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# Analysis of Existing Localization Methods*

Jaromir GAJEWSKI

Military University of Technology, Warsaw, Poland

Correspondence should be addressed to: Jaromir GAJEWSKI, jaromir.gajewski@wat.edu.pl

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## Abstract

The article presents an overview of modern methods for locating electromagnetic signal sources, which are used in many fields, such as autonomous navigation, robotics, logistics, security, and military operations. The basic groups of methods are presented, classified according to their operating principles: methods based on amplitude, phase, time, frequency, and methods enabling the simultaneous localization of multiple transmitters operating on the same frequency. The main theoretical assumptions and examples of technical solutions are discussed, indicating their advantages and limitations.

**Keywords**: localization, DOA estimation, positioning

## Introduction

In contemporary times localization methods are playing crucial role in many various fields [N. Tayem, A. Bochem, Y. Mao] such as autonomous navigation, robotics, augmented reality, logistics, emergency response and military operations [A Duarte]. Although there are GPS devices that can determine location, it is sometimes necessary to determine the location of another device that does not inform us in any way about its location. Due to that fact many localization methods were created to determine electromagnetic transmitter position. This paper presents most known methods divided into groups based on their operating principles such as amplitude based methods, Phase based methods, time based methods, frequency based methods and methods enabling simultaneous localization of many devices using the same frequency.

## Amplitude based methods

These are methods based on the use of directional antenna properties. They are characterized by the fact that the measurement of the angular coordinate is closely related to the evaluation of the amplitude of the received signal, i.e., information about the angular position of the emission source is contained in the amplitude of the received signal. Most of these are single-channel search methods. Amplitude methods include:

### *Maximum signal level*

The antenna of the radio receiver rotates, and the amplitude of the signal at the receiver output changes according to the directional characteristics of the antenna. The bearing reading is taken when the signal at the receiver output reaches its maximum value, when the direction of the antenna is the same as the azimuth - $\Theta = \Psi$.

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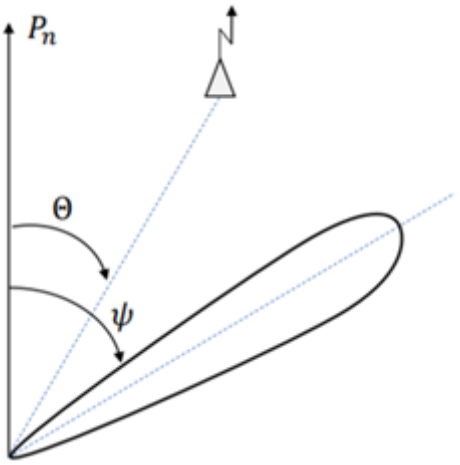


**Fig. 1 The idea of maximum signal level positioning**

The advantages of this method are:

- ease of technical implementation,
- the ability to track weak signals.

The disadvantage of this method, however, is its low accuracy, especially when using an antenna with a wide radiation pattern.

## *Minimum signal level*

This method is based on the use of an antenna with a distinct minimum directional characteristic. The UR antenna rotates to the position where the received signal value is lowest, i.e., similar to the maximum signal method Θ = ψ, and the antenna is pointed in the same direction as the azimuth to the radiation source.

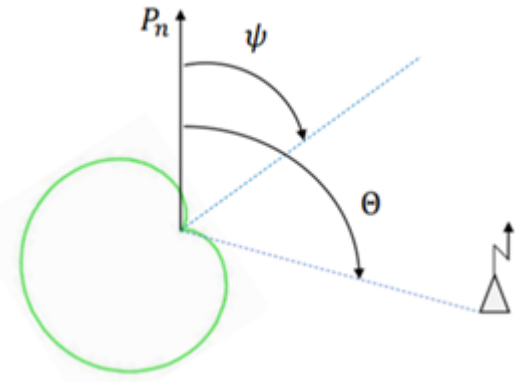


**Fig. 2 The idea of minimum signal level positioning**

The advantage of this method over the maximum signal method is that it provides greater accuracy when receiving strong signals.

## *Same signal level*

With this method, the azimuth measurement for the radiation source can be performed based on two measurements taken with a single antenna in two different positions, or with two antennas with identical directional characteristics.

If the same signal value is received at the outputs of the receivers to which the antennas are connected, it means that the axis of symmetry of the antenna system is directed towards the operating radiation source.

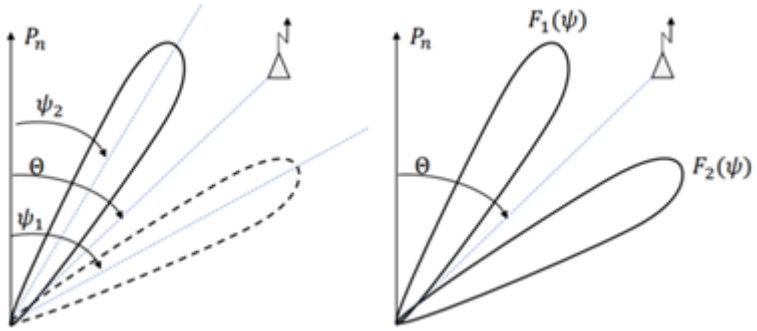


**Fig. 3 The idea of same signal level positioning**

The advantage of this method is its relatively high accuracy compared to other amplitude methods, combined with the uncomplicated technical implementation of the system that allows this method to be used.

## *Signals comparison*

This method involves comparing the amplitude of signals from two independent pairs of antennas with figure-eight directional characteristics oriented precisely according to the cardinal directions.

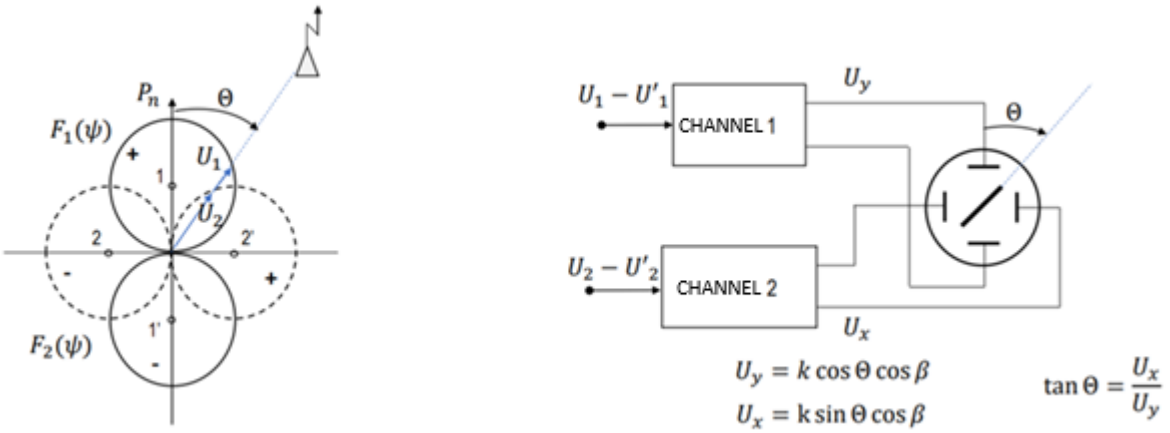


**Fig. 4 The idea of signal comparison positioning**

This solution provides the highest accuracy among all amplitude-based tracking methods. However, this comes at the cost of relatively complex technical solutions and the fact that the accuracy of tracking depends on the direction from which the radio wave comes. Namely, the accuracy decreases the closer the azimuth of the operating radiation source is to one of the axes of symmetry of the antenna pair's characteristics.

## Phase based Methods

These methods are used in systems whose antennas are not highly directional. They involve comparing the phases of signals received by at least two separate antenna-receiver systems. All phase methods are multichannel methods classified as instantaneous methods.

An example of the application of the phase method can be illustrated by the operation of a phase locator with four fixed antennas.

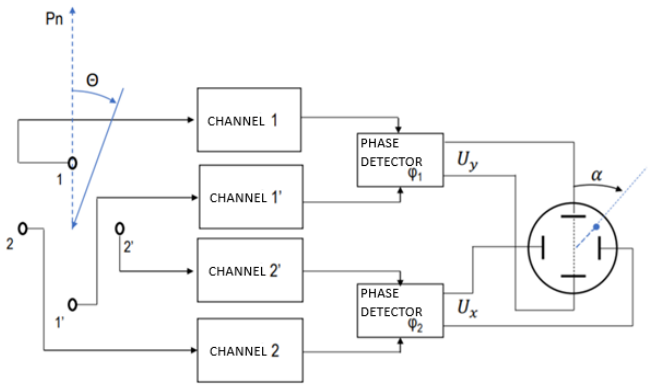


**Fig. 5 Direction finding device schema**

Phase detectors at the channel outputs determine the phase difference between the signals from the north-south and east-west antenna pairs.

$\varphi 1 = md \cos\Theta \cos\beta$

$\varphi 2 = md \sin\Theta \cos\beta$

The DC voltages at the output of the phase detectors are proportional to the phase difference between the input signals

$U_y = k\varphi_1$

$U_x = k\varphi_2$

$\tan \alpha = U_x / U_y = \varphi_2 / \varphi_1 = \tan \Theta$

## Time based Methods

This is a group of methods based on measuring the time or difference in signal arrival times, referred to as TOA (time of arrival) or TDOA (time difference of arrival), respectively.

An example of a tracking device that uses this method is a correlation locator, which works by measuring the time difference between the induction of signals in two spaced antennas.

The antennas are spaced apart by a distance d, and tracking is performed according to the maximum voltage at the correlator output, which occurs when the antenna alignment line is perpendicular to the direction of wave arrival.

## Frequency based Methods

These methods are based on measuring changes in the frequency of the received signal resulting from the movement of objects, i.e., related to the measurement of Doppler frequency shift. Methods in this group include FOA/FDOA (frequency of arrival/frequency difference of arrival), DPD (direct position determination), and SDF (signal Doppler frequency)

SDF is a method that the Military University of Technology has been developing since 2006. This method provides the ability to simultaneously locate multiple radiation sources in both open and urban areas using only one mobile platform.

## Methods enabling simultaneous localization of many devices using the same frequency

*MUSIC (Multiple Signal Classification)*

The method uses signal covariance matrix eigenvectors – it divides the space into signal and noise parts. It searches for directions in which the steering vectors are orthogonal to the noise space, which allows for precise estimation of the angles of arrival (DOA) of signals.

*ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques)*

It is based on the property of rotational invariance between two antenna submatrices. It uses the linear relationship between them to directly calculate the angles of arrival, without the need to search the space as in MUSIC.

*ML (Maximum Likelihood)*

A parameter estimation method that selects values (e.g., arrival angles) that maximize the likelihood of obtaining the observed data. It usually provides the highest accuracy but requires high computing power.

## Conclusions

The analysis of signal localization methods showed that each group has a different range of applications and a compromise between accuracy, technical complexity, and computational requirements. Amplitude-based methods are simple to implement but have limited precision. Phase and time-based techniques provide greater accuracy at the expense of more complex measuring equipment. Frequency-based methods, on the other hand, allow for effective localization of moving objects. The greatest development potential lies in modern algorithms based on signal space analysis, such as MUSIC, ESPRIT, and ML, which enable simultaneous tracking of multiple signal sources with high estimation accuracy. Further research should focus on combining different approaches and optimizing algorithms for operation in noisy and mobile environments.

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