

2. Understanding what EPTS tracks

2.1 Technical aspects of EPTS

Introduction

In the field of sport, different processes are utilized in order to achieve success or victory. Within these processes, we find the evaluation, whose main function is to establish the basis and prospects for improvement during the development established, under a given goal. The path towards the optimisation of human performance is oriented to the correct use of collected data in the different evaluations that athletes performed on a daily basis. Therefore, in-depth analysis, details and ongoing corrections are factors that navigate under the same premise: To be consistent with the final target.

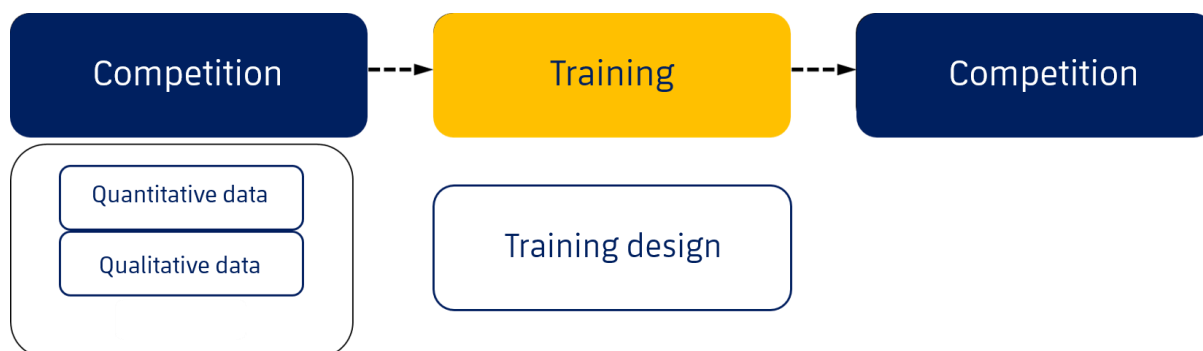
In this field, at a general level, two types of activities are generally addressed: those related to competition and those related to training. The main goal of those activities related to the competition is to enable the athlete to reach its best performance to achieve success. Furthermore, in training activities, the objectives can be very varied but they all aim to prepare the competition in the best way possible. Based on a specific target those activities can be grouped as follows:

- Recovery.
- Rehabilitation.
- Preparation.
- Re-adaptation.
- Others.

Obtaining information on the competition and training activities is vital at the sporting level so that they are carried out under the necessary standards and meet the established objectives. For this reason, it is important to know beforehand the requirements of the competition so that the training is consistent and the athlete is prepared to face them. We call this: **competitive demand profile**. This information is vital in order to determine the orientation of the training. On the other hand, it is also necessary to know the training requirements and to ensure that the sessions comply with the basic principles of physical, physiological and psychological load, and are in line with what will be faced in the competition.

The concept of planning must be based on an interval of time. In the case of collective sports, the interval is between match and match. Based on this data, the person responsible for organizing the training sessions must distribute the load in accordance with the fundamental principles of the training (volume, intensity, rest, type, among others) to enable athletes to reach the competition in the most suitable physical, physiological, psychological and tactical conditions (Figure 1).

Figure 1: Time interval in team sports



Source: Prepared by the authors.

Until only a few years ago, this distribution of the load was purely theoretical, as no objective data was available to carry it out otherwise. However, technological advances have introduced devices that can obtain the data in a non-invasive way. The information gathered from these instruments has increased in quantity and quality, from having little data a few years ago to having many today.

The provenance of data can be varied. They are classified according to multiple factors, including:

- Subjective data of the player. In this group, we can include all the data obtained through the subjective perception of the player, related to the effort made or to a specific task or situation (intensity, quality of sleep, stress, quality of life, spatial location, among others).
- Subjective data from the coach. In this group, we can include all the data obtained through the perception of the coach or coaches (intensity of play, spatial distribution, tactical compliance, distribution of tasks, the achievement of objectives, among others).
- Qualitative video data. In this group would be all the data that the trainers obtain by recording the training sessions and/or matches, and their subsequent analysis in a technical way (expert criteria, comparison charts, structured questionnaires, control of tactical technical actions, among others).
- Objective player data via EPTS positioning devices <https://football-technology.fifa.com/en/media-tiles/epts-1/>. Using this technology we mainly obtain positioning data from players in time and space.

The FIFA Committee of Experts lists three types of technologies that can be used: optical-based camera systems, local positioning system (LPS) and GPS/GNSS positioning system. FIFA. Electronic Performance Tracking Devices. Football Technology, <https://football-technology.fifa.com/es/media-tiles/epts1/> (2019)

FIFA's Football Technology Innovation Department works on the standardisation of electronic performance and tracking systems (EPTS) and thereby looking to provide guidance to football's stakeholders in regard to the use of EPTS in competitive matches. (FIFA, s. f., <https://football-technology.fifa.com/es/media-tiles/about-the-ims-standard-for-wearable-tracking-devices/>)

Speed and distance, as well as positioning, are obtained directly. Indirectly, the acceleration is obtained by applying the derivative to the speed signal.

- External physiological objective player data. In this case, we talk about the variables of heart rate, RR (heart rate variability), oxygen saturation, among others.
- Objective internal physiological player data. In this case, we refer to lactic acid, hormones, markers of blood damage, among others. Djaoui L, Haddad M, Chamari K. (2017).

Furthermore, in the field of technology and informatics, the use of basic terms is used to refer to certain concepts that help to understand the phenomena studied. On the contrary, in sport, this terminology is not frequently used, because commonly as sports scientists that we are we receive processed information from different systems, software and technologies, which are used in the evaluation, monitoring and follow-up of athletes. This is why this section presents theoretical concepts that will contribute to the understanding of the course contents.

Signal

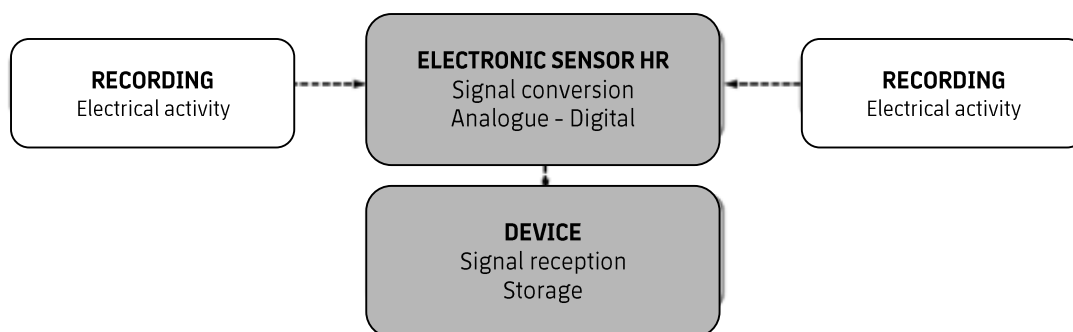
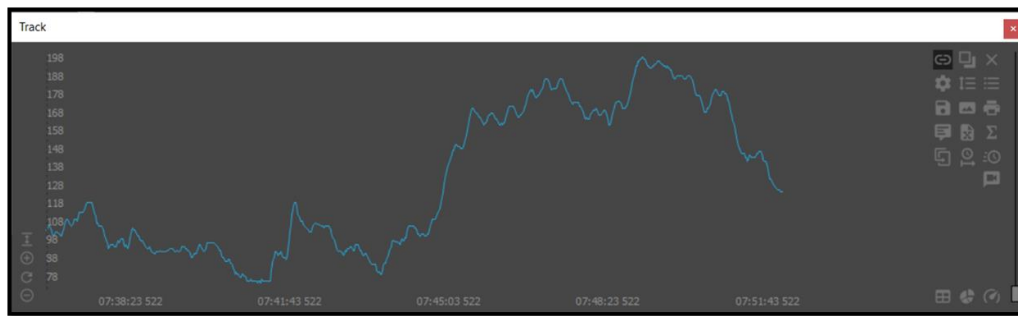
An electrical signal is a type of information generated by some electromagnetic phenomenon. These signals can be of two types: analogue if they vary continuously over time; or digital, if they vary discretely (with parameters that break from one value to the next; for example, binary values 0 and 1). An electrical signal can be understood as a hydraulic model, with parameters of:

- The potential difference (tension), where this one is expressed between two electrically charged points in the passage of time.
- Flow rate, referring to the current intensity. Power.

http://www.csanpablo.com.ar/v1/apuntes_archivos/fisica_archivos/Electricidad3.PDF

Figure 2 shows a basic heart rate recording scheme, transmitted by an electromagnetic phenomenon and captured by a special monitor that converts the electrical signal.

Figure 2: Heart rate recording.



Source: Realtrack Systems SL, 2019.

Digital signal processing

We can say that when we perform any digital process to modify the digital representation of a signal we are doing digital processing. As a digital process, it can be from the simplest made by a logical door to the most complex made by a specific circuit of a digital signal processor (DSP). When talking about the digital process we usually refer to a program that works on a PC, microcontroller, DSP programmable logic devices. Martínez Sober, Serrano López, Gómez Sanchíz (2010). <http://ocw.uv.es/ingenieria-y-arquitectura/1-1/tema1.pdf>

Electronic filter

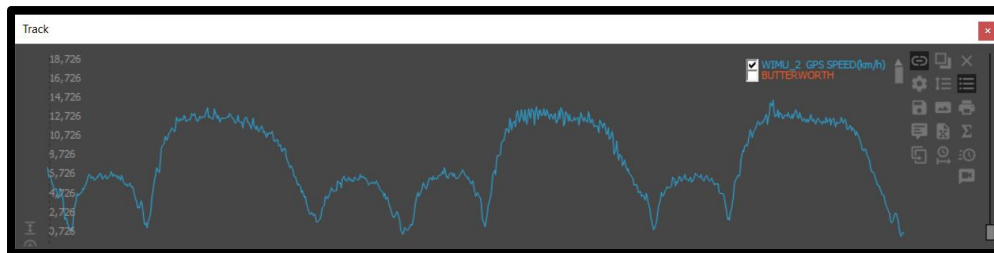
An electric filter is a system (circuit) whose function is to modify, deform or manipulate in general, the frequency spectrum of an input signal (excitation) according to certain requirements (specifications). Filters are used to attenuate or amplify input components with frequencies within a given range or to reject or isolate components at specific frequencies. (2004) <http://www2.imse-cnm.csic.es/~rafael/SETI/tema2.pdf>.

These can be: active or passive, analogue or digital, high-pass (HPF), low-pass (LPF), bandpass (BPF), band elimination (notch filters or band-stop filters) or all-pass filters, discrete-time or continuous-time, infinite impulse response (IIR) or finite impulse response (FIR).

These types of filters are signal-smoothing, so that the information that might be considered part of the imprecision, due to the difficulty of measuring certain variables, has a closer behaviour to reality by eliminating noise. This is done thanks to the fact that

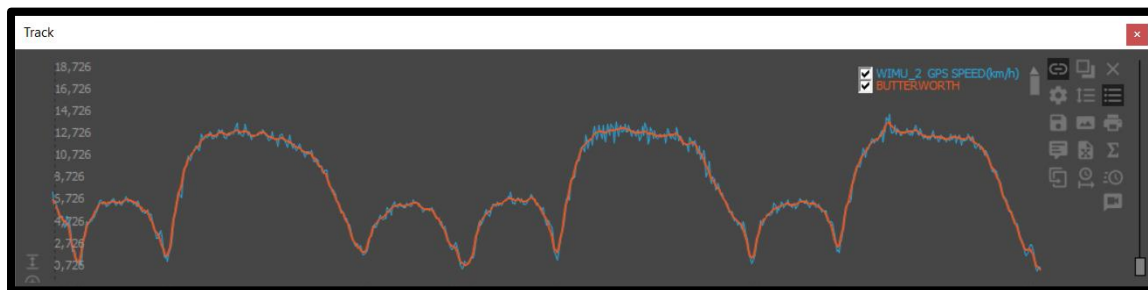
movement, location, temperature, quality of the signal, among other factors, affect the quality of the data. Figure 3 shows the speed returned by a GPS sensor. The following figure shows the same signal with the Butterworth filter.

Figure 3: Speed tracked by a GPS sensor



Source: Realtrack Systems SL, 2019.

Figure 4: Speed tracked by a GPS using the Butterworth filter



Source: Realtrack Systems SL, 2019.

As can be noted, when applying a filter the signal is softened, losing data in the graph, but always with the aim of obtaining the best quality of measurement possible. Basically, this type of filtering has to be applied to all signals, but few companies provide information about this.

Smoothing filter

In statistics and image processing, smoothing a data set is creating an approximate function that tries to capture important patterns in the data, while leaving aside noise or other fine-scale structures or rapid phenomena. In smoothing, the data points of a signal are modified, thus reducing them individually (presumably due to noise), while the points that are lower than the adjacent ones are increased, which leads to a softer signal. Smoothing may be used in two ways that help with the data analysis:

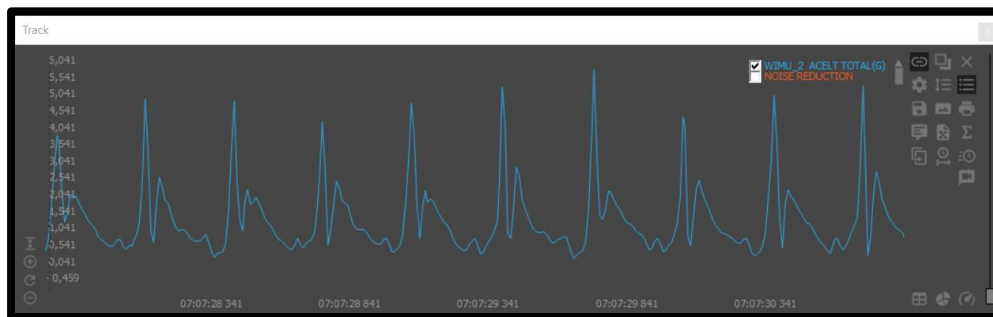
1. Allows extracting more information from the data, provided that the smoothing assumption is reasonable.
2. It provides a flexible and robust analysis.

Many different algorithms are used to smooth.

There are different smoothing techniques, for example, Savitzky-Golay, LOWESS, circular median.

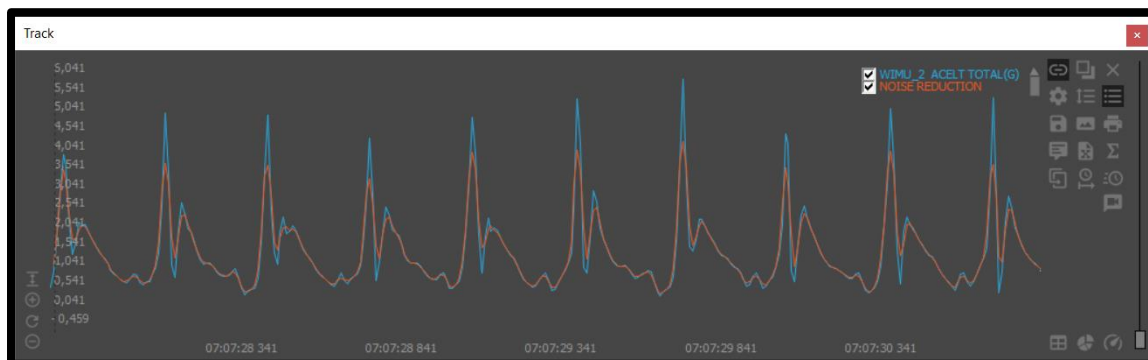
Figure 5 shows the recording of an accelerometer signal (vector sum) during a race. A smoothing filter has been applied in Figure 6.

Figure 5: Recording of an accelerometer signal



Source: Realtrack Systems SL, 2019.

Figure 6: Vector sum with smoothing filter



Source: Realtrack Systems SL, 2019.

As can be seen, when applying a filter some of the information is lost, especially the maximum and minimum values.

Sampling frequency

The sampling rate or frequency, also known as signal discretization, is the first step in the process of converting an analogue signal (continuous-time and amplitude) into a digital signal (discrete-time and amplitude). The conversion of the analogue signal into digital (A/D conversion) is carried out, among other reasons because digital signals have great advantages in being transmitted and/or processed: higher noise immunity, easier processing, and multiplexing facility. In technological applications, the samples are taken at equal intervals of time, this process is called "periodic sampling of signal", which facilitates processes such as "the signal reconstruction."

FundamentosYAplicacionDelMuestreoEnSenalesUbicadas-4742487.pdf

In this sense, frequencies are usually expressed in hertz (Hz, cycles per second) or their multiples, such as kilohertz (kHz), although other magnitudes can be used.

It commonly refers to Hz as the amount of data per second that the device or system is capable of measuring.

Inertial devices integrate different sensors, each sensor has its own sampling frequency. For example, the **Wimu Pro** device has:

- 20 Hz GPS sensor, currently set to 10 Hz.
- UWB sensor - 18 Hz.
- Accelerometer - 1000 Hz.
- Gyroscope - 1000 Hz.
- Magnetometer - 160 Hz.
- Barometer - 100 Hz.

Figure 7: Wimbu Pro device



Source: Realtrack Systems SL, 2019.

Figure 8 shows the speed measured with two GNSS/LPS technologies. Data obtained with GNSS technology have been collected at a frequency of 10Hz, and data with LPS technology were collected at 18 Hz. The information delivered can be seen at the bottom of the figure. The first column corresponds to the time, the second shows the data registered with GNSS technology and the next with LPS technology. It can be noted that in this column there are more data per unit of time since the frequency is higher.

Figure 8: Speed measured with GNSS/LPS technologies



Source: Realtrack Systems SL, 2019.

Sensor

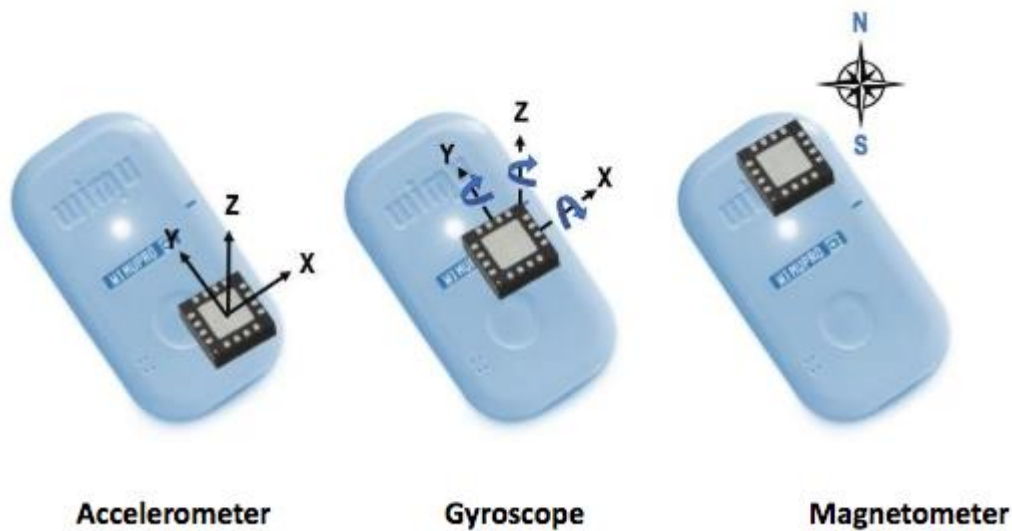
Sensors are the main elements of any measurement system. They collect data from the physical system (input) and provide an electrical signal in response to them (output). (Vara Rodriguez, 2014, p. 31)
<https://uvadoc.uva.es/bitstream/handle/10324/12884/TFGP161.pdf;jsessionid=37B1BCB2F2E37193DDCCCB9307DEDAC0?sequence=1>.

Axes of an inertial sensor

An inertial measurement unit or IMU is an electronic component based on sensors of acceleration and angular speed (accelerometers and gyroscopes respectively) which reports the movement and orientation that this unit undergoes. (Vara Rodriguez, 2014, p. 56)
<https://uvadoc.uva.es/bitstream/handle/10324/12884/TFGP161.pdf;jsessionid=37B1BCB2F2E37193DDCCCB9307DEDAC0?sequence=1>.

Sensors usually have three axes to measure on all three planes (figure 9).

Figure 9: Axes



Source: Realtrack Systems SL, 2019.

Redundancy

A redundant control system is based on duplicating some of the elements of the control system in such a way as to allow the system to continue its process, even in the case of failure of any of the components of the system. The duplicity of the elements or the way in which the duplicity is performed is not always identical, depends on the component to be duplicated and also on the actual implementation made by the manufacturer. (Pelegrí Aldavert, 2016, p. 10) https://upcommons.upc.edu/bitstream/handle/2117/97990/UPC_Implementaci%C3%B3n%20de%20un%20sistema%20redundante.pdf?sequence=1&isAllowed=y

It usually refers to the capacity to obtain data using several sensors of the same type at once, in order to achieve parallel measurements and thus ensure that these are of the best quality.

Full Scale

Full Scale is the difference between the highest value and the lowest limit of measurement.



Accelerometer

An accelerometer is an electromechanical device that allows us to measure acceleration forces. These forces may be static like the constant force of gravity or may be dynamic, caused by motion or vibration of the accelerometer. (Pérez López, s.f., p.11) <http://www.realtracksystems.com/wp-content/uploads/2018/11/Un-m%C3%A9todo-de-calibraci%C3%B3n-de-sensores-inerciales.pdf>

Table 1: Accelerometer data

	Max. scale	Default scale	Frequency
ACCEL. 1	± 16 G.	± 16 G.	10 / 100 / 500 / 1000 Hz
ACCEL. 2	± 16 G.	± 16 G.	10 / 100 / 500 / 1000 Hz
ACCEL. 3	± 32 G.	± 16 G.	10 / 100 / 500 / 1000 Hz
ACCEL. 4	± 400 G.	± 100 G.	10 / 100 / 500 / 1000 Hz

Source: Realtrack Systems SL, 2019.

As shown in the table above, corresponding to the Wimbu pro device, this integrates 4 accelerometers, thus offering redundancy in measurement. When a low-intensity movement is detected, accelerometers of 16 G are measured. If a very intense movement is performed, accelerometer 3 and 4 are used. The management of this process is carried out directly by the device. The sensor also records at a frequency of 1000 Hz (sensor sampling rate), but the device can be configured to record at 10Hz, 100Hz, 500Hz or 1000 Hz (by default it records at 100 Hz).

**Gyroscope**

“A gyroscope is a device capable of measuring angular velocity, based on the principle of conservation of angular momentum.” (Pérez López, s.f., p. 13).

<http://www.realtracksystems.com/wp-content/uploads/2018/11/Un-m%C3%A9todo-de-calibraci%C3%B3n-de-sensores-inerciales.pdf>.

Table 2: Data extracted from a gyroscope

	Max. scale	Default scale	Frequency
GYRO. 1	± 2000 °/s	± 500 °/s	10 / 100 / 500 / 1000 Hz
GYRO. 2	± 2000 °/s	± 2000 °/s	10 / 100 / 500 / 1000 Hz
GYRO. 3	± 4000 °/s	± 4000 °/s	10 / 100 / 500 / 1000 Hz

Source: Realtrack Systems SL, 2019.

As seen in the table of the Wimbu pro device, this integrates 3 gyroscopes, therefore, redundancy in measurement. These sensors register angular velocity. Therefore, when a low-intensity movement is detected, it is measured with gyroscope 1 and 2. If a very intense movement is performed it will be captured with gyroscope 3. The management of

this process is carried out directly by the device. Moreover, the sensor registers at a frequency of 1000 Hz (sample frequency of the sensor), but the device can be configured previously to register at 10Hz, 100Hz, 500Hz or 1000 Hz (by default it registers at 100 Hz).



Magnetometer

A magnetometer measures the force or direction of a magnetic signal. In this way, the information is used to locate the device in space and orient its movement in a certain direction.

Table 3: Information delivered by a magnetometer

MAGNETO.	± 8 Gauss	± 1,3 Gauss *	10 - 100 Hz
		* Dynamic selection in Power On.	

Source: Realtrack Systems SL, 2019.



Barometer

We can measure atmospheric pressure using a barometer.

Table 4: Atmospheric pressure by a barometer

BAROMETER	± 1200 mbar	± 1200 mbar	10 - 100 Hz
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Source: Realtrack Systems SL, 2019.

Sensory fusion

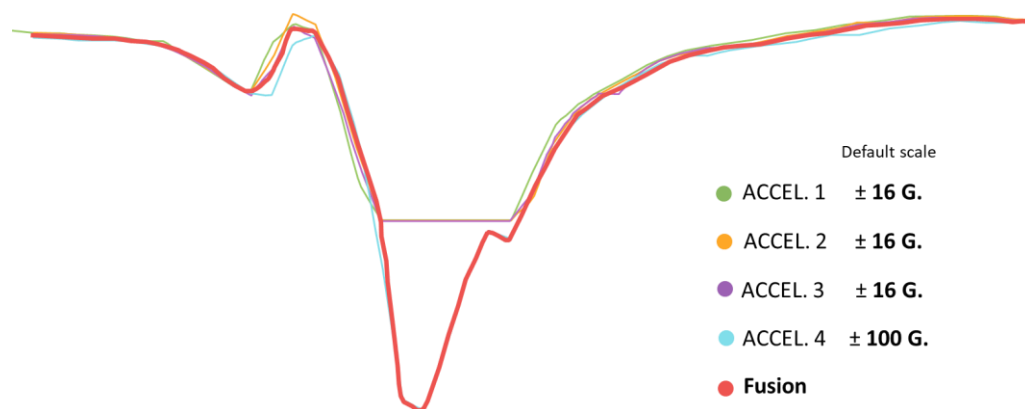
The fusion of data in detection problems focuses on the acquisition, processing and synergistic combination of several sources of information collected by one or more sensors and thus provides a better understanding of the phenomenon to be considered. In this way, so-called data fusion techniques seek to combine multiple sources of information to achieve accuracy and precision in decision-making that would not be possible with the use of a single source of information in isolation. The fusion of multiple sources of information, apart from adding a certain redundancy that provides reliability and robustness, can provide additional information to increase performance and accuracy in the decision-making process. (Soriano Tolosa, 2013, p. 19).

<https://riunet.upv.es/bitstream/handle/10251/34780/Soriano%20-%20Fusi%C3%B3n%20de%20datos%20estad%C3%ADsticamente%20dependientes%20en%20sistemas%20de%20detecci%C3%B3n.pdf?sequence=1>



Accelerometer. Fusion

Figure 10: Accelerometer and Fusion



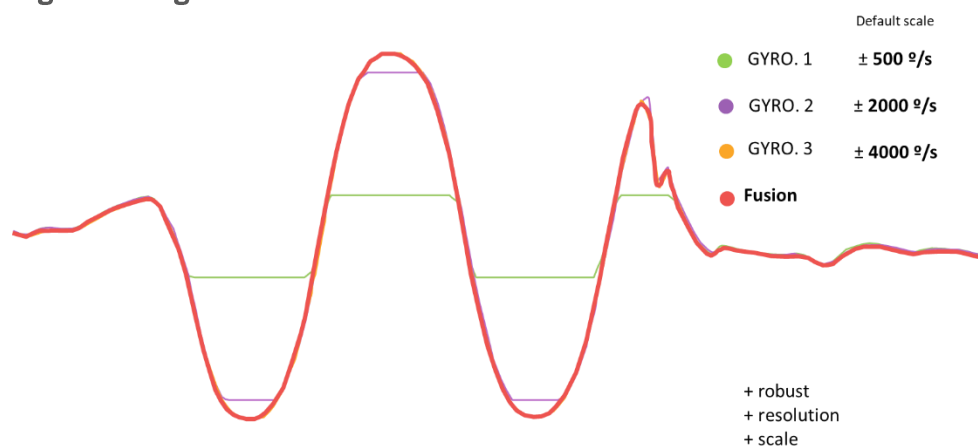
Source: Realtrack Systems SL, 2019.

The graph shows the signal of 4 accelerometers of the Wimbu pro device. By fusion, any movement can be captured and the quality is higher because it integrates the information of all accelerometers.



Gyroscope. Fusion

Figure 11: Signal from four accelerometers in the movement record.



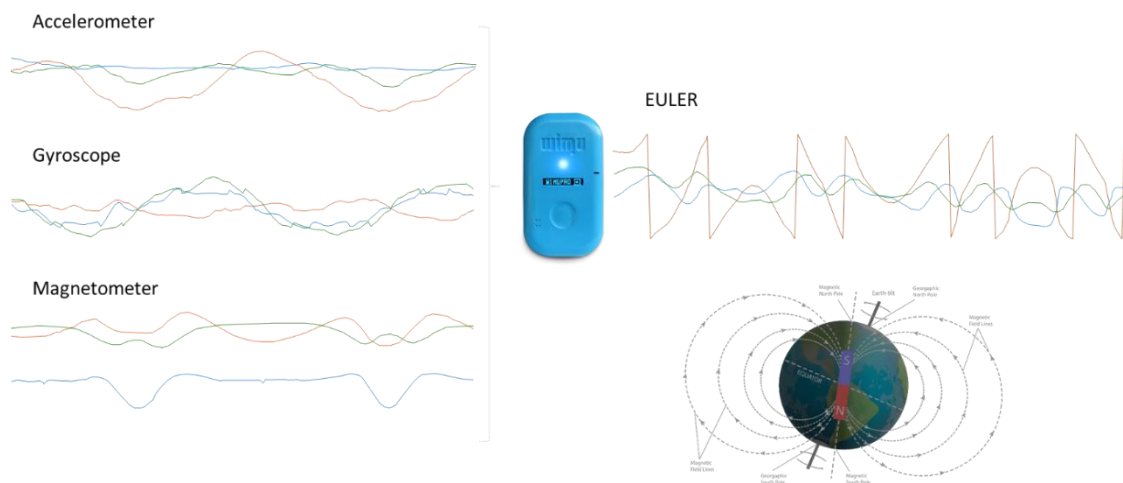
Source: Realtrack Systems SL, 2019.

Figure 11 shows the 3 gyroscope signal of the Wimbu pro device. As in Figure 10, it can be seen how the movement record and the quality is higher.

Attitude

It provides 3D orientation by integrating gyroscopes, fusing this data with accelerometer data and magnetometer data. With sensor fusion, drift from the gyroscopes integration is compensated by reference vectors, namely gravity, and the earth's magnetic field. https://erlerobotics.gitbooks.io/erlerobot/content/es/beaglepilot/attitude_heading_reference_system.html

Figure 12: Fusion, movement, and quality



Source: Realtrack Systems SL, 2019.

Raw data of a signal

The RAW format refers to the so-called "raw" data. It is the purest form in which the data are presented.

Algorithm

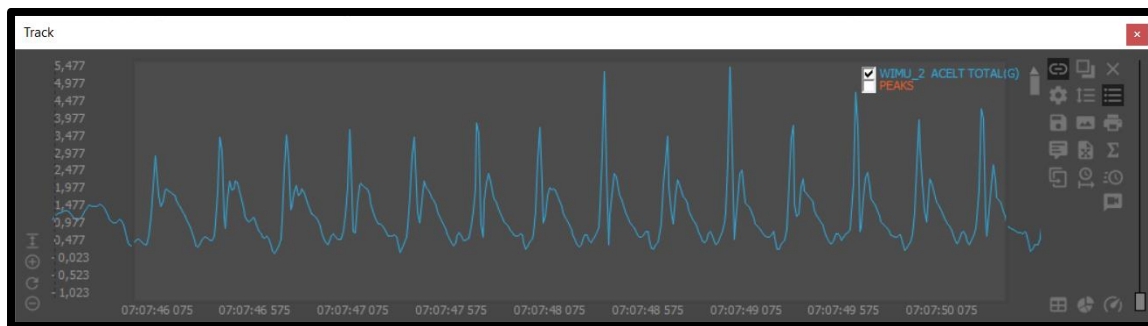
It is a sequence of instructions that represent a solution model for a certain type of problem. Also, it is defined as a set of instructions that carry out in sequence they lead to the solution of a problem. At the same time, it is important to emphasize that algorithms are independent of the programming language. That is, in each problem the algorithm can be written and then run in a different programming language. In other words, it is the infrastructure of any solution. http://ing.unne.edu.ar/pub/informatica/Alg_diag.pdf

In the case of sports sciences, useful data is obtained in practice.

Figure 13 shows the accelerometry signal (vector sum).

Figure 14 shows the application of an algorithm to detect supports.

Figure 13: Vector sum, accelerometry signal



Source: Realtrack Systems SL, 2019.

Figure 14: Application of an algorithm to detect supports



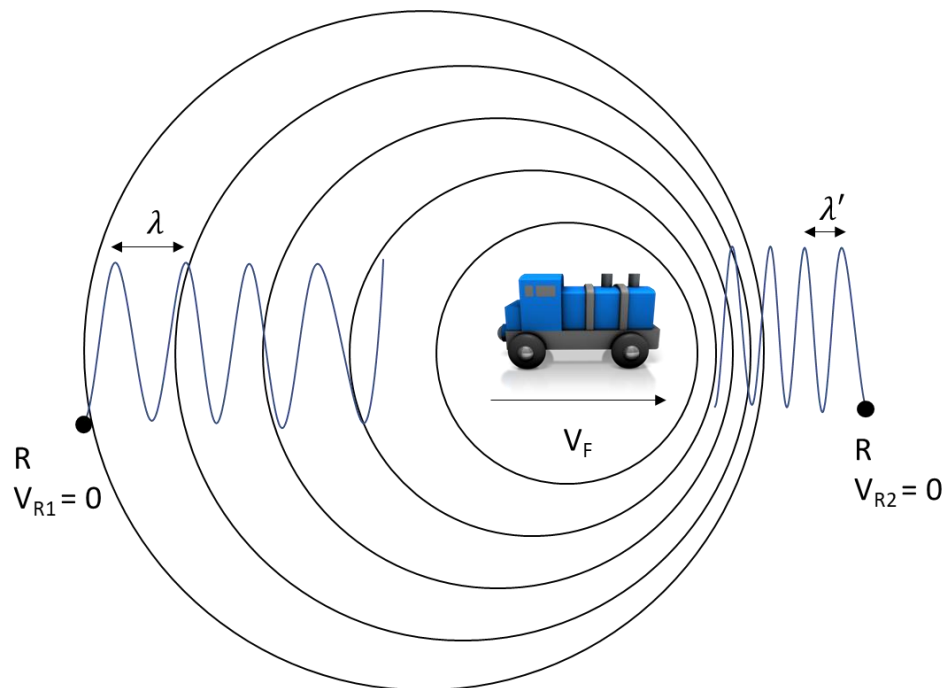
Fuente: Realtrack Systems SL, 2019.

The vast majority of systems used for collecting data in the sports field incorporate mathematical algorithms to detect different actions. But in sports, each person usually performs an action in a different way. Therefore, in the example we have given, the software SPRO (developed by the company Realtrack [Almería]) does allow us to modify the variables on which the algorithm is based.

The Doppler effect

The Doppler effect is a physical phenomenon whose manifestations have allowed important advances in a considerable number of domains. Furthermore, we can express that the Doppler effect, remains unalterable, as a phenomenon exclusive to harmonic waves, this effect is linked to compressions and expansions of any pulse in the domain of time and space. (Roatta. Welti, 2009, p. 1304-2). <http://www.scielo.br/pdf/rbef/v31n1/v31n1a04.pdf>

Figure 15: Doppler Effect



Fuente: Realtrack Systems SL, 2019.

Inertial measurement unit

The term IMU (inertial measurement unit) is used to refer to a box containing three accelerometers and three gyroscopes. Accelerometers are positioned, for example, in such a way that their measuring axes are orthogonal to each other; they measure the inertial acceleration, known as forces G . In turn, the three gyroscopes are located in a similar orthogonal pattern, thus measuring the rotational position in reference to an arbitrarily selected coordinate system. (Gomez Hernández, 2018, p. 32) http://oa.upm.es/51632/1/TFM_PEDRO_ROMERO_HERNANDEZ.pdf

Figure 16: IMU Integration



Source: <https://www.qualisys.com/integrations/imu/>.

Global Positioning System

The operation of the GPS system is based on the mathematical principle of triangulation, in which according to Delaunay (1934), you can know the point or place where you are located, and even trace and locate the origin of a transmission thanks to radio signals. The GPS system creates virtual spheres by accurately measuring the distance between it and the satellites. (Antichán, Morán, Núñez, 2009, p. 59). <https://www.redalyc.org/pdf/784/78411787005.pdf>

This technique is carried out by vehicle device manufacturers. In this sense, in the field of sport, it is also used this technique, as well as others to locate in the space and movement of displacement.

2.2 Practical aspects of EPTS

Obtaining spatial positioning data

There are numerous works concerning the instruments used to obtain data during matches and/or training sessions. Initially, these data were obtained through the observational methodology in a subjective way. In other words, they were the result of expert analysis. Today, however, technological advances have made it possible to obtain objective data. One of the first variables recorded was heart rate.

Advances in software development and in image capture have allowed the increase of systems where both technologies are combined (what is called video tracking).

This system, using mathematical algorithms, allows a semi-automatic tracking of players (previous calibration).

With the technology improvement, satellite-based positioning systems (GNSS/GPS) applied to the sport began to be developed. Satellite positioning technology has its advantages and disadvantages. Among the latter, we can mention that in interior spaces does not work, and in certain circumstances (sometimes it depends on speed and displacement) the quality is not very good. Sports companies that develop technology have taken advantage of imposing themselves in other areas, such as companies that work with positioning technologies on oil platforms, hospitals, etc. thus exposing products denominated at a general level local positioning system (LPS). For these systems to work it is necessary to install an antenna array around the space where the activity will take place.

The following is a summary of the main characteristics of each of the positioning methodologies used in the sport.

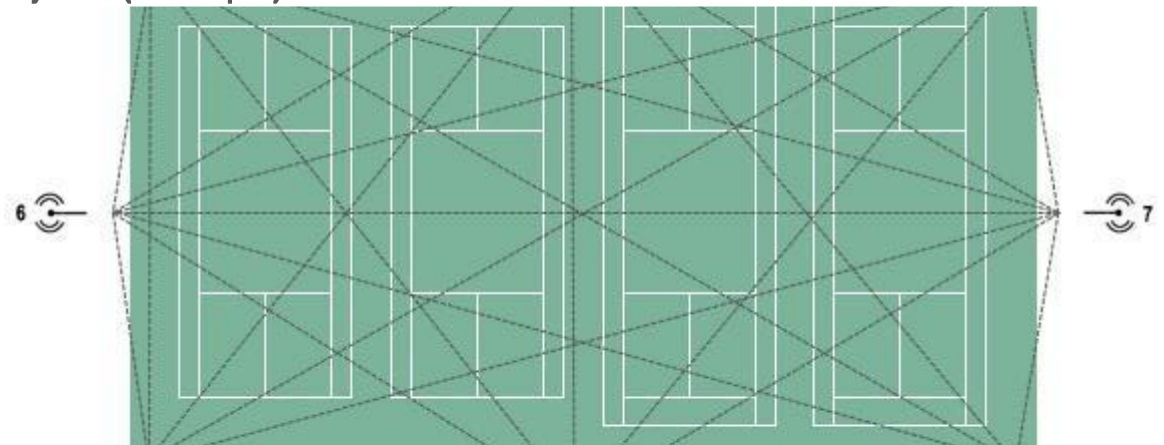
- *Video tracking*
 - Mathematical algorithms of player and ball recognition.
 - They collect data from coordinates X, Y.
 - From coordinates and time, they calculate distance and speed. The acceleration is calculated by applying the mathematical derivative to the speed signal.
 - The rest of the variables are calculated.
- GNSS/GPS
 - They directly provide distance.
 - Speed is calculated by the Doppler effect, in almost all companies.
 - The positioning data are latitude and longitude.
 - The variable acceleration is calculated by applying the mathematical derivative to the speed signal.
 - The rest of the variables are calculated.
- LPS
 - The positioning data are the X, Y coordinates.

- The variable acceleration is calculated by applying the mathematical derivative to the speed signal.
- From the positioning data, the rest of the variables are calculated.

The systems that integrate a GNSS/GPS sensor and/or an LPS sensor, also usually integrate more sensors. They usually have an accelerometer, a gyroscope, and a magnetometer. They are usually called IMU (inertial movement unit).

Below is shown the record of a badminton match using an LPS system (WIMU pro). For data acquisition, it is necessary to install antennas that allow obtaining the coordinates.

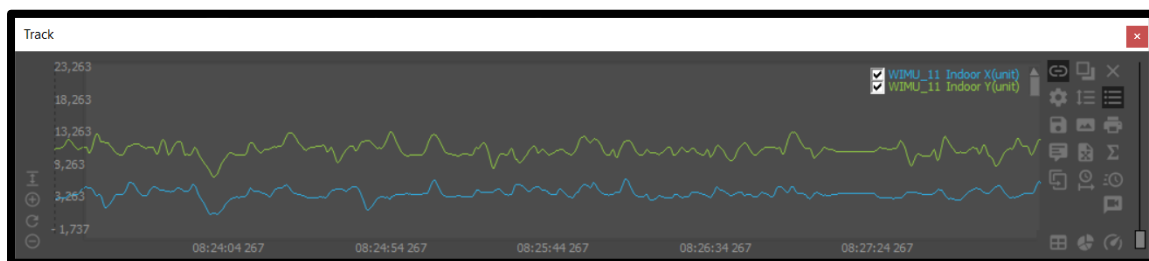
Figure 17: LPS system (WIMU pro) in a badminton match



Source: Prepared by the authors.

Figure 18 shows the X - Y coordinates of a player during a set.

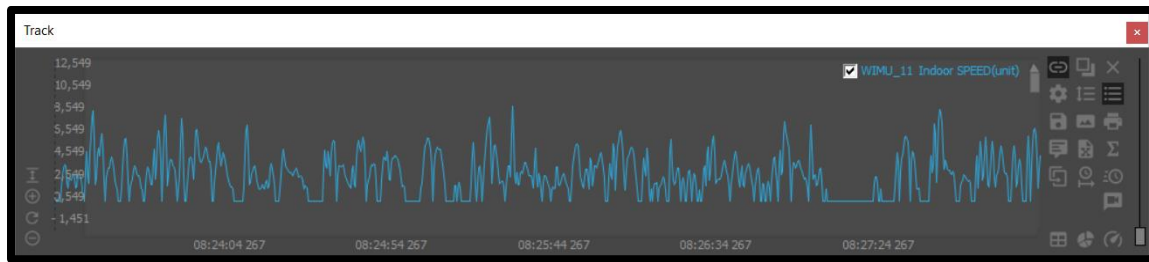
Figure 18: Coordinates X – Y during a Badminton set.



Source: Prepared by the authors based on Realtrack Systems, 2019.

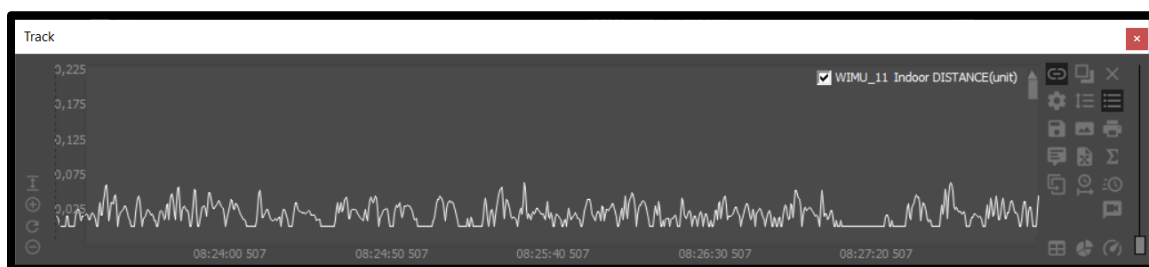
The direct variables that records are speed and distance (Figures 19 and 20).

Figure 19: Direct variables: Speed and distance



Source: Prepared by the authors based on Realtrack Systems, 2019.

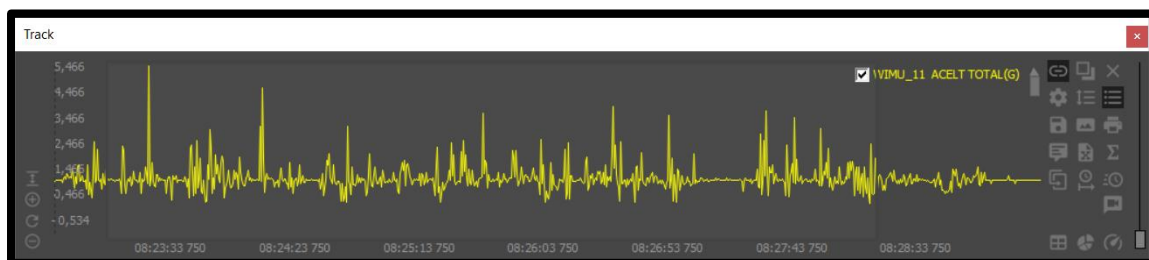
Figure 20: Data collected on direct variables.



Source: Prepared by the authors based on Realtrack Systems, 2019.

As mentioned before, other variables can be obtained using inertial sensors. Figure 21 shows the vector sum of the accelerometer data.

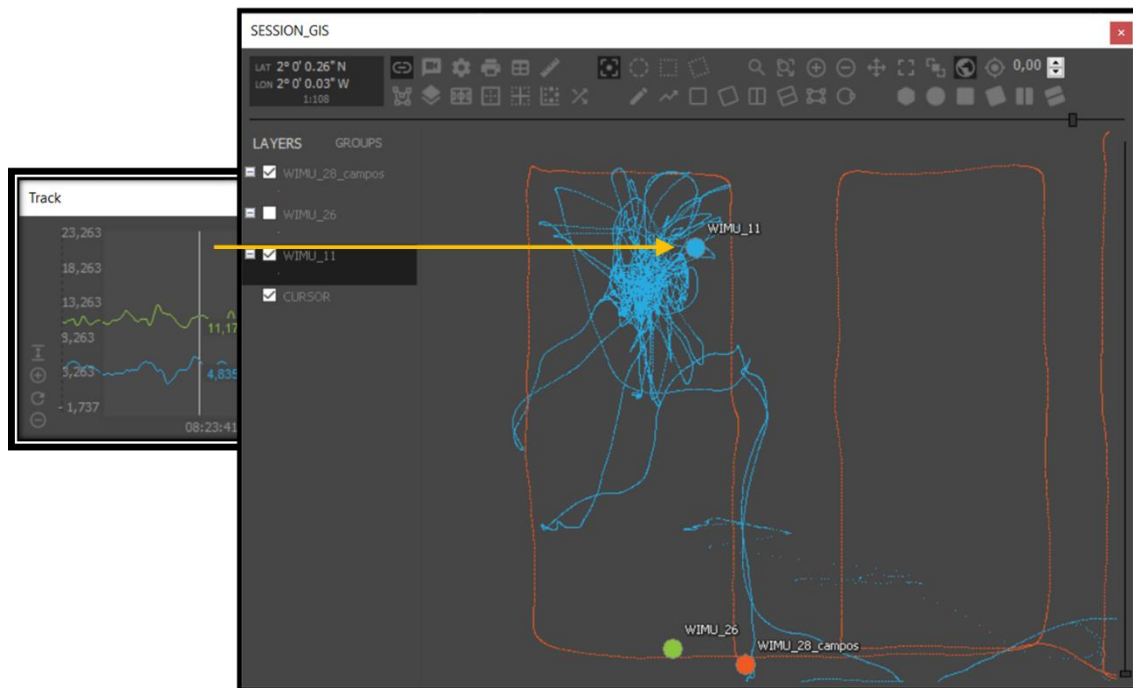
Figure 21: Vector sum of accelerometer data



Source: Prepared by the authors based on Realtrack Systems, 2019.

The positioning data, in other words, the X and Y coordinates can be displayed in space (figure 22).

Figure 22: Positioning data

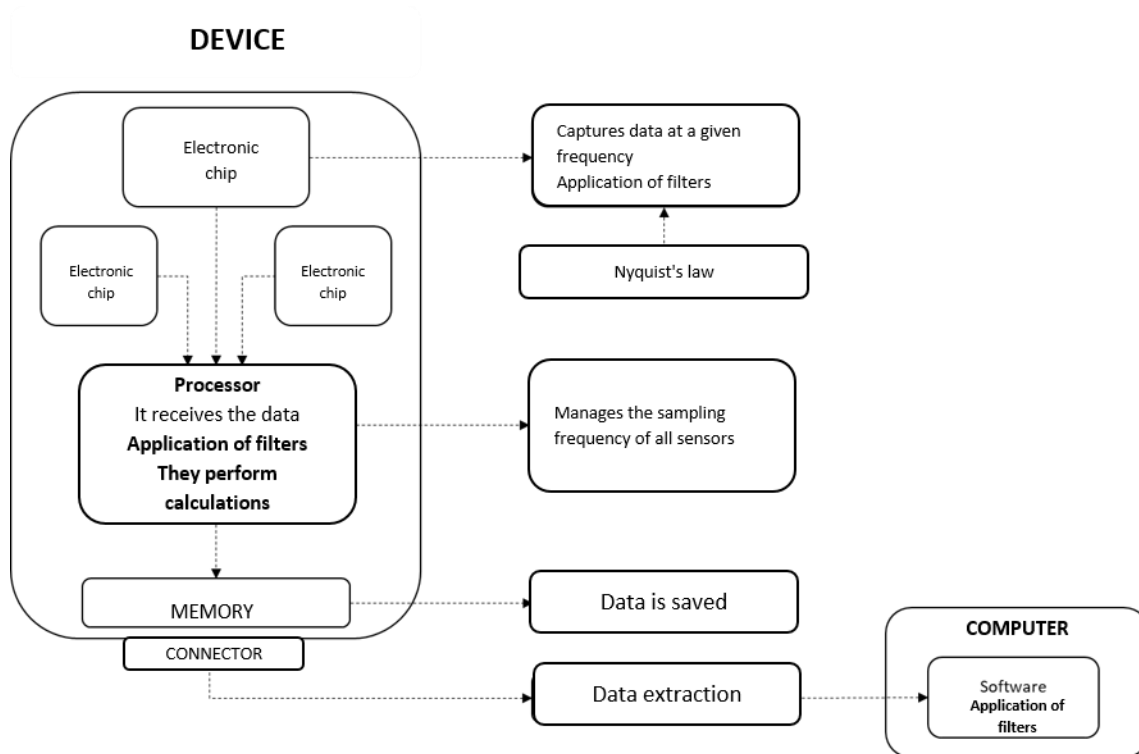


Source: Prepared by the authors based on Realtrack Systems, 2019.

Signal Processing

Figure 23 shows the overall signal capture and processing process.

Figure 23: Different signals



Source: Prepared by the authors

As can be seen, devices used in the sports field have different sensors. Sensor manufacturers include filters for signal processing, thus obtaining information on this. It is important to note that this information is not provided by most companies for purely commercial reasons. This type of sensor is integrated into a plate together with other components, as a general rule, all devices have a microprocessor to manage the integration of all the signals. In consequence, filters are also applied to this microprocessor, in some cases at the same time some kind of calculation is performed. Finally, the data obtained is stored in the memory of the device.

In the next step, the data is downloaded to the computer. Some manufacturers also apply filters in data processing to specific software.

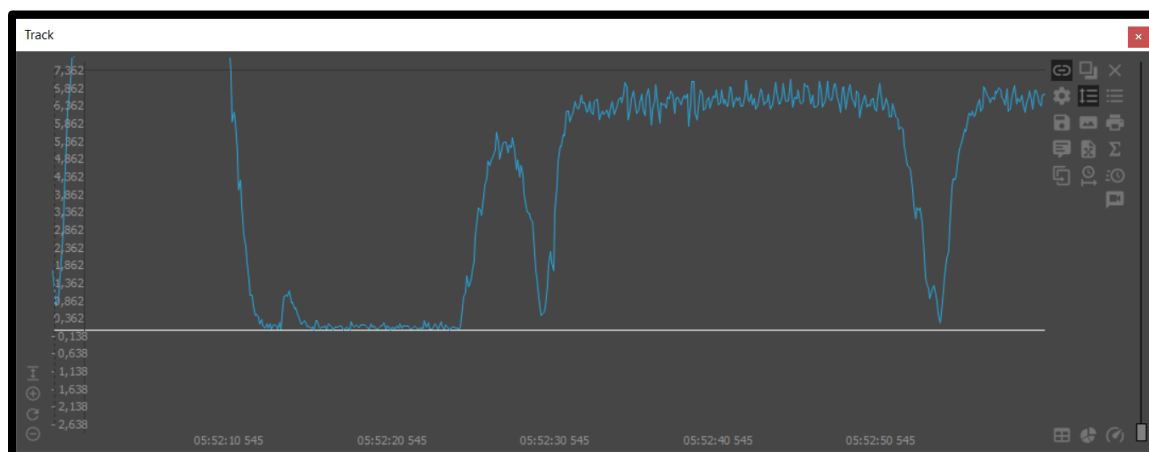
In summary, we can say that from the moment the sensor captures the data until it is displayed on the computer screen, it goes through different phases where undergoes different treatments.

Filter Types

Currently, there are a lot of filters, among the most used are the Chebyshev filter, the Butterworth and the Cauer filter. In addition, it is known that no company reveals the filters it uses. In this sense, the implementation of the filter can lead to a modification of the original signal.

We can mention, for example, the speed data obtained with GNSS technology. Technically the speed may not be zero, but most companies apply filters at different levels so that when the player is not moving the speed is equal to zero. Figure 24 shows the player speed obtained with the GPS sensor, the white line is zero speed. As can be seen at the bottom, although the athlete is immobile the speed is not equal to zero.

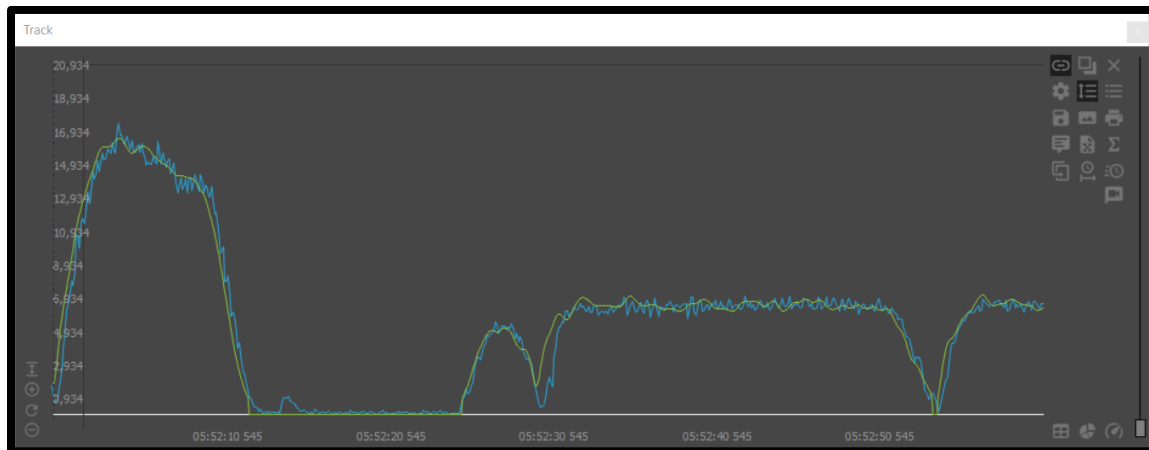
Figure 24: Speed of a player using a GPS sensor



Source: Prepared by the authors based on Realtrack Systems, 2019.

Figure 25 shows overlapped the speed obtained with the LPS system (green line) and the speed obtained with the GPS sensor (blue line). In this case, it can be observed that when the subject is immobile, the speed itself is equal to zero.

Figure 25: Speed obtained by two different systems (LPS and GPS)



Source: Prepared by the authors based on Realtrack Systems, 2019.

On a practical level, these details do not affect data analysis.

To conclude, we can say that filters have been applied when a manufacturer provides the speed RAW data and the values are equal to zero when the individual is immobile.

Variables

Companies that develop these devices offer different possibilities that we will address below.

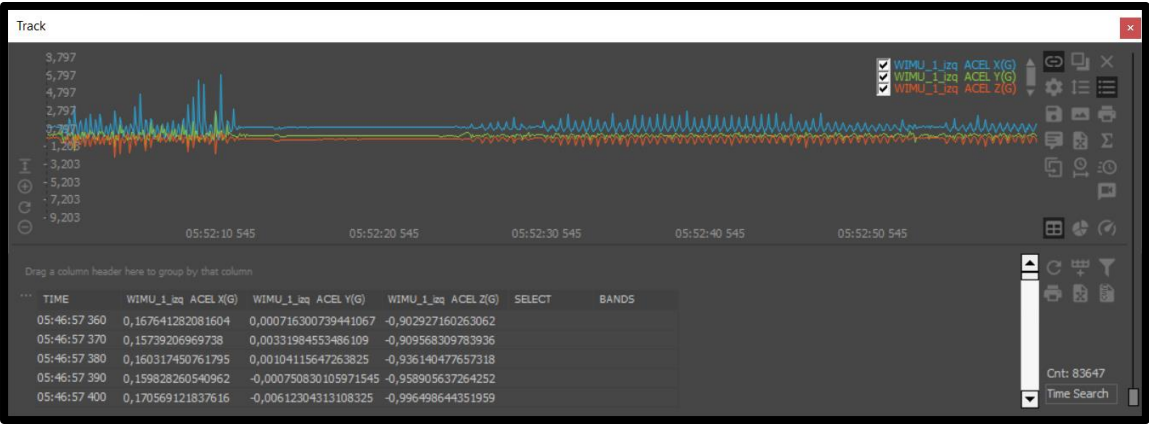
RAW data from sensors

Not all companies that develop the devices offer the raw data of the sensors. Here are the main sensors:

- Acceleration (X, Y, Z) Raw data.
- Gyroscope (X, Y, Z) Raw data.
- Magnetometer (X, Y, Z) Raw data.
- GPS (latitude/longitude, distance, speed).
- LPS (coordinate X, Y, speed, distance).
- Heart rate (beats/min, RR, code).

Figure 26 shows the acceleration sensor data in its three channels.

Figure 26: Acceleration sensor in its three channels.

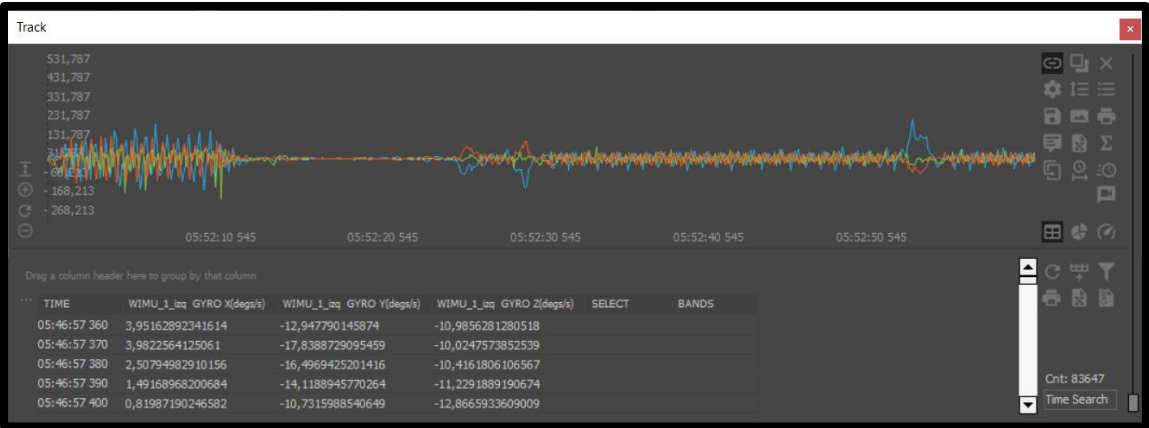


Source: Prepared by the authors based on Realtrack Systems, 2019.

As can be seen, at the bottom there are four columns of data. The first corresponds to time. In this case, it has been recorded at a frequency of 10Hz.

Figure 27 shows the gyroscope data. As in the previous sensor, it has three channels.

Figure 27: Data obtained with a Gyroscope.



Source: Prepared by the authors based on Realtrack Systems, 2019.

The Magnetometer sensor also has three channels, as shown in Figure 28.

Figure 28: Magnetometer sensor and its three channels

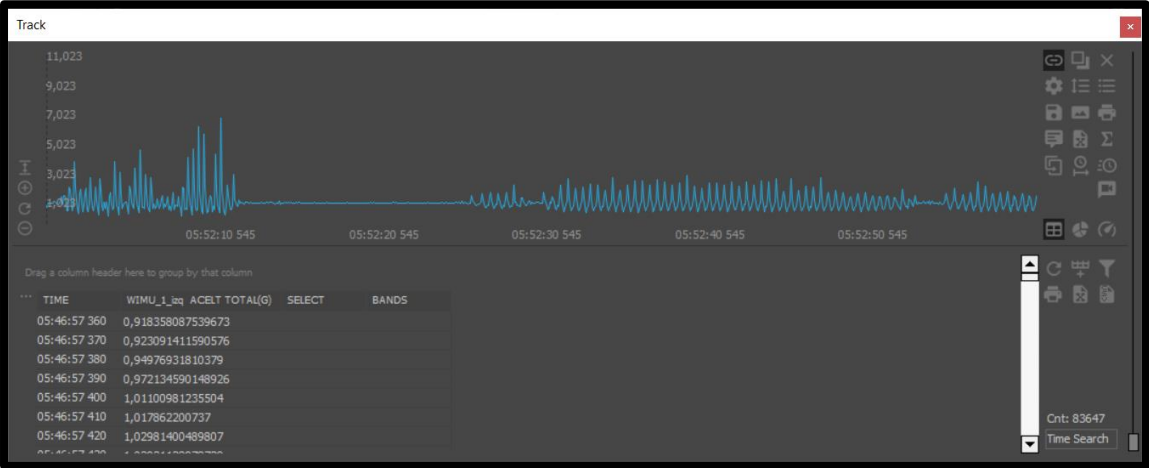


Source: Prepared by the authors based on Realtrack Systems, 2019.

Device-calculated data

In some cases, the microprocessor of the device performs certain calculations, for example, the vector sum of the accelerometer. The resulting vector is shown in figure 29.

Figure 29: Data from the resulting vector



Source: Prepared by the authors based on Realtrack Systems, 2019.

Data calculated in the analysis software

In the vast majority of systems that exist in the market, the data are calculated in specific software. In some cases the software where the calculations are made runs on the computer, while in other cases it runs on the cloud.

There is great heterogeneity in terms of the variables reported, especially in team sports.

Table 5: Distance-related variables

Variable	Definition	Unit
Duration	Duration of the session/drill in format hours:minutes:seconds	hh:mm:ss
Distance	Total travelled distance	m
Explosive Distance	Total travelled distance with an acceleration greater than 1.12 ms ⁻²	m
Explosive Distance/min	Explosive distance per minute	m min ⁻¹
HIBD	Total distance travelled in high-intensity braking with a deceleration greater than 2 ms ⁻²	m
HIBD/min	High-intensity braking distance per minute.	m min ⁻¹
HSR Rel Dis	Short for High-Speed Running Relative. This is the travelled distance at speeds above the player threshold (by default 75.5% of the maximum speed).	m
HSR Rel/min	HSR Relative per minute.	m min ⁻¹
HSR Rel Count:	The number of times (counter) the player has run at a speed above his HSR Rel threshold.	

% HSR Rel	Percentage of travelled distance at speeds above HSR Rel.	%
HSR Abs Dist	Short for High-Speed Running Absolute. It is the distance travelled at speeds above HIA (default 21 km/h).	m
HSR Abs/min	HSR Absolute per minute.	m min ⁻¹
HSR Abs Count	The number of times (counter) the player has run at a speed above the HSR Abs threshold.	
% HSR Abs	Percentage of the travelled distance at speeds above HSR Abs.	%
Zones (m) Rel	Total travelled distance in each relative speed zone (% relative to the maximum speed value of the player).	m
Zones (m) Abs	Total travelled distance in each absolute speed zone.	m
Zones (%) Rel	Percentage of the travelled distance in each relative speed zone (% relative to the maximum speed value of the player).	%

Zones (%) Abs	Percentage of the travelled distance in each absolute speed zone.	%
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Source: Prepared by the authors

Table 6: Acceleration-related variables

Variable	Definition	Unit
Duration	Duration of the session/drill in hours:minutes:seconds format	hh:mm:ss
Accelerations	The number of accelerations	acc
Decelerations	The number of decelerations	dec
Acc/min	The number of accelerations per minute.	acc·min ⁻¹
Dec/min	The number of decelerations per minute.	dec·min ⁻¹
Max Acc	Maximum acceleration achieved.	m s ⁻²
Max Dec	Maximum deceleration achieved.	m s ⁻²
Avg Acc	The average value of the number of accelerations.	m s ⁻²
Avg Dec	The average value of the number of decelerations.	m s ⁻²
Diff. Acc/Dec:	Difference between accelerations and decelerations with a value greater than 3 ms ⁻²	
Distance Acc	Total travelled distance in acceleration.	m
Distance Dec	Total travelled distance in deceleration.	m
Zones Acc Abs	The number (counter) of accelerations/decelerations in each defined area of absolute acceleration.	
Zones Acc Rel	The number (counter) of accelerations/decelerations in each defined zone of relative acceleration (relative to the player's maximum acceleration value).	
Zones Acc Abs/minute	The number (counter) of accelerations/decelerations per minute in each defined area of absolute acceleration.	min ⁻¹
Zones Acc Rel/minute	The number (counter) of accelerations/decelerations per minute in each defined zone of relative acceleration.	min ⁻¹
Zones Acc Abs (%)	Percentage of the number of accelerations/decelerations in each defined area of absolute acceleration.	%

Zones Acc Rel (%)	Percentage of the number of accelerations/decelerations in each defined area of relative acceleration.	%
Zones Acc Abs (m)	Travelled distance for each defined area of absolute acceleration/deceleration.	m
Zones Acc Rel (m)	Distance travelled for each defined area of relative acceleration/deceleration (relative to the player's maximum acceleration value).	m

Source: Prepared by the authors

Table 7: Variables related to sprints

Variable	Definition	Unit
Duration	Duration of the sessions/drill in hours:minutes:seconds format	hh:mm:ss
Sprint Abs (m)	Travelled distance above the absolute sprint speed threshold (default: 24 km/h).	m
Sprints Rel (m)	Travelled distance above the relative speed threshold of a sprint (by default, 95% of the player's maximum speed).	m
Sprint Abs	The number of sprints above the sprint absolute speed threshold.	
Sprint Abs Avg Dur	The average duration of absolute sprints.	s
Sprints Rel	The number of sprints above the sprint relative speed threshold.	
Sprint Rel Avg Dur	The average duration of the relative sprints.	s
Max Speed	Maximum speed attained	km h ⁻¹
Avg Speed	Value of the average speed.	km h ⁻¹
Min/Sprints	The number of minutes per sprint.	min

Source: Prepared by the authors

Table 8: Heart rate related variables

Variable	Definition	Unit
HR duration	Effective time duration in which there has been a signal of the HR strap.	hh:mm:ss
Max HR	The maximum heart rate value reached.	ppm
Avg HR	The average heart rate value reached	ppm
Relative HR %	Percentage of the heart rate average value regarding the maximum heart rate.	%
Zones (%):	Percentage of time in each heart rate zone.	%

Source: Prepared by the authors

Table 9: Load-related variables

Variable	Definition	Unit
Duration	Duration of the sessions/drill in hours:minutes:seconds format	hh:mm:ss
Player Load:	Value of the player load of the session index. This index is calculated as follows: $Player\ Load = \sqrt{\frac{(a_y - a_{y-1}) + (a_x - a_{x-1}) + (a_z - a_{z-1})}{100}}$ Where ax is the anterior-posterior acceleration, ay is the medial-lateral acceleration, and az is the vertical acceleration.	
Player Load/min	Value of the player load index per minute.	min ⁻¹
Power Met	Developed metabolic power. It is the metabolic cost per kilogram and per second.	W kg ⁻¹
Power Met Avg	The average value of metabolic power.	W kg ⁻¹
Power Met/min	Metabolic power value per minute.	W min ⁻¹ kg ⁻¹
EDI Max	Value of the EDI index, which represents the distance a player would have travelled at a stable speed on grass (e.g., football), using the total energy spent during the match, divided by the total distance travelled.	
EDI/min	EDI developed per minute	min ⁻¹

HMLD	Abbreviation for High Metabolic Load Distance. It is the distance travelled by a player when his metabolic power is above 25.5 W kg ⁻¹	m
HML cnt	Number of times (counter) the player has been with a metabolic power greater than 25.5 W kg ⁻¹	
HML/min	Value of HMLD per minute.	m min ⁻¹
Energy Expenditure	Total energy expenditure associated with activities that include accelerations or decelerations. It is based on the activity level and is scaled based on the player's weight (configured in his profile).	kcal
Energy Expenditure/min	Energy expenditure per minute.	kcal min ⁻¹
DSL	Abbreviation for Dynamic Stress Load. The number of impacts weighted above 2G.	
DSL/min	Value of DSL per minute.	min ⁻¹
TRIMPS BANISTER	TRIMPS value calculated using the Banister formula.	
TRIMPS EDWARDS	TRIMPS value calculated using the Edwards formula.	
Zones (m) HMLD	Distance travelled in each zone of defined Metabolic Power.	m
Zones (nº) HMLD	The number of times the player accesses each Metabolic Power zone.	

Source: Prepared by the authors

These variables are reported by the software SPRO, of the company Realtrack Systems S.L.

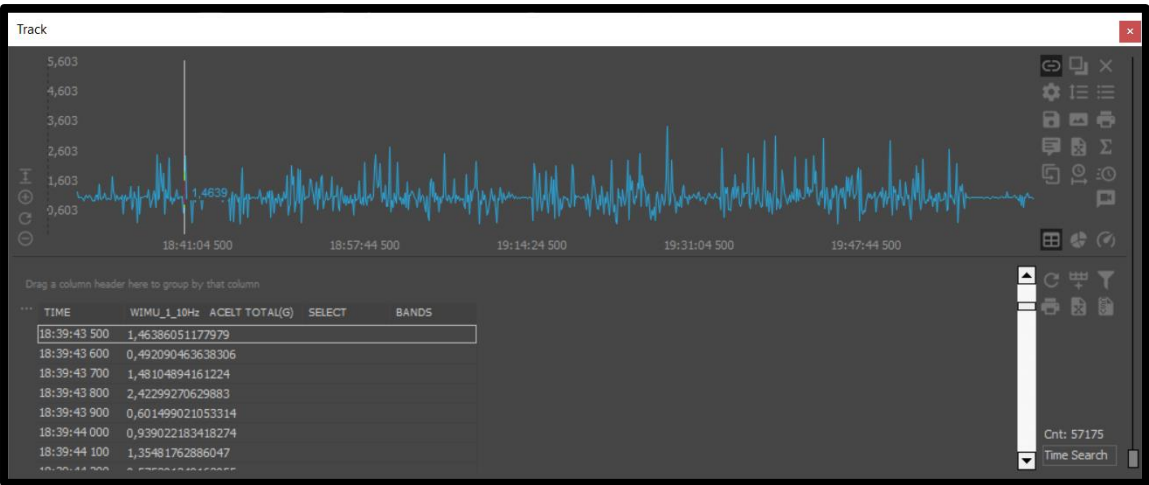
Most variables are obtained from positioning over time. Others are obtained from the inertial sensors that integrate these devices. Below are some variables calculated from the inertial sensors:

- Accelerometer. Load indicator. Player load.
- Total impact counter and zones classification.
- Jump counter and zones classification based on take-off and landing.
- Step counter.
- Monopodal postural stability
- FFT.
- Player load.
- Dynamic load of stress.

Another important aspect worth mentioning in relation to the variables is the frequency of sampling of the sensor and the frequency of sampling of the device.

The vector sum of the accelerometer is shown in Figure 30. This sensor records at 1000 Hz, but the capture frequency of the device was 10Hz.

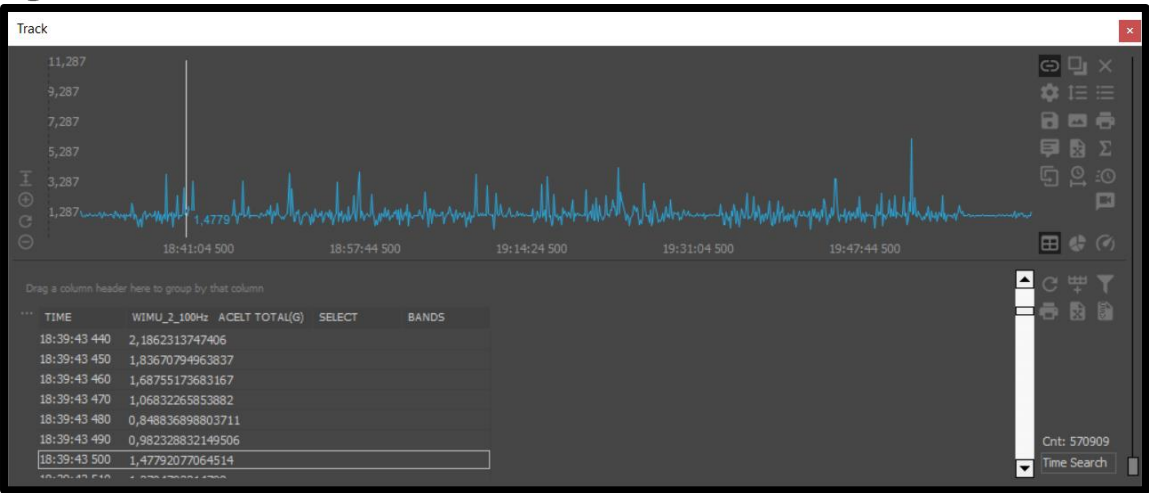
Figure 30: Sample vector sum of accelerometer



Source: Prepared by the authors based on Realtrack Systems, 2019.

Figure 31 shows the registration at 100 Hz.

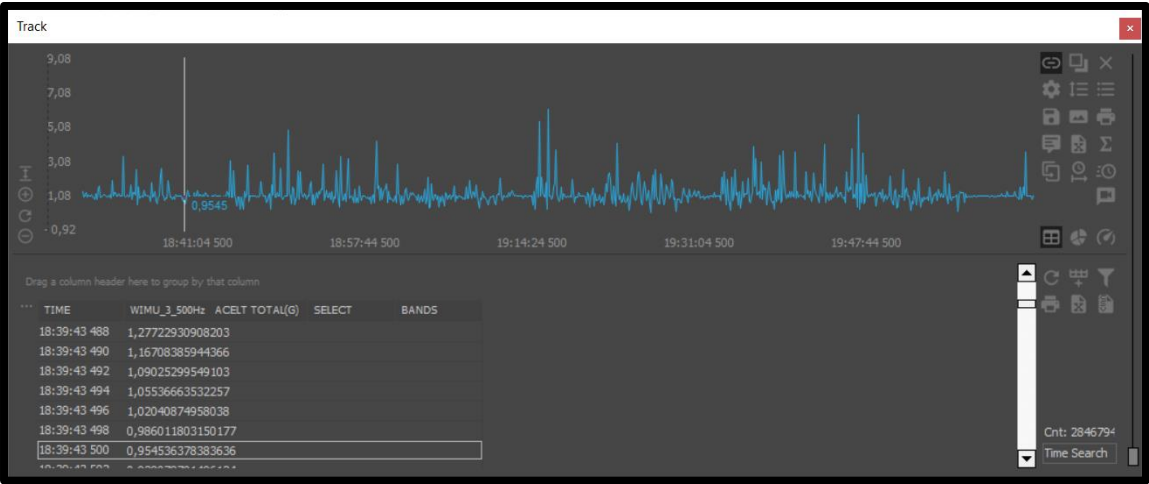
Figure 31: Vector sum at 100 Hz



Source: Prepared by the authors based on Realtrack Systems, 2019.

Figure 32 shows the registration at 500 Hz.

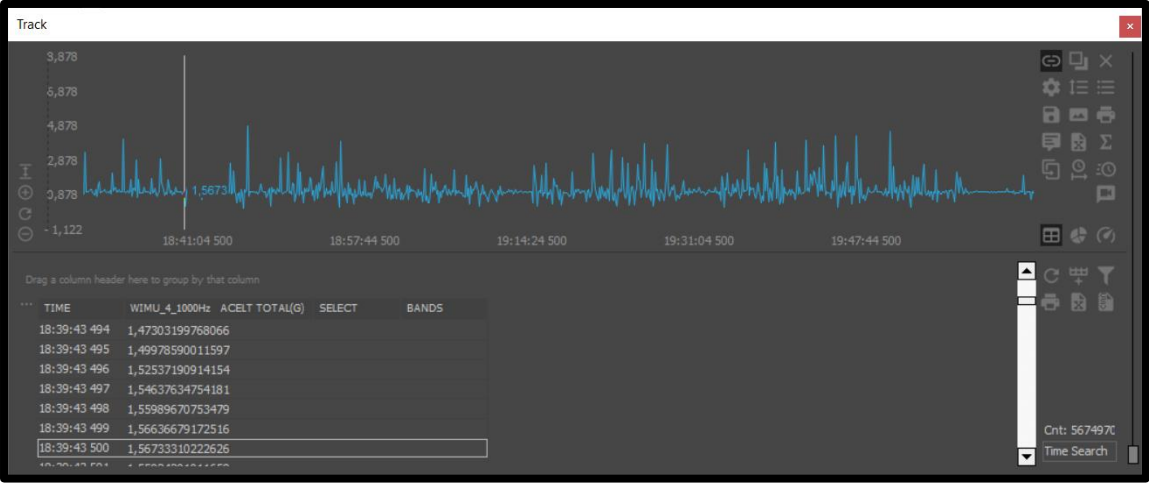
Figure 32: Registration at 500 Hz.



Source: Prepared by the authors based on Realtrack Systems, 2019.

Figure 33 shows the same variable, but the sampling frequency was 1000 Hz.

Figure 33: Sampling frequency 1000 Hz



Source: Prepared by the authors based on Realtrack Systems, 2019.

Finally, Figure 34 shows the four records, namely 10Hz, 100Hz, 500Hz and 1000Hz. As can be seen in the right-hand column, the accelerometer registers at 1000 Hz and the sampling frequency of the device is also 1000 Hz, every millisecond data is recorded.

Figure 34: Records at 10 Hz, 100 Hz, 500 Hz, and 1000 Hz



Source: Prepared by the authors based on Realtrack Systems, 2019.

Viewing of variables

One aspect that arouses great interest is the viewing of variables. In the field of football, the World Cup held in Russia in 2018 was the beginning of the use of technology during the competition, as well as the use of data, although only on a verbal level. After the World Cup, real-time viewing of the data is also allowed.

Real-time

For real-time viewing there are different technical issues to consider:

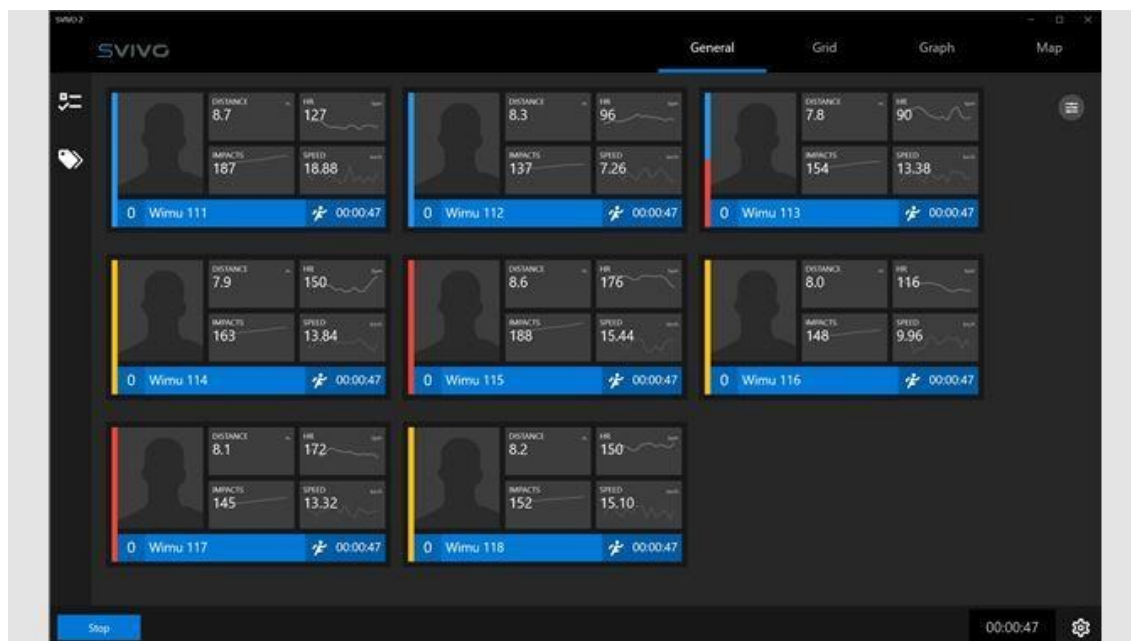
1. There are variables that are direct, such as heart rate. The strap that players wear captures this data and sends it through the device to a peripheral (for example, a computer). In addition to heart rate will be included speed, distance, etc.
2. There are other variables, for example, the load indicator Player load. This indicator is a calculated variable. There are different possibilities, these are:
 - a. Perform the calculation on the device and send the result (few companies perform this action because it requires incorporating powerful microprocessors into the device).
 - b. Send the data to the receiver (computer) so that the latter, using a software, performs the corresponding calculations.

Regarding how the information is delivered, there are different options:

- Wireless technology like Bluetooth, Ant+, Wifi.
- Create a system based on a telecommunication standard in the sports facility.

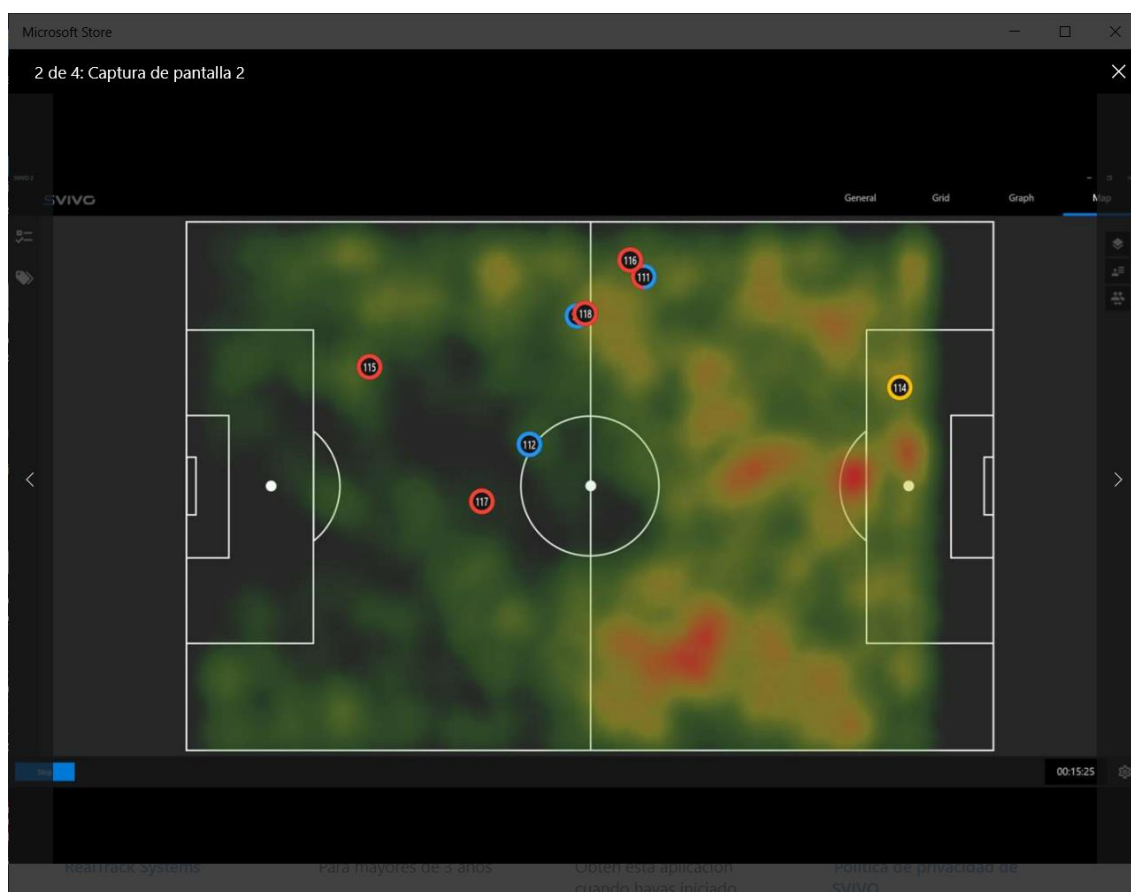
The information is displayed on laptop computers or tablets (Figures 35 and 36).

Figure 35: Information displayed on a laptop.



Source: Prepared by the authors based on Realtrack Systems, 2019.

Figure 36: Information taken from tablets



Source: Prepared by the authors based on Realtrack Systems, 2019.

Post-process

The analysis of post-process information is complex. Companies have adopted different techniques:

- Computer: perform the calculations on the computer using specific software.
- Cloud: perform calculations on a server, so there is no data locally.
- Computer + Cloud: a combination of the two above.

Data or algorithms

In the field of sport, it is very common to use software to carry out different actions. Such a process requires the development of software and its implementation.

The phases in the development of a program are as follows:

1. To analyze the problem is to know exactly what it is and what results you want to obtain.
2. Planning the solution of the problem, if complicated, dividing it into a sequence of simpler stages. This phase is carried out ON PAPER, establishing as clearly as possible the purpose of each step, the data that is needed for input, the data that will produce in the output the algorithms.
3. Editing the source code, that is, writing it using a simple text editor (without formatting) and a programming language. Source programs will be stored in text files, usually on the computer's hard drive.
4. Compiling and running the program into machine language.
5. Correcting program errors. Errors will be corrected in the source code, repeating steps 3 and 4 as many times as necessary. If there are errors in the logic of the program, that is, if the program "works" but produces incorrect results, you have to modify the algorithm back to step 2. These errors are the most difficult to detect.
6. Documentation. Once the program is working properly, it is advisable to review the source code to sort them, eliminate unnecessary calculations and include the necessary comment lines, which should normally include brief explanations at the beginning of the code on the purpose of the program and its input and output arguments.

In figure 37, input, processing, and output are shown schematically.

Algorithms

A computer is able to perform "alone" only a few simple actions, such as adding, comparing, or transferring data, but the problems that are normally in the interest of solving are more complex to solve. In order to solve a real problem, it is first necessary to find a method of resolution and then to determine the succession of simple actions (capable of being executed by a computer) in which the method is decomposed. Not all problem-solving methods can be put into practice on a computer. For a procedure to be implemented on a computer it must be:

- Precise: be composed of well-defined (unambiguous) and ordered steps.
- Definite: if you follow it twice, you get the same result each time.
- Finite: have a finite number of steps. (unpublished, recovered from 2009, <http://alojamientos.us.es/edan/php/asig/LICFIS/LFIPC/Tema5FISPC0809.pdf>)

A procedure or method to solve a problem that meets the above requirements is said to be an algorithm.

An algorithm is a method to solve a problem through a sequence of well-defined, ordered and finite steps.

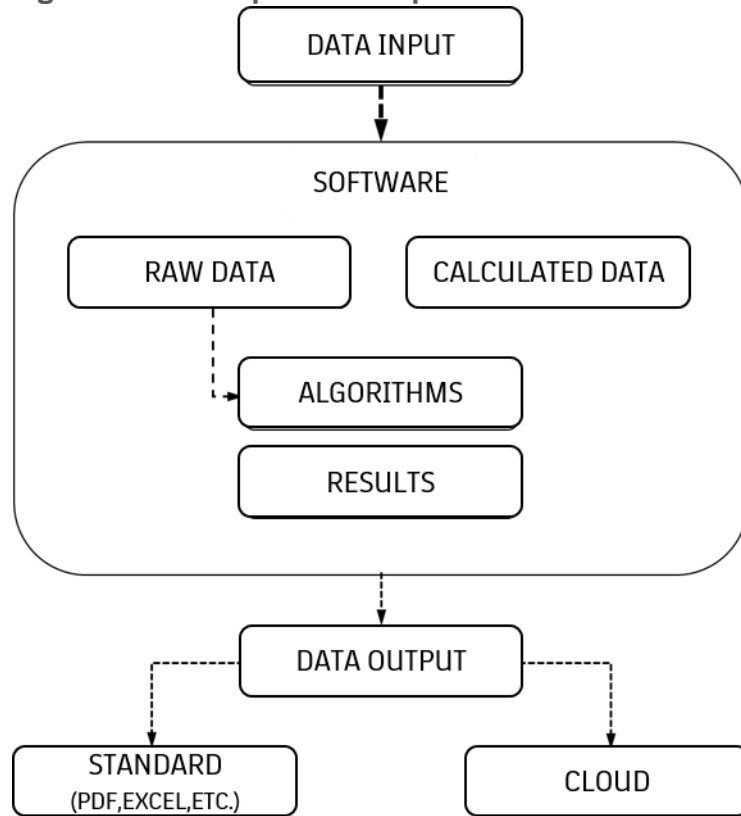
For the algorithm to be executed, it is also necessary to have the appropriate tools available to carry out each of the steps. If this is not the case, they must, in turn, be decomposed into a sequence (algorithm) of simpler steps that can be carried out.

A computer program is a collection of instructions that describes an algorithm, written in such a way that it can be understood by the computer.

In an algorithm, and therefore in a program, the following actions are distinguished:

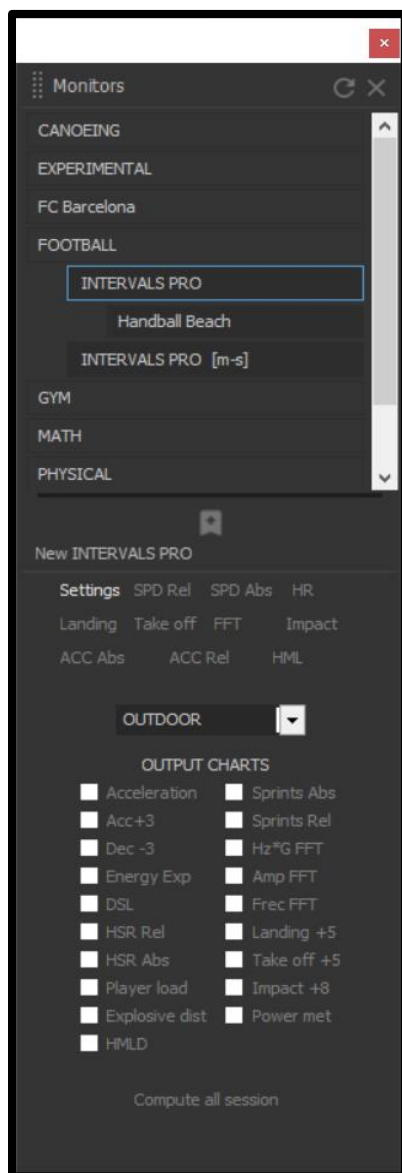
- Input: it is the starting information that the algorithm needs to boot.
- Process: is the set of all operations to be performed. (unpublished, recovered from, 2009, <http://alojamientos.us.es/edan/php/asig/LICFIS/LFIPC/Tema5FISPC0809.pdf>)

Figure 37: Data input and output



Source: Prepared by the authors

Figura 38: Intervals



Source: Prepared by the authors based on Realtrack Systems, 2019.

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