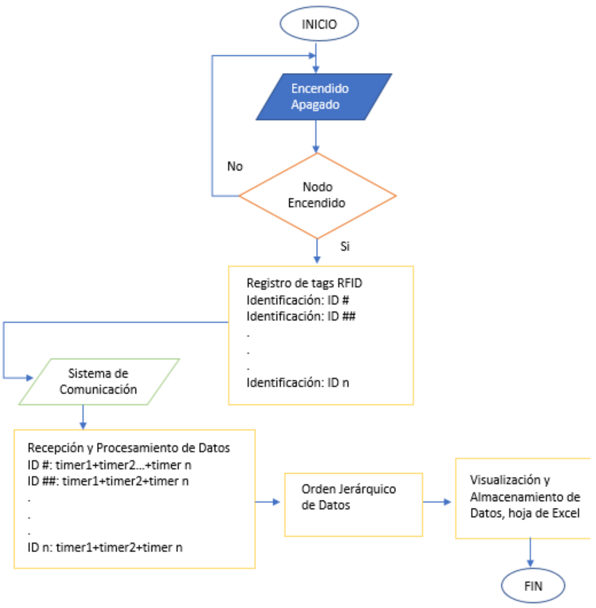

Figure 9. Diagram of central node flow.
Source: Authorship.

3.6 Schematic of connection of the elements that form the subsystems in the nodes.

The central node consists of several elements of electronics that help to develop all the systems immersed within the processing of the node, reason why the nucleus of it is an Arduino Mega in charge of the reception and processing of data.

The data reception is based on a wireless communication system with the help of an Xbee module and its shield since this element consists of several protections so that the Xbee module does not suffer any damage and helps the module to adhere to the board development without the use of cables.

The RFID system is developed using the RFID-RC522 Module and the RFID tags, the module is coupled to the development board by means of cables. All of the above with regard to the connection of the electronics of the system and their respective pins, can be seen in figure 10.

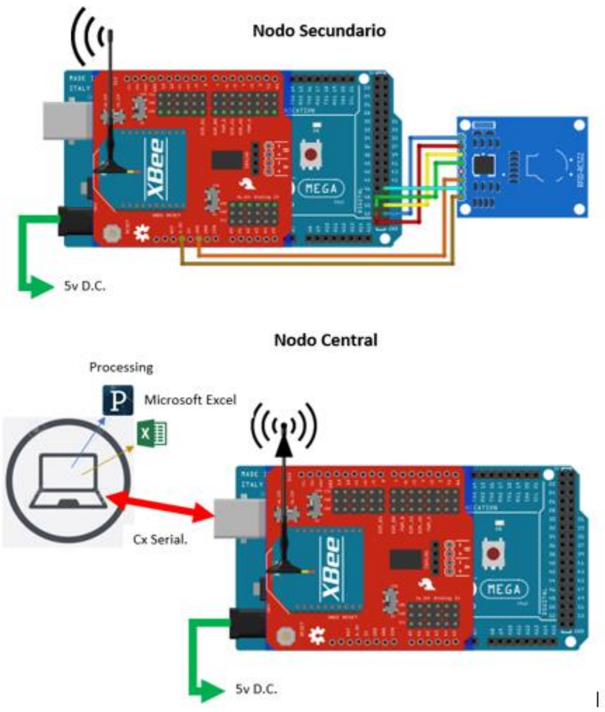

Figure 10. Connection Diagram Secondary Node and Central Node
Source: *Authorship.*

3.7 Analysis of the electrical energy consumption of the system.

As a requirement of the system, it must be in constant power supply so that this of the best benefits. Therefore it is taken into account that all the Arduino boards to be used must be fed by 5v and in relation to the current consumption depends on the peripherals that are connected to the board which make up the subsystems of the project.

The elements that make up the subsystems as they are: the module Rfc-522 according to the characteristics of the same presented previously and present in the datasheets works with a feeding of 3.3v. With regard to the module Xbee pro S1 just like the RFID module works at 3.3v and through the implementation of its shield helps with regard to power since it is suitable for the use and protection of the Xbee module.

The circuit developed in the project has a consumption of 400 [mA], detailed in table 8:

Electricity consumption of the circuit used in the project	
Element	**Amp per hour**
Arduino mega	96 [mA]
Módulo rfc-522	19,5 [mA]
Modulo X-bee S1 y Shield X-bee	215 [mA]
Zumbador	40 [mA]
2 Leds	20[mA] x 2
	Total= 390,5 [mA] ≈ 400 [mA]

Table 8. Analysis of the electricity consumption in the project circuit.

Source: Authorship.

This table details the electrical consumption of all the elements present in the circuit developed for the project, so it is necessary to design a power supply for the circuit that has a consumption of 400 [mA] to 9 [v].

3.8 Costs that lead to the development of the system.

According to the acquisition of all the materials used for the development of the system in relation to economic costs can be seen in table 9.

Costs acquisition of materials for the development of the project.			
Descripción.	***Quantity.***	***Unit Value [$]***	***Total Value. [$]***
Arduino Mega 2560	3	60	90
Módulo Xbee S1	3	81	243
Módulo rc522	2	11	22
Shield Xbee pro	3	11,40	34,2
Tag RFID	20	3	60
		TOTAL	449,2

Table 9. Costs acquisition of materials for the development of the project.
Source: Authorship.

4. Tests of the systems that make up the project.

Once the design of the timing system is finished, it is necessary to perform the corresponding tests, which will lead to validate the correct functioning of the systems and all the electronic elements that make up the same. All tests performed have a single main objective, which is the collection of accurate reliable data and short results for further analysis.

In the first instance a laboratory test of the subsystems is performed separately to analyze the failures and strengths of each of them and how they will influence the operation of the entire timing system.

<u>Time-taking system.</u>

The secondary nodes that make up part of the system, whose nucleus is the platform of development Arduino, are in charge to take the time during the operation of the system for which it is necessary to implement within the programming of the plate the bookstore time, which helps easily measure time without the need to occupy part of the development board processing with calculations and count cycles.

This library is not included in the Arduino IDE for what should be downloaded and installed, this library declares a variable time_t that consists of 32 bits and is responsible for storing the seconds that run during the operation of the Arduino board, all conversions from seconds to minutes and hours are made by the same bookstore. The main strength of using this library for the operation of the system is that the time data is based on a count per second, you can perform addition or subtraction operations with great ease.

To start working with the library inside the Arduino IDE it is necessary to initialize it as follows #include <Time.h>, to later insert the data to start the count taken into account the following format: setTime (00,00,00, 00.00,0000) hour, minutes, seconds, days, month, year. For the development of the project it is necessary to insert zero to all these values, because there is more importance in the time counting.

The tests performed on the library to be used are based on the comparison of the time data obtained by the library and two devices, an ASTRO heart rate monitor and a cell phone timer. The results obtained can be seen in Table 10.

Timing Test			
Time	**Datos obtained [Segundos, Milisegundos]**		
	Librería	Pulsador	Celphone
3min 14seg 0miliseg	± 0,10	≥ 0,50	≥ 0,33
5min 0seg 0miliseg	± 0,08	≥ 0,52	≥ 0,28
10min 0seg 0miliseg	≤0.01	≥ 0,29	± 0,10
23min 15seg 0miliseg	≤0.20	≥ 0,89	≥ 0,75
27min 53seg 0miliseg	≤0.25	≥ 0,63	≥ 0,47
33min 53seg 0miliseg	≤0.75	≥ 0,83	≥ 0,67
40min 28seg 0miliseg	≤1.50	≥ 0,59	≥ 0,34
46min 47seg 0miliseg	≤1.80	≥ 0,96	≥ 0,80
52min 0seg 0miliseg	≤2.10	≥ 0,28	≥ 0,03
58min 0seg 0miliseg	≤2.40	≥ 0,71	≥ 0,62
1hora 03min 13seg 0miliseg	≤2.59	≥ 0,13	≤0.25
1hora 10min 12seg 0miliseg	≤2.68	≥ 0,20	≤0.35
1hora 17min 43seg 0miliseg	≤2.75	≥ 0,05	≥ 0.19
1hora 23min 45seg 0miliseg	≤3.74	≥ 0,15	≥ 0.65

1hora 30min 04seg 0miliseg	≤4.05	≤0.25	≥ 0.10

Table 10. Timing tests with 3 different devices.
Source: Authorship.

The different results obtained during the tests carried out within one hour 30 minutes, in relation to the lowest and highest time used by athletes of the triathlon club UTN during a training.

RFID system.

The implementation of a radio frequency identification system within the development of the project starts with the RC522 module.

To work with the module in Arduino it is necessary to download its corresponding library and initialize it in the following way #include <MFRC522.h>. The tests performed for the implementation of the RFID system can be seen in Table 11.

Tests made to the RFID system.

Funcionality test	Results
Reading distance	≤ 3 [cm]
Response time	≤ 1 [seg]
EPC reading per second	±25
Reading more than one tag at a time	3 tags maximum

Table 11. Performance tests performed on the RFID system.
Source: Authorship.

The results obtained show the efficiency of the RFID system that aims to identify the tags provided to the athletes of the UTN club during a triathlon training, so the Arduino mega board and the RFC522 module work in the best way during the functioning of the system.

The analysis of the same helps to understand that the minimum distance to which a tag should be approached for reading in relation to the module is very low, which does not bother the athletes very much so that they should bring the enough tag times required by the timing system.

Wireless communication system.

As previously stated the nodes that make up the system must be connected, so the use of X-bee modules help in this work.

These modules must be configured using the XCTU program as shown in Table 12.

Configuration X-Bee Modules

MAC module X-bee	Network setting s	Network ID	High destination address	Low destination address	Identification of the node
0013A200 40F3C35A	Standard Router	7FAA	0	FFFF	Central Node
0013A200 40F3C300	End Device	7FAA	0	FFFF	Nodo Sec
0013A200 40F3C340	End Device	7FAA	0	FFFF	Nodo Sec

Table 12. Configuration X-Bee modules with the help of the XCTU program.
Source: Authorship.

In order to work with X-Bee devices, the corresponding configuration must be made for each module as can be seen in the table above, this can be done thanks to the XCTU software.

It is necessary to determine the destination addresses High in 0 and Low in FFFF which means that there is a broadcast communication between the three nodes, and the way of operation of each XBee Pro DigiMesh 2.4 S1, since these are the devices to use within the project development.

The tests performed on this system can be seen in Table 13.

Tests made to the Wireless Communication system

Performance tests	Results
Minimum Tx and Rx data distance	≥ 1 [cm]
Maximum distance of Tx and Rx data.	≤ 1000 [m]
Response time at minimum distance.	≤1 [segundo]
Response time at maximum distance.	≤ 1[segundo]

Table 13. Tests made to the Wireless Communication system
Source: Authorship.

The results obtained during the tests made to the wireless communication system show that the work performed is optimal for its implementation within the timing system, since it would not add a significant time during the transmission of data for later processing.

Application of Pc.

The use of Processing for the development of an application that can handle all the data obtained is of great help since it has the possibility to show a graphical environment in which the manipulation of the system and of all the data obtained is immersed.

The graphic environment developed in Processing is divided into four phases and only has two buttons which start and end the system according to the disciplines that will be performed during a training. These buttons facilitate the manipulation of the entire system can be seen in Figure 11a.

The START button starts the system in relation to the discipline to be performed and displays a timer as a display of elapsed time and the STOP button only stops it. Everything described can be seen in Figure 11b.

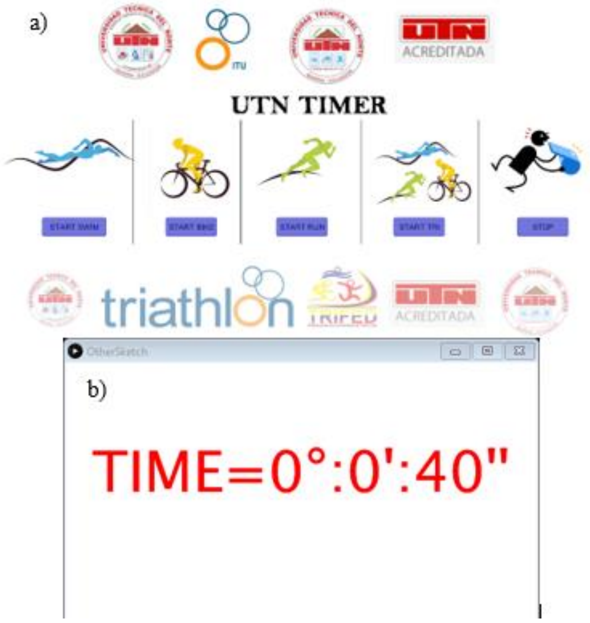

Figure 11. Graphical environment timing system.
Fuente: Authorship.

Additionally there is another application that its function is to show the MAC of the tags that will later be used by the athletes of the triathlon club UTN as can be seen in figure 12, this will help when registering the tags and names of the athletes in the spreadsheet according to the discipline to be performed.

Figure 12. Graphical environment, record of handles.
Fuente: Authorship.

The development of these software applications makes the system very easy to manipulate either for the registration of the tags provided to the athletes or for time control so its implementation helps to give the best performance to the performance of the timing system .

<u>Processing, visualization and storage of obtained data.</u>

The easiest way to get all the system is provided is the START and STOP buttons in the graphical environment of the system, as these not only fulfill the function of starting and stopping the display timer.

Each button has a specific programming, the START button creates a file whose extension is .csv and it processes all the data obtained by the system while the STOP button saves the file and stores it in the location described within the programming. Processing.

A spreadsheet developed in Excel and with some programming allows you to take the data from the file described above, display it and sort it as specified in the system requirements, making the results obtained are intended to be manipulated and interpreted after the end of the session. training by the person in charge of the timing system, as described above can be seen in figure 13.

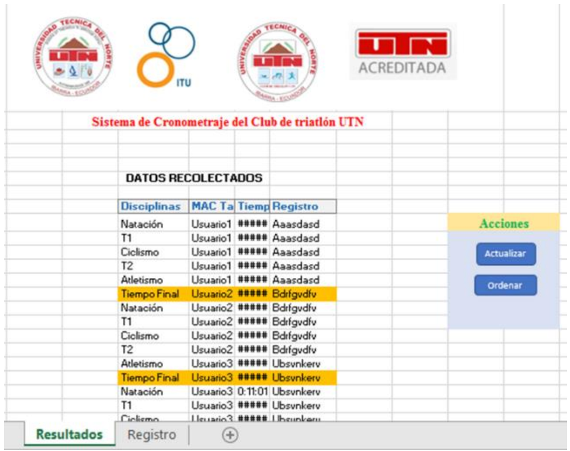

Figure 13. Viewing and Storing Data.
Source: Autohrship.

4.1 Tests made to the timing system.

The development of these tests took place during the training sessions of the UTN triathlon club and in conjunction with the Imbabura Sports Federation (FDI) triathlon team due to the similarity of training plans, discipline on different days of the week.

Additionally the timing system was subjected to a competition environment which helped to take into account different points of view regarding the performance of the system during official competition or training. This helps to measure the versatility of the timing system in different test environments and under different working conditions in various sports scenarios.

<u>Trainings UTN triathlon club.</u>

Thanks to the members of the UTN triathlon club, it was possible to carry out functional tests of the timing system in different locations and under the environmental conditions that entails being in them. These tests were performed on different days of the week depending on the training schedule established by Lic. Jorge Pulles, as can be seen in Table 14.

Schedule of tests performed at the UTN Triathlon Club

Date	Discipline	Triathlon team	Training venue	Training detail
14/06/2017	Swimming	UTN	UTN Aquatic Complex	750m distance swimming Sprint Triathlon, pace of competition.
15/05/2017	Athletics	UTN	YAHUARCOCHA	10km resistance on track at competitive pace.
19/06/2017	Cycling	UTN	YAHUARCOCHA	Tour of 10 km in track to 70% 80% of maximum consumption.
21/06/2017	Triathlon	UTN	YAHUARCOCHA	Simulacro of competence and control of times.

Tabla 1e. C*Schedule of tests performed at the UTN Triathlon Club*
Source: Authorship.

As can be seen in the table the tests of the timing system were carried out in different sports scenarios and according to the discipline evaluated in the same way the environmental conditions in which they were made are different, which resulted in the system of timing and the teams that form the same carry out their work without any inconvenience.

Finally, the results obtained in the different training sessions are subjected to an analysis to determine the physical performance of the members of the club based on the manual records made by the trainer, which can be seen in table 15.

Analysis of data obtained by the timing system based on records made by the club coach.

Discipline and Training Detail	Member	Datos: Timing system	Datos: Registration done by the coach	Difference of times	Sports performance
Swimming 750 m freestyle	Mateo López	11'30"	13'22"	1'52"	Excellent
	Carlos Granada	11'05"	11'58"	53"	Good
	Brayan Vallejos	11'27"	11'34"	7"	Good
	Leonardo Caiza	12'39"	12'30"	9"	Good
	Michael Rosero	13'06"	No Record		Regular
Triatlón Sprint	Gabriela Sandoval	1°23'17"	1°21'40"	2'33"	Regular
	Estefanía Farinango	1°30'12"	Sin Registro		Good
	Lorena Ramírez	1°33'24"	1°23'17"		Good
	Jonathan Esparza	58'10"	1°02'20"	4'10"	Excellent
	Jorge Pulles	1°15'51"	1°23'29"	8'22"	Excellent
	Alejandro Gavilánez	1°08'51"	1°05'10"	3'41"	Regular
	José Luis Jaramillo	1°12'02"	1°10'17"	2'15"	Regular

Table 15. Analysis of data obtained by the timing system based on records made by the club coach.
Source: Authorship.

This analysis was developed jointly with the help of Lic. Jorge Pulles, coach of the triathlon club UTN, so a comparison was made between the data obtained by the timing system and the physical records that the trainer carries and it was determined that the members of the club are at an average level Good to perform within a competition.

FDI triathlon team trainings.

The tests done to the FDI triathlon team were executed in days prior to the ITU WORD CUP Pan American Championship held in YAHUARCOCHA, so that the system was subjected to conditions similar to a competition due to the speed that athletes wear during these training sessions. The schedule of tests performed to the FDI triathlon team can be seen in table 16.

Schedule of tests performed to the FDI Triathlon team

Date	Discipline	Triathlon	Team	Venue Training Detail
13/06/2017	Athletics	FDI	Ibarra Olympic Stadium	Speed 400 m flat at 60% consumption.
15/05/2017	Athletics	FDI	Ibarra Olympic Stadium	800m resistance on track at competitive pace.

Table 16. Schedule of tests performed to the FDI Triathlon team
Source: Authorship.

In this case, the tests were carried out in the open field at the Olympic stadium of Ibarra on a sandy surface due to the wear of the synthetic track of the same and at an ambient temperature of 24 ° C and with a concurrence of 10 athletes.

<u>Championship Acuatlón FF.AA. (Armed Forces of Ecuador).</u>

On 27 June 2017 at the YAHUARCOCHA Race Track, the timing system in the Acuatlon competition organized by the FF.AA could be tested. What made this system can be subjected to a stronger environment in terms of its performance.

This test demonstrated the development of all elements of hardware and software used for the development of the system, under environmental conditions such as rain and a muddy surface due to the agglomeration of people on the edge of the lagoon of YAHUARCOCHA.

The distance of separation of the nodes is a very important point to point out since unlike the trainings this was fixed between the 400 meters as can be seen in the illustration 52, without giving any problem as far as the transmission of data between them, providing 100% wireless communication between the entire system.

Conclusions.

The use of free Software and Hardware elements allows the development of a timing system capable of meeting all the objectives of the same in any environment in which it is tested, and even more important with an affordable cost for its implementation.

All the bibliographic analysis made allows to take into account all the necessary criteria for a correct design of the timing system, which leads to determine the equipment to be used for the development and implementation of the same.

The handles or tags provided are imperceptible on the part of the athletes, this makes them easy to carry during the activities in which the timing system is tested.

During a training session of the UTN triathlon club it is not necessary to make a mark as indicated by the ITU regulation. This is because the handles provided to the athletes have a unique coding which helps to make the recognition of who is carrying it in that moment.

The tests performed on the timing system in different working environments helped to determine that it is not suitable for use during competition due to the distance limitations of the RC522 RFID module during the reading of tags worn by athletes.

The timing system developed can be subjected to all environmental conditions or stress present during the development of the training sessions of the members of the UTN triathlon club without these may affect in any way the performance of the same.

This system reduces the number of people involved in taking time within a competition or a training session, since everything is digitized so there is a minimal intrusion of individuals within the management of the same or processing of the data obtained.

Compared with the different timing systems present in the market based on the economic and functional aspect, the development of this project entails a saving of 80% and fulfills the same functions as a system acquired abroad.

The development methodology used for the development of this project entails to follow different steps systematically, which, if properly followed, greatly aid in the choice of the different elements of hardware and software used, which together form the timing system developed in this project.

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