Perspectives for development of new positioning systems

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Abstract: In this article are analyzed some possibilities of integration between telecommunications area and terrestrial measurements to determine the opportunities to achieve for new positioning systems. After a brief overview of positioning systems based on their topology and technology used for positioning are presented the main techniques used for positioning through radio waves used at the present time. In the second part of this article is presented Multiple Signal Classification algorithm and hardware configuration used for testing the algorithm in order to determine the Angle of Arrival of the Received Signal, in context that it together with LabView software could be the basis of a position determination system.

Key-Words: positioning, emitter, receiver, signal, frequency, radio waves, Multiple Signal Classification, angle of arrival

1 Introduction

The utility of GNSS (Global Navigation Satellite System) positioning technology made his presence felt in most sectors of work where the main subject is represented by spatial data, but in practice are encountered situations where GNSS technology could not be used. Two frequent cases of this problem are crowded urban areas where satellite signal is obstructed by high rise buildings or when it is desired that position to be carried out within enclosed spaces, in which case because of the signal propagation properties, handset is put in the impossibility to take over the satellite signals in order to determine the position, cases in which is necessary to recourse to other techniques for positioning.[1] The known momentum of the technique in the last period allowed the development of new positioning technologies in the covered areas become necessary and even vital in many areas of work. The usable positioning technologies in enclosed spaces want to complete and to cover the drawback that is produced by the drawback impossibility to provide accurate data through GNSS technology in these conditions. [2]

Depending on the field of measurement and the precision that aims to be reached by the observations, modern measurement techniques in the field of engineering geodesy have seen an unprecedented development and a higher degree of automation together with the development through known technological aspect in the past two decades. Thus, techniques that up to that time were used in exclusive areas such as military applications, have come that today be used successfully for a variety of areas. The growing need of various areas working for positioning in covered areas led to the creation of new systems and equipment or integration of the that already existing within complex systems, which will result in determination of the position of a mobile terminal. In order that the positioning to be more reliable, and their price is low comes to the detriment of precision of that respective system, thereby, trying to maintain a balance between system costs and its accuracy in frequent cases resorting to integration of the system in other existing systems that already have a developed infrastructure in very broad areas such as the example of the infrastructure for mobile phones. These considerations have led to integration within the mobile devices in addition to GPS antenna capable of producing a sufficiently accurate positioning in spaces without obstruction of satellite signals and other types of equipment such as gyroscopes and accelerators, that integrated in an appropriate manner and with a adequate software support allows the possibility of positioning in enclosed spaces. Another example to use of existing infrastructure is GPS system. The system cannot be used indoors, because the frequencies at which the satellites transmit signals do not penetrate buildings, but the solution was created indoor GPS environment that uses fixed transmitters called pseudolites to generate the required signals. These systems offers a centimetre-level accuracy using a differential carrier phase technique, and an auxiliary optical tracker is required to resolve the ambiguities.

2 Classification of positioning system

The positioning systems can be divided into several categories point of view of their topology, depending on where the system components are located that allow getting data and those which aim to process the data received to determine the position of the followed device. According to these classifications, devices which are part of these systems can be equipped with either only one emission systems, the reception and processing of data, and with all the three systems integrated into the same device, the determination of position device followed.[3][4]

Based on this characteristic, positioning systems can be classified as:

The "direct" system are systems provided with devices that allow both acquisition and signal processing received from transmitters as well as automatic calculation of their position.

Systems based on network services in which signals transmitted by the mobile device are retrieved and processed by the reference stations integrated in a network, where, each station occupies a known position.

The "indirect" system are systems in which the signals are picked up by one of system devices, and their processing is performed by the other device.

For determining the position in covered areas are used various systems based on different technologies position and the most common are:

Infrared devices are cheap and easy to get, and so are often used for indoor positioning. The signals will not travel through walls, unlike radio signals that can penetrate the obstacle found between transmitter and receiver. Because IR technology has already been exploited commercially, it is inexpensive and readily available for developing new applications such as the Active Badge and the Wireless Indoor Positioning System (WIPS), but the accuracy of positioning is quite low in comparison with systems based on other technologies.

Ultrasonic multilateration systems determine the positions of objects by measuring distances between ultrasound sources and detectors. These systems rely on measurements of the time taken for ultrasound to travel between sources and detectors and the distance measurement methods are based on a knowledge of the speed of ultrasound in air, which is around 340m/s, so units with microsecond resolution are sufficient to measure distances with sub-centimetre accuracy and so the electronic complexity of the systems is low.

Radio-based positioning systems are frequently used because the signals they use can pass through solid objects. Radio systems are used in positioning both in outdoor environments, as well as in indoor environments, signal reflections from objects are problematic. The main components that determine the resolution attainable in measuring distances through wireless technology are: signal parameters, the characteristics of the system used, and the physical and electromagnetic environment through which the signal propagates. Achieving high resolution in determining distances requires the use of large band-width systems, a high energy in order to obtain a signal / noise ratio favorable to the use of high-frequency oscillators. Positioning accuracy based on determining the time passed between transmitter and receiver signal depends largely on the accuracy with which syncs the clock receiver transmitters installed in known positions. Since the accuracy of the determination of the time passed between the transmitter and the receiver signal increases with an increase in the transmission bandwidth and, if the phase measurement accuracy of the determination of the time covered by the signal is enhanced by filtration. Reduction of the bandwidth leads to an increase in the time of measurement, while the use of larger tape width results in the signal / noise ratio.

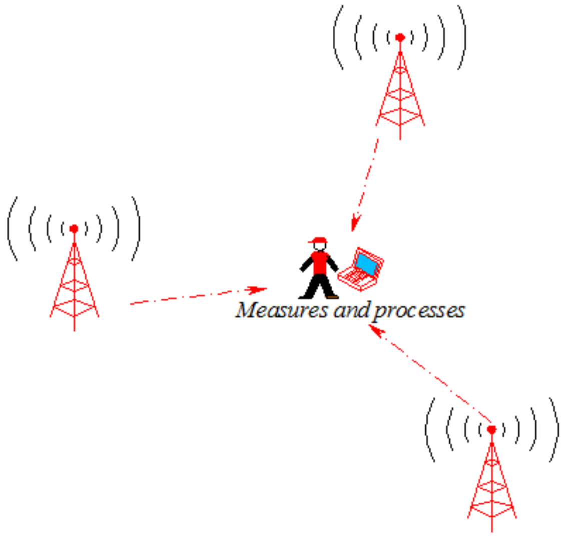

Fig. 1: Direct System

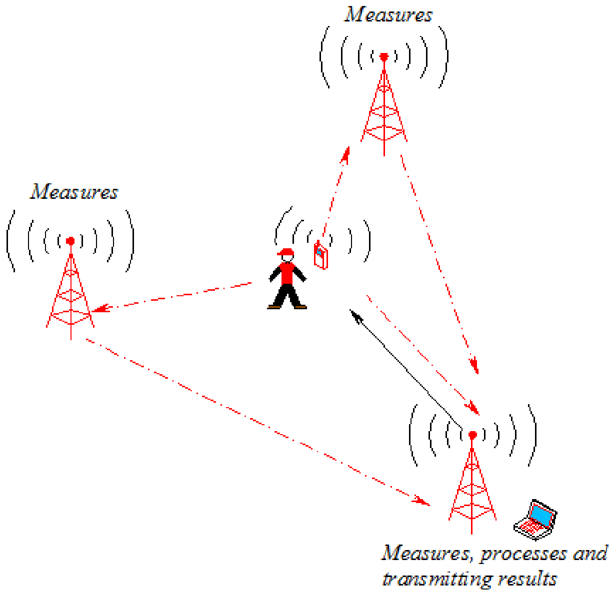

Fig. 2: Indirect System

3 Positioning techniques using radio waves

Because of the many areas in which pervaded through, as well as the properties of propagation of electromagnetic waves, in the field of radio frequency systems based on these have seen in recent years a very large development for positioning applications. One area of wide interest is represented by determining the position of mobile terminals in the telecommunications sector. This sector has the advantage that already holds a highly developed infrastructure of mobile phones becoming at present almost indispensable devices regardless of level of development and the financial situation of a community, requirement at which operators have responded by developing a very good infrastructure, as in a few areas would be possible because of the high costs. Thus aiming to maximize existing infrastructure, but also as a result of the Directive E911 a FCC (Federal Communications Commission) that imposes an obligation to achieve of services offered by network operators for locating mobile terminals having as main argument the need for rapid discovery of terminals that launches emergency calls. . Radio systems used for positioning are quite varied and use a number of techniques for positioning implemented at the communications and the mobile terminal, in which case network, are required changes of software and hardware at the level of mobile terminal.

3.1 Cell identification

The method is based on installing multiple reference points in a network through which is estimated the user position and mobile receiver position estimation is based on the determination of the center of gravity of the configuration data of all fixed stations detected by the mobile receiver.

$$X = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (1)$$

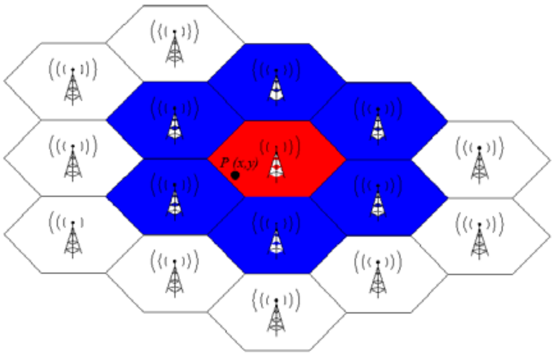

Fig. 3: Cell of origin

3.2 Received signal strength

The principle of the method is that the signal strength decreases as the distance between the transmitter and receiver increases. For modeling the received signal, it can be divided into two parts, namely a constant component for the direct wave, and a variable component in which is considered to be effects of the environment on the signal such as: signal attenuation, the effect of multipath, dispersion and diffraction of the signal.

According [5] to model signal strength between the transmitter and receiver can be used the following relationship:

$$p = \alpha - 10\beta \cdot \log(d) \qquad (2)$$

where:
p – signal strenght
α - parameter of power transmission
β - influence of the environment
d – the distance between transmitter and receiver

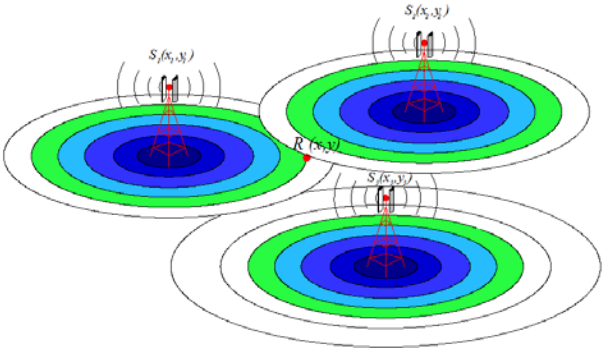

Fig. 4: Received signal strength

3.3 Time of arrival

The method is based on determining the time traveled of signal on the route of transmitter and receiver, in which are calculated relative distances between them and the receiver position is determined by the trilateration principle known in topography.

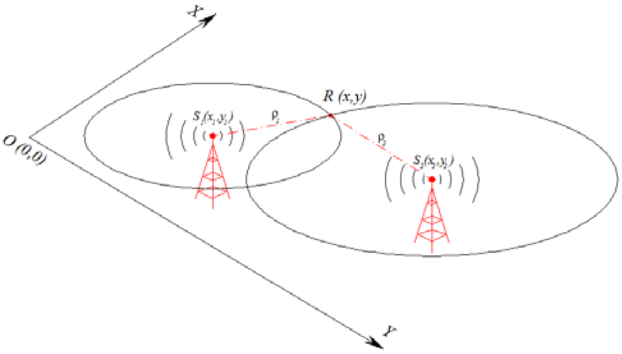

Fig.5: Determining the position based on time traveled between transmitter and receiver

The method requires very precise synchronization between the transmitter and receiver clocks, and while for a 2D position is requires two transmitters installed in positions known 3D positioning requires at least three emitters whose position is known. Considering two fixed reference stations installed in known positions S1 and S2 receiver position R can be calculated from the reference station coordinates and distances between each station and the receiver as the intersection of two circles of equal ray transmitter-receiver distance and with origins in S1 and S2 respectively.

The distances between the transmitter and receiver are calculated based on the difference between the time of signal transmission, reception time and the propagation velocity of light.

$$\rho_1 = (t_1 - t_i) \cdot c \qquad (3)$$

$$\rho_2 = (t_2 - t_i) \cdot c$$

t_i – the emission time
t_1 – the reception time at S_1
t_2 – the reception time at S_2

The time of the signal arrival at the receiver is determined by the internal clocks of receivers. The main disadvantage of this method is that several clock synchronization receivers installed in a network time with the clock transmitter is an operation difficult to achieve and entails considerable additional costs.

If in the equation for determining the time passed by signal between the transmitter and receiver it is considered that the error clock between the transmitter and receiver can be determined also if we take into account the errors induced by the transmitter clock frequency and the influence of environmental effects on the transmitted signal, is obtained a relationship of the form:[6]

$$t = t_i + \frac{d}{c} + \varepsilon_S + \varepsilon_c + \varepsilon_m \qquad (4)$$

t_i – transmission time
ε_S –sincronization error between transmitter and receiver
ε_c – clock error of the receiver
ε_m – the errors induced by the propagation effects

While the receiver clock error that has a constant value, error due to the influence of the environment on the signal transmitted ε_m varies, and is dependent on the configuration settlement of the transmitters and receivers in the network, being usually established in that system calibration phase and expressed as standard deviation.

3.4 Angle of arrival

The method aims to determine the angle of incidence by received signal for the application of the triangulation procedure for calculation of the position of the mobile device, and has the advantage that it does not require the determination of transmitter-receiver distances. The main problem of the method is represented by the influence obstacles along the route of the transmitter and receiver, and the position of the receiver R can be determined according to the principle of the intersection angle met in the topography.

$$x = \frac{x_2 \cdot \tan\Theta_{s2-R} - y_2}{\tan\Theta_{s2-R} - \tan\Theta_{s1-R}} \qquad (5)$$

$$y = x \cdot \tan\Theta_{s1-R}$$

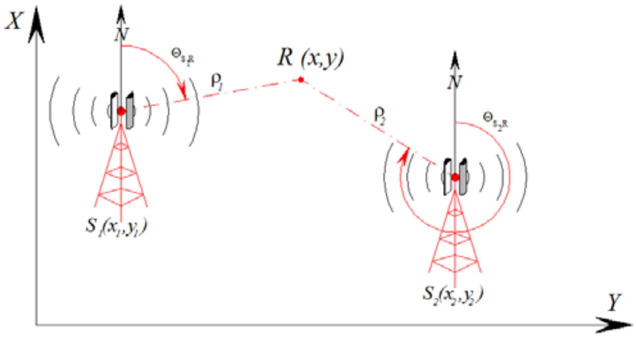

Fig. 6: Determining the position based on time angle of arrival

3.5 Polar coordinates

This positioning method can be used with the transmitter whose position is known must be equipped with directional antennas and measurement system for determining the distance, and the receiver is equipped with compasses for determining the orientation of the vector described range between the transmitter and the receiver. Receiver position can be determined based on the well known principle of classical topography polar coordinates method by calculating relative coordinates Δx increases and Δy between transmitter and receiver.

$$X_R = X_E + \rho \cdot \cos\Theta_{ER} \qquad (6)$$

$$Y_R = Y_E + \rho \cdot \sin\Theta_{ER}$$

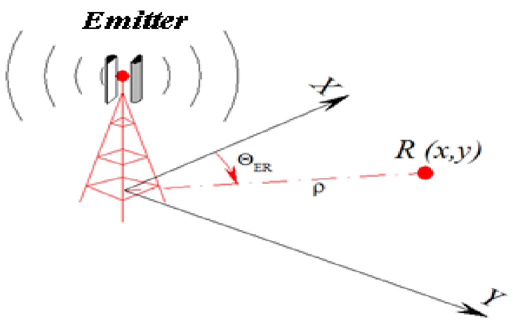

Fig. 7: Determining the position based on polar coordinates

3.6 Fingerprint method

This positioning method is based on the integration and correlation of different types of information within the same system. For location, the mobile receiver must be equipped with devices which would allow taking as many types of signals used for positioning and subsequent sending them to the central server that is designed to correlate measurements with information from the database and then determining the mobile receiver location.

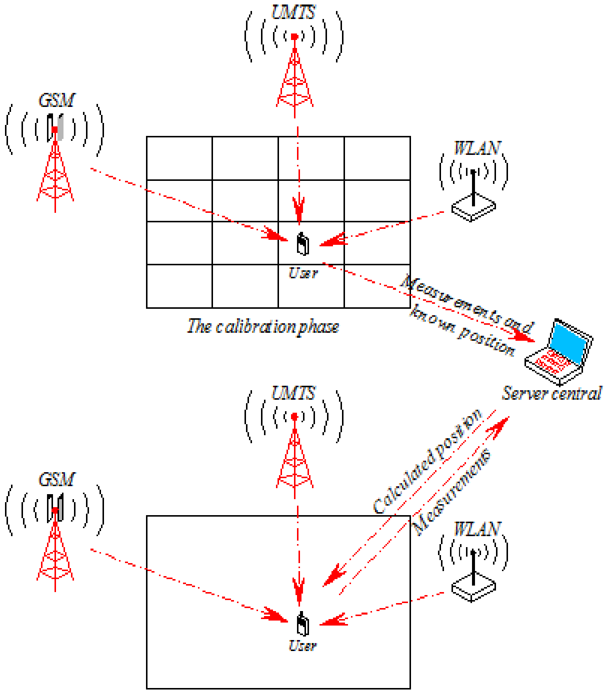

Fig. 8: Fingerprint method in calibration phase and in use phase of the system

In the calibration phase of the system is required that the area in which the calibration is performed to be split quadratic form of a grid, and position information collected from the receiver and transmitter measurements are subsequently transmitted to a database in order to be processed.

4. The MUSIC algorithm

The MUSIC (Multiple Signal Classification) is known for over two decades, knowing a wider spread and utility for areas with have the principal concern electromagnetic waves in the radio frequency. This algorithm allows on the measurement and interpretation of the signals received at the level of receiver antennas to be estimated elements such as antenna polarization, angle of incidence of the received signal, the number signals received, noise and interference intensity. The MUSIC algorithm is a efficient method of direction of arrival estimation, and it has many variations like: Spectral MUSIC, Root-MUSIC, Constrained MUSIC and Beamspace MUSIC. The method estimates the noise subspace from available samples by either eigenvalue decomposition of the estimated array correlation matrix or singular value decomposition of the data matrix, with its N columns being the N snapshots of the array signal vectors. [7]

According [9], the purpose of direction-of-arrival estimation is to use the data received on the downlink at the base-station sensor array to estimate the directions of the signals from the desired mobile users as well as the directions of interference signals. The results of direction-of-arrival estimation are then used by adjusting the weights of the adaptive beam-former so that the radiated power is maximized towards the desired users, and radiation nulls are placed in the directions of interference signals. Hence, a successful design of an adaptive array depends highly on the choice of the direction-of-arrival estimation algorithm which should be highly accurate and robust.

The mathematical model of MUSIC algorithm has the form: [10]

$$X = AF + W \qquad (7)$$

F – the complex values of incident signals represented in amplitude and phase

W – the vector of the noise

A – the matrix of the known functions of the signal arrival angles

The matrix A of the system is composed of a sequence of direction vectors in which knowledge of the elements of a vector direction a(Θ$_i$) equivalent to knowing the orientation Θ $_i$. While for a 2D coordinate system the elements of matrix A for the orientation Θ consisting of one single parameter, consisting of one single parameter, in the case of a 3D Cartesian system of elements a(Θ$_i$) will be composed of the polar elements that characterize the transmitter position and the horizontal angle, angle in a vertical plane and distance between the transmitter and receiver and are established during the calibration of the system.

Assuming that the incident signals and noise are uncorrelated, the covariance matrix of the vector X has the form:

$$S = APA^* + \lambda S_0 \qquad (8)$$

Knowing that the euclidean distance for vector Y can be written as:

$$d^2 = Y^* E_N E_N^* Y \qquad (9)$$

can be written as a continuous function a(Θ) of the form:

$$P_{MU}(\Theta) = \frac{1}{a^{*}(\Theta) E_N E_N^* a(\Theta)} \qquad (10)$$

Where EN is defined by M X N matrix whose columns are the N noise eigenvectors.

After retrieving data and calculate the structure of S matrix, must evaluate the PMU(Θ) versus Θ and calculate remaining parameters with:

$$P = (A^*A)^{-1} A^* (S - \lambda_{min} S_0) A (A^*A)^{-1} \qquad (11)$$

5. Case study

For testing the MUSIC algorithm and verifying its ability for determining direction of arrival have been used dedicated equipment produced by the National Instruments Company, and data processing was carried out by the software LabView. The direction of arrival is made by measuring the difference in received phase at each element in the antenna array. In this testing it was used the same configuration.

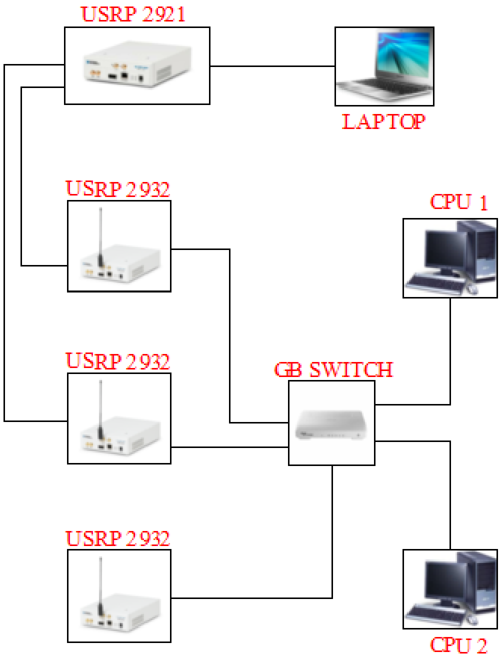

Fig. 9: The hardware configuration

The NI USRP-2932 transceiver is an affordable and easy-to-use RF platform with high precision frequency accuracy and synchronization with a coverage from 400 MHz to 4.4 GHz with an integrated GPS receiver. The local oscillator sincronization among the NI USRPs was carried out using the high precision of the 10 MHz reference clock integrated in the three NI USRP 2932 units. The NI USRP 2921 was used as the transmitter at a frequency of 2,5 GHz. After filter the received signals in the software, and sincronization signal to evaluate the channel phase offset among different received antennas, the signals was align in phase and gain. The first desktop coordinate a NI USRP unit which is intended to eliminate the uncertainties in phase and gain among the USRP receivers. The second desktop coordinate the two NI USRP used as receivers, at which applies the MUSIC algorithm and is determined the angle of arrival of the received signal. The signals was transmitted at a frequency of 10 KHz and the carrier frequency have chosen at 2,5 GHz.

Fig. 10: The receivers

To separate the target signal from USRP 2921 and the signal from USRP which is used for calibrating the phase uncertainty among the receivers, was used a low pass filter. In order to eliminate the disadvantages caused by reflected waves, the tests were conducted in open space on the roof a building. After the installation of the system components and its calibration, the transmitter was placed successively in positions for which the angle of incidence of the incoming signal is known, so that results can be compared with the true values of the direction of incidence.

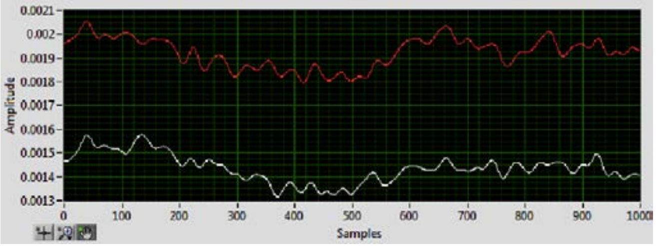

Fig. 11: Direct wave before started the reference clock

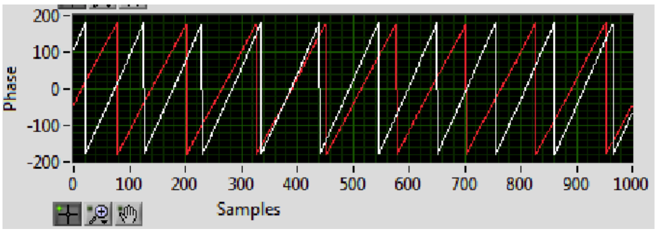

Fig. 12:Direct wave phase before phase syncronized

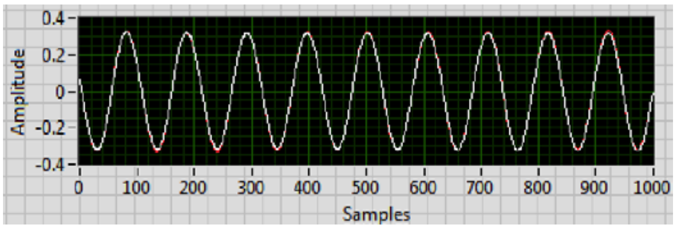

Fig. 13: Direct wave after phase synchronized

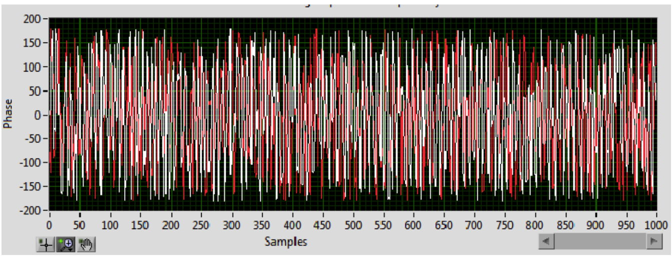

Fig. 14: Air signal before phase synchronized

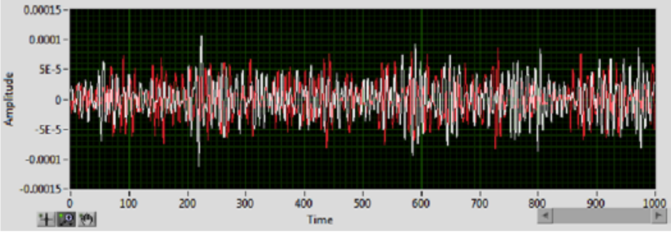

Fig. 15: Air signal after phase synchronized

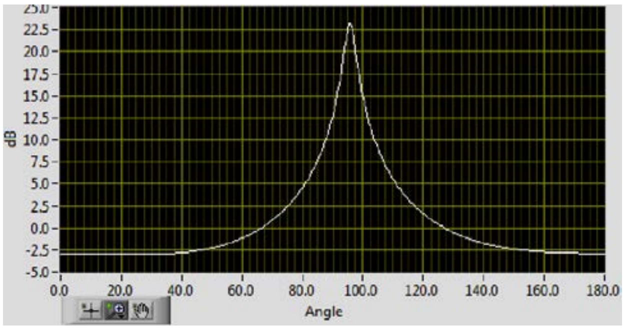

Fig. 16: The MUSIC results for direction of arrival

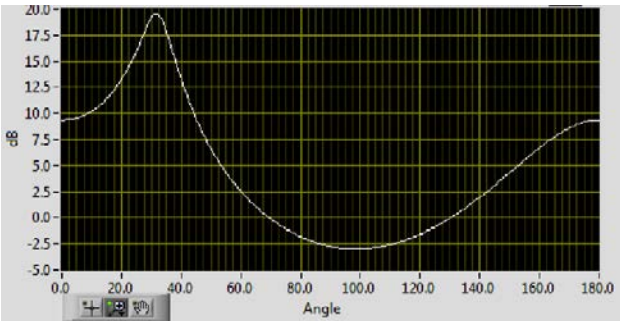

Fig. 17: The MUSIC results for direction of arrival

The standard deviation of a point position:

$$\sigma_P = \sqrt{\sigma_D^2 + \left(\frac{\sigma_\beta}{\rho} D\right)^2} \qquad (12)$$

D - distance between emitter and receiver
ρ - transformation coefficient
Starting from the relationship for standard deviation of position of a point on the basis of the values obtained within the experiment, in the context of a distance of several meters between the transmitter and receiver is obtained a standard deviation of position of a point of decimetres order, large enough value compared to precision specific to the field of terrestrial measurements.

6 Conclusion

The article offers some perspectives for implementing these systems in various types of applications in production, in which requirements for the necessary precision are not very restrictive. Positioning systems presented constitute a interdisciplinary subject of research in the context of integration with GIS technology and presents an important step in making connections between different areas such as: telecommunications, electronics, computer, mechatronics and positioning.
Obtaining a high resolution at determine the position requires the use of systems with large widths of band, of a high energy consumption in order to obtain a signal/noise ratio favorable and utilization oscillators with high-frequency.
After analyzing the experiment results we can conclude that the use of dedicated equipment to other areas of work such as telecommunications, integrated with LabView software creates research perspectives concerning creation of new systems for tracking and positioning.

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