Discussion on UWB Technology and Its Applicability in Different Fields

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Abstract—**This paper discusses the evolution of UWB technology, its applicability in a multitude of both civilian and military fields. To exemplify it, it is presented the realization of a data transmission system on the UWB platform, using UWB type sensors and classical detection methods. The connection between the way transient signals work and the way information is extracted using secure and efficient methods is not unequivocal. Communications have evolved steadily over the last decade. The study of various methods and research, benchmarked by new technologies, has progressively increased the complexity of communications and data transmission from a sender to a receiver**.

Index Terms—**detection curve, methods, pulses, transformed, wireless.**

I. Introduction

In the field of research, it is useful to obtain approximately the same results for exactly the same process, in order to best characterize the studied process. Wireless communications have evolved substantially in the last 20 years. It is expected that in the coming years there will be an explosive growth of wireless communications and continue in the future, due to the demand for wireless services of all kinds. The new generations of wireless radio systems aim to offer flexibility in data transmission and a wide variety of applications for mobile phone users. More and more devices will work with wireless technology, but at the same time it will face spectral congestion and the coexistence of wireless devices will be a major problem. UWB (Ultra WideBand) technology was not neglected and was first studied and used in the military field and then applied and implemented in various forms in civilian companies. The main novelty and defining feature of UWB transmissions is that it can coexist in the same spectrum with other applications (mobile phone systems, GPS location systems, etc.) without causing interference [2]. Under these conditions, this system has large openings for local area networks (LAN), personal networks (PAN) with high transfer rates, low consumption sensors, location and positioning devices. In other words, another field of activity in which this work can be used is the military field.

The high potential of UWB allows the possibility of low complexity and lowcost communications. The dominant method for current wireless communications is based on sine waves. Sine electromagnetic waves have become so universal in radio communications that most do not know that the first communication systems were based on pulses [3].

II. Theoretical Aspects

Putting it differently, these extremely short pulses with fast rising and falling front times and have a very wide spectrum and very low energy content. Because they are extremely short, UWB pulses can be filtered or ignored. They can be easily distinguished from unwanted multi-way reflections due to evolution over time. This leads to the characteristic of immunity and the propagation in multiple ways. The low frequency components of UWB pulses make it possible to propagate through materials such as cement, brick or earth. The high bandwidth of UWB systems means that extremely high data rates can be achieved, which results in UWB systems having a high spectral capacity [3].

The key advantages of UWB can be summarized in the following main ideas:

1. High data speed
2. Low equipment cost
3. Immunity to multiple pathways
4. Determining the distance but also communication at the same time.

This UWB technology is completely different from conventional narrowband wireless technology because UWB scatters the signal in a wide frequency band, and the narrowband one broadcasts on different frequencies. Pulse trains of hundreds of millions of pulses per second take the place of typical sine waves [4].

UWB transmitters and receivers do not require expensive or large components such as modulators, demodulators or FI (intermediate frequency) stages. This can reduce the cost, size, weight and power consumption of UWB systems compared to conventional narrowband communication systems [5].

We can highlight the power spectral density of UWB systems that is generally considered to be very low. Power density (DSP) is defined as:

$$DSP = \frac{P}{D}\ \left[W/Hz\right], \tag{1}$$

where P is the transmitted power $[W]$, and D is the bandwidth of the signal $[Hz]$ [5]. Thus, frequency and time are inversely proportional, the sinusoidal communication systems have narrow D band and long t duration, and for UWB systems the pulses have short t duration and very long B band.

To exemplify the applicability of UWB technology, a data transmission system on the UWB platform will be described. In other words, a communications system will be presented that will determine and locate in the 3D space the position of a target, subsequently the information being provided to the user through a graphical interface.

Transient signals will be emitted to the alleged target, positioned in the direction of the alleged attacker. They will hit it and will be reflected towards the receiver thus determining its coordinates in the 3D space as can be seen in Fig. 1.

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Digital Object Identifier 10.32754/JMT.2021.1.05

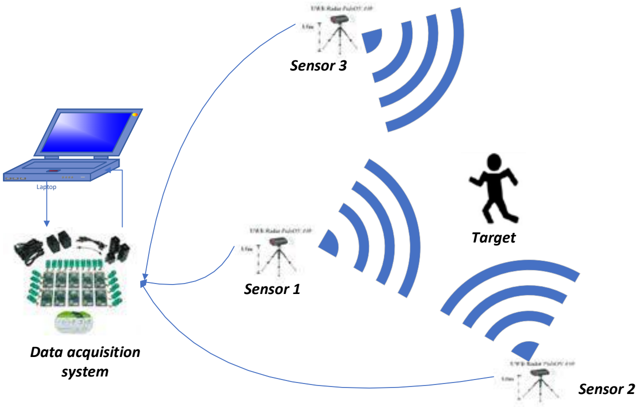

Figure 1. Block Diagram

Within the realization of this system, algorithms will be implemented for processing the signals received by the sensors, so as to determine the time in which the signal travels the distance from the target to the receiver. This will determine the distance from the sensors to the target. These values received by the sensors will be entered in the detection algorithms implemented and then we will determine the location of the source. These algorithms use traditional detection methods such as Correlation, Wavelet Transform, Recurrence Plot Analysis method. Based on them, the accuracy and precision of the implementations will be compared in order to choose the optimal method.

III. Methods Used

The most important question, however, remains: which methods are more effective?

A. *The correlation method*

The optimal reception technique, the most used in UWB, is the correlation. The correlation represents the degree of similarity between two or more signals taking into account no gap. This is also the relationship between two or more phenomena. The correlation method includes both autocorrelation and cross-correlation [7].

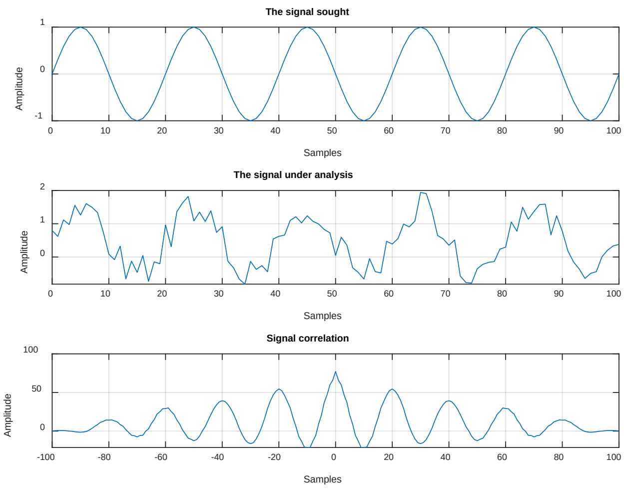

Figure 2. Correlation

To express the correlation function, we consider two real signals, discrete $x[k]$ and $z[k]$, its equation being the following:

$$y[k]=\sum_{k=0}^{M-1} x[k]z[n+k-(M-1)], \quad (2)$$

where M represents the number of signal samples, $x[k]$ represents the signal shape, and $z[n]$ represents the signal under analysis.

As a result of the equation, the correlation is the sum of the products between the samples of the signal under analysis and the delayed samples of the sought waveform, having a maximum when they most closely resemble, in other words, if they overlap perfectly.

B. *Wavelet Transform*

Most of the signals studied so far can be represented in the time domain. Detailed information about time signals can be obtained by applying signal analysis; in other words signals are transformed using an analysis function.

The Fourier transform is one of the best methods of analyzing a time signal due to its frequency content. This method of the wavelet transform has several major advantages over the Fourier transform, which makes it an interesting and effective alternative for many applications [8].

The Fourier transform breaks down a signal into basic orthogonal trigonometric functions. This transform of a continuous signal is defined in (3). The transformed signal provides a global distribution of the time signal frequency. The signal can be reconstructed using the inverse Fourier transform (4) [9]

$$X_{FT}(f)=\int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt \quad (3)$$

$$x(t)=\int_{-\infty}^{\infty} X_{FT}(f)e^{j2\pi ft}df \quad (4)$$

Using these equations, signal $x(t)$ can be transformed into the frequency domain and returning to the time domain very quickly. Transformation and reconstruction by the Fourier transform are possible if the Dirichlet conditions are met. [8]

The Wavelet transform is similar to the Fourier transform. While the Fourier transform breaks down the signal into sines and cosines, the Wavelet transform uses waveforms to analyze both frequency and temporal components.

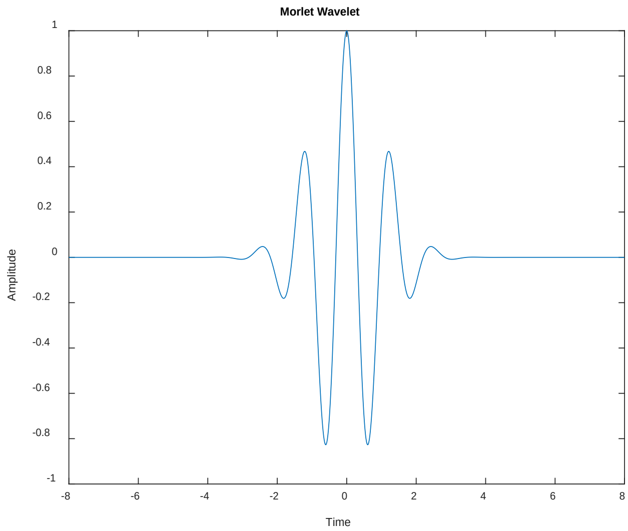

Figure 3. Morlet Wavelet

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Using FT or STFT to analyze a non-stationary signal is not always the most efficient method. Satisfactory results can be obtained using Wavelet analysis. The advantage of wave analysis is the ability to perform local analyzes on the signal. It is able to represent aspects of the signal, such as breakdown points, interruptions, aspects that after the use of FT or STFT are not achievable. The capacities of this transform depend on the size of the chosen time interval, because the narrow time interval can provide a significantly better temporal accuracy, but in this way, the problem of time-frequency resolution caused by Heissenberg's uncertainty principle will arise [9].

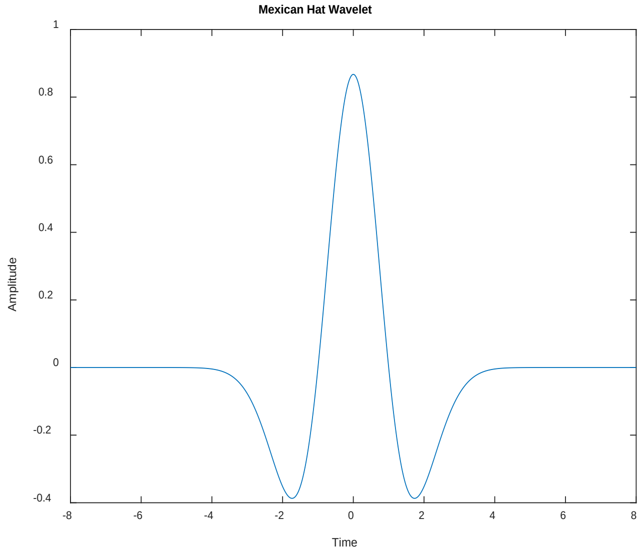

Figure 4. Mexican Hat Wavelet

C. *Recurrence Plot Analysis*

In order to deepen and understand in detail what an analysis of recurrences is, we must first explain what a series of time means. A time series represents a set of values from the development of a certain phenomenon, for example temperature, water level of a lake, flow rate of a river, made at equidistant moments of time, ordered chronologically according to their reception. Two aspects can be defined in order to study time series: their analysis and modeling. The purpose of the analysis is to highlight the properties of a time series and to characterize its features. This analysis can be performed in either the time domain or the frequency domain. In the time domain the temporal properties are emphasized, and in the frequency domain we refer to the spectral properties. In other words, the two forms of analysis are complementary, because the same information is processed in different ways, thus leading to a better analysis of the time series and a better vision of the evolution of the studied phenomenon.

The graphical representation of the time series can be seen in relation to Fig. 5. This representation does not give us much information about the process that generated the time series. However, in Fig. 6 we represented pairs of data in the form of points in the Cartesian plane. The result being unexpected, approaching the shape of a parabola, gives us the idea that time series samples can hide certain information that does not seem to be highlighted in the time domain.

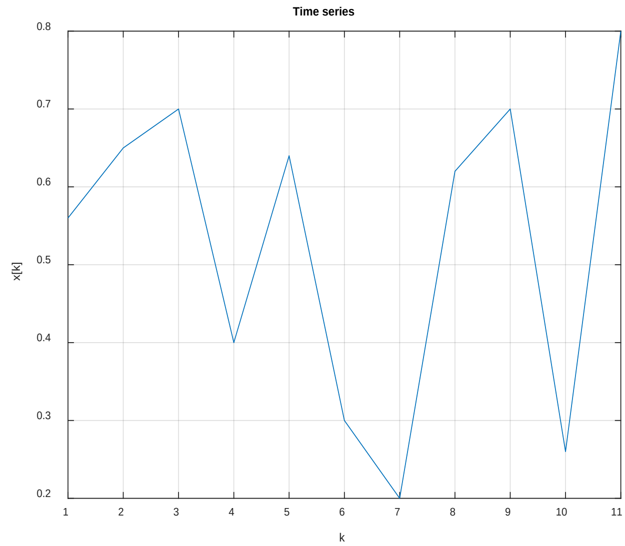

Figure 5. Time series - representation of values according to the time series time index

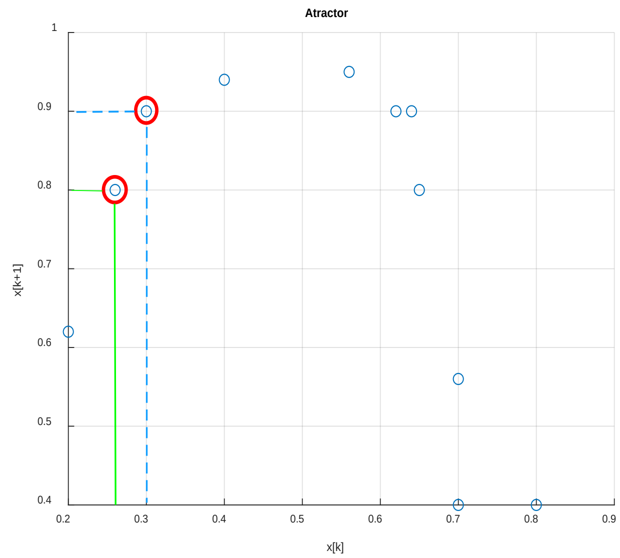

Figure 6. Time series - representation of values according to previous values

The choice and representation of the time series values according to its delayed values is called phase portrait, and can be considered the successive representation of the states of the time series generating process in the phase plan, a representation also called attractor.

IV. Results and Discussion

A. *Correlation*

It is known that the correlation method is an ideal method for both noise-free and noise-affected signals. Following the simulations performed and the analysis on the signals of interest, it was found that this method offers very good results even for SNR values of 8 *dB*, providing the same coordinates as those obtained in the ideal case.

This method has advantages and disadvantages, as an advantage can be mentioned the low computing power, being a fast method of obtaining the signal source, and as a disadvantage is represented by the fact that this method requires knowledge of the main characteristics of the waveform such as sampling frequency, signal shape, type of modulation used.

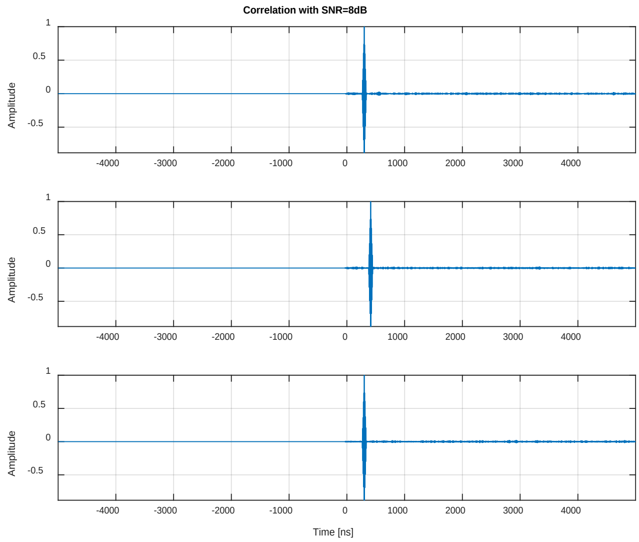

Figure 7. Synthetic correlation

B. Wavelet Transform

Following the application of the discrete Wavelet transform on the signals received by the three sensors, the results obtained will be analyzed. To achieve this, the “modwt” function was used, which returns the wavelet coefficients of the analyzed signal calculated at different decomposition levels. This function needs the following input parameters in order to be used: the signal of interest, the wavelet used for its analysis and the number of decomposition levels.

There are currently a multitude of types of wavelet classes: Coiflet, Meyer, Shannon, Mexican Hat, Morlet. For such analyzes, this class must be chosen carefully. Therefore, these simulations compare the results obtained using the following wavelets: Haar - “haar”, Daubechies - “db4” and Fejer-Korovkin - “fk4”, and at the end of the analysis to choose the most satisfactory results by one of the three classes.

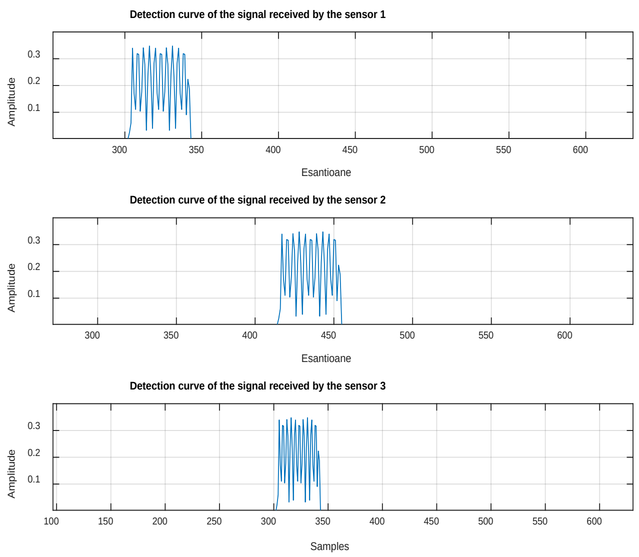

Figure 8. Synthetic Wavelet

C. Recurrence Plot Analysis

This matrix of distances is a quadratic matrix, symmetrical to the main diagonal, being a way of representing the distances between all pairs of points in the state vector, providing a two-dimensional representation.

This matrix was made using two functions provided by the Matlab programming environment, pdist and square form, the first returning the distances between all pairs of points present in the given vector as input parameter, the norm used being Euclidean and the second function realizes the matrix of distances.

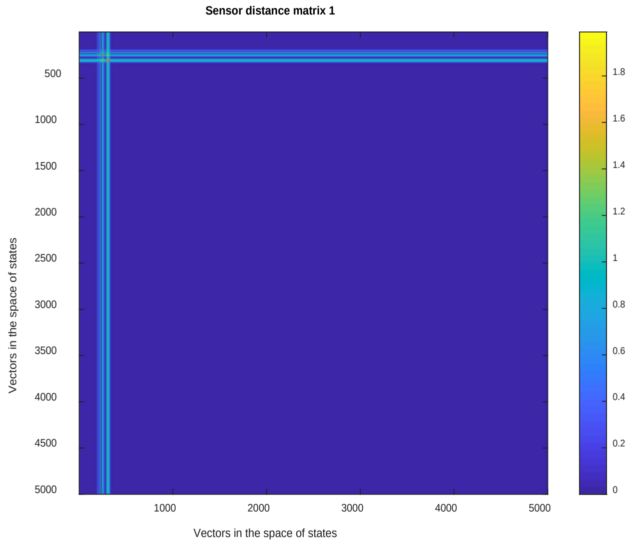

Figure 9. Synthetic Recurrence Plot Analysis

Following the application of the algorithms, the target coordinates were calculated according to each level of the SNR. We can see that in each simulation the errors were a few cm, the correlation method being the most resistant to variations in noise level. This is due to the fact that the desired waveform is known.

In other words, we can say that the methods based on Recurrence Analysis and Wavelet Transform, are very close, determining values of delays, represented in samples, almost identical. Even if these methods generate larger errors in the simulations, they have a major advantage over the correlation-based method, that they do not require knowledge of the input signal parameters analyzed.

These errors, in the case of the three methods, can be based on the presence of noise but also on the thresholds chosen in the detection curves. All these things can amplify the errors accumulated by the algorithms, such as in the case of recurrences the empirical choice of the encapsulation size.

D. Results system

In the following we will analyze the capabilities of the algorithms previously implemented for the detection and location of a target in the real case. To ensure that we have a functional system we will position the three items of equipment at 50 *cm* from the origin of the system on the three axes, considering the origin of the system in (0,0,0).

Before starting the real simulations, we can discuss the concept of Time of Arrival (TOA). It is a method of locating a target, one of the fastest and least expensive methods, in terms of the processing power of the operations to be performed to determine the target. We can say that this method laid the theoretical foundations, after which the first location systems were developed.

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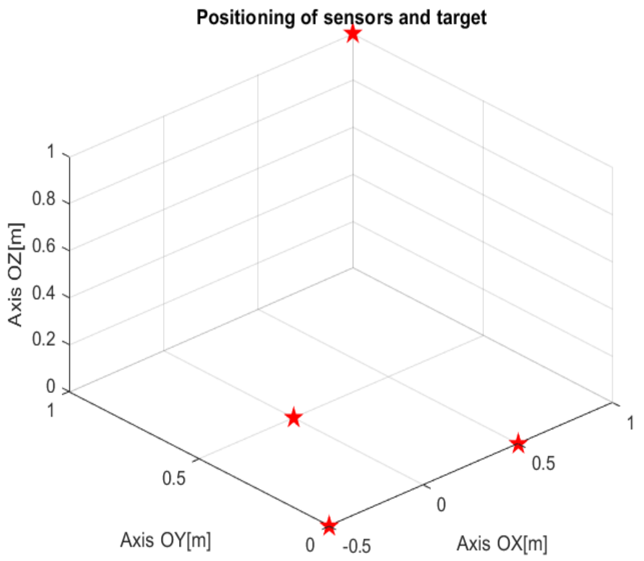

Figure 10. Detection System

Given that the PulsON P440 module has a standard graphical interface, to facilitate the availability and ease of operation, a suggestive graphical interface has been created in the Matlab programming environment, with which any user can operate with it.

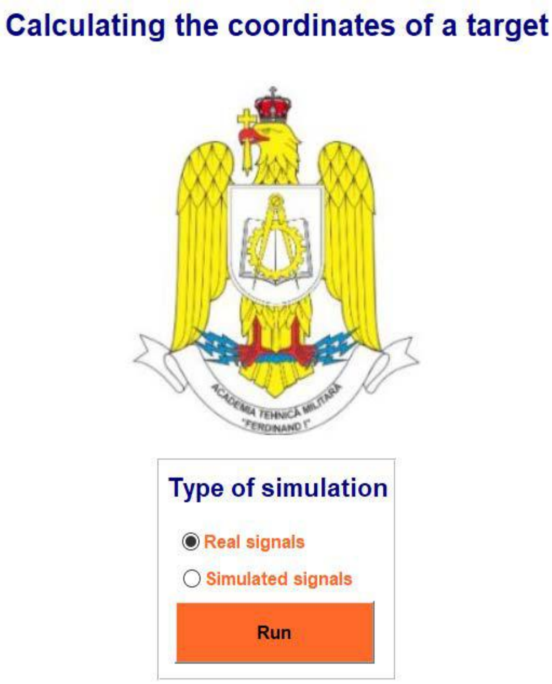

Figure 11. Graphic Interface-Start

Fig. 11 shows the home page of the graphical interface created for the algorithms that will run later. As you can see it consists of two buttons suggestively titled. In the case of the "Real signals" button, you can view the reception of signals from PulsON P440 sensors and their processing in order to obtain the coordinates of the moving target. By using the "Simulated Signals" button, simulations of synthetic signals can be performed, with the help of which the algorithms described above are developed and the attempt to be as optimal as possible for the real case.

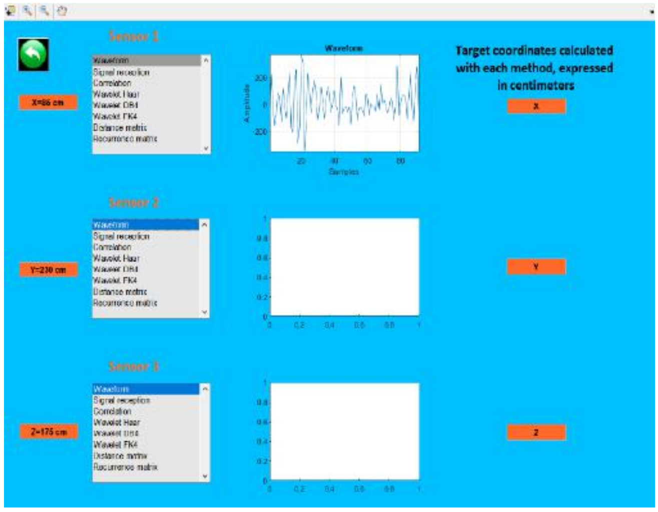

Figure 12. Real signals simulation

Fig. 12 shows the first part of the interface, where the real signals are present, those received by the PulsON P440 sensors. By selecting each detection method from each sensor, in the middle of the interface, the graphs resulting from the application of the method will be displayed, and on the right side of the interface will be displayed simultaneously with the selection of the detection method and the coordinates find out the target. Coordinate calculations are performed automatically based on the algorithm with a fairly high accuracy.

Within the interface with "Simulated Signals" we can enter any type of synthetic signal from the Matlab programming environment and thus we can simulate the detection and location of a target in the territory. The lists next to each sensor indicate that different levels of the SNR have been considered. This is due to the fact that in the real environment, there are interferences and distortions of the signal that can make it difficult for us. As for the thresholds chosen for each method, they can be changed in a very simple way, being noted suggestively from the interface code or from the source code of the algorithms.

This interface comprising the synthetic signals is shown in Fig. 13.

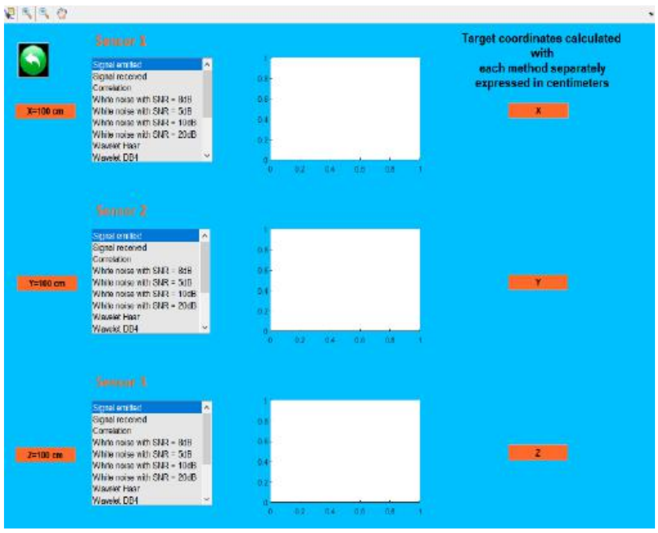

Figure 13. Synthetic signal simulation

This interface aims to provide the user with a simpler way to analyze the results taken from these sensors, seeing the characteristics of waveforms and real-time results of their processing, being able to easily operate and view the graphs of each signal without having to run the program again.

With the help of the results obtained previously and in order to be able to make a comparison of the performances of the three methods, in Table I there are presented the coordinates of the targets resulted from the application of the three detection and location methods.

TABLE I. RESULTS SIMULATION

Method used	Real coordinates (cm)	Coordinates obtained (cm)
Correlation	(85,230,175)	(66,201,165)
Wavelet Haar	(85,230,175)	(69,233,195)
Wavelet DB4	(85,230,175)	(73,221,186)
Wavelet FK4	(85,230,175)	(113,190,180)
Recurrence Plot Analysis	(85,230,175)	(77,205,173)

We can see that the highest errors are recorded in the case of the correlation-based method, and this is explained, as predicted in the previous chapter, by the fact that it requires knowledge of the waveform sought. If this differs, the possibility of errors increases, as the position of the maximum value of the correlation will not coincide with the starting sample of the signal to be detected.

Also, in the previous chapter it was specified that the methods based on Recurrence Analysis and Wavelet Transform keep their detection performance in the case of real signal analysis, the coordinates offered by these methods being close to the real coordinates of the target.

These two methods, having close results, determine values of the delays, expressed in samples, almost identical.

V. CONCLUSION

Algorithms for processing signals received through sensors that are part of the acquisition system. These sensors are also part of the equipment used by UWB technology and are based on three detection methods: correlation, wavelet transformation and recurrence analysis.

The detection of the waves was based on determining the arrival times in which the wave reaches each sensor, and the coordinates of the target were obtained on the principle of TOA (Time of Arrival) method, solving the system of equations made in the paper.

In other words, determining the arrival times of the waves are essential elements of the whole simulation and implicitly of the system of equations.

This system can be easily used in both the civilian and military fields, for the detection of an enemy accessing the perimeter of the base or for unidentified persons entering certain prohibited areas.

UWB technology is in a continuous development both in the field of communications and in other fields of activity with the help of which, some manual actions will be automated.

On the other hand, this system can be improved by creating a mobile application through which to receive in real time on the location of the alleged targets, being available for both Android and IOS.

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 Digital Object Identifier 10.32754/JMT.2021.1.05