SIMULATION MODELING OF RADIO DIRECTION FINDING RESULTS

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Abstract

It is sometimes difficult to determine analytically error probabilities of direction finding results for evaluating algorithms of practical interest. Probalistic simulation models are described in this paper that can be to study error performance of new direction finding systems or to geographical modifications of existing configurations.

Keywords:

1. Introduction

Radio direction finding is very important for monitoring radio transmitters activities by governmental supervising services in the whole world. Designers of such systems must be able to estimate the accuracy of the located transmitter position if parameters of individual direction finders are known. The same need arises at the user if a geometrical reconfiguration of an existing direction finding system is necessary.

In practice, not only classical so called angle-measuring systems are used. Up to day short wave radio direction finders are able to determine both anazimuth and a distance of the located transmitter, respectively. Such systems are sometimes called distance-measuring.

The error analysis of classical angle-measuring systems is well known and it is presented in many textbooks (e.g. [1],[2],[3]). The distance-measuring system is analyzed in [4] for the special case where the gravity center estimation rule is used. Measured positions by individual finders form vertices of a polygon. The gravity center of this polygon serves like the estimate of the transmitter location. The rigorous mathematical analysis is possible in this case. Simulation models that are suitable for a performance analysis of more general evaluating algorithms of practical interest will be described in this paper.

2. Simulation model concept

The individual direction finders of the analyzed system are located in a properly chosen Cartesian coordinate system Ouv according to Fig.1. Values of azimuths Θ_i and distances r_i can be easily calculated from Cartesian coordinates u_{zi}, v_{zi}. The correct position of the transmitter is represented by the point V(d,H).

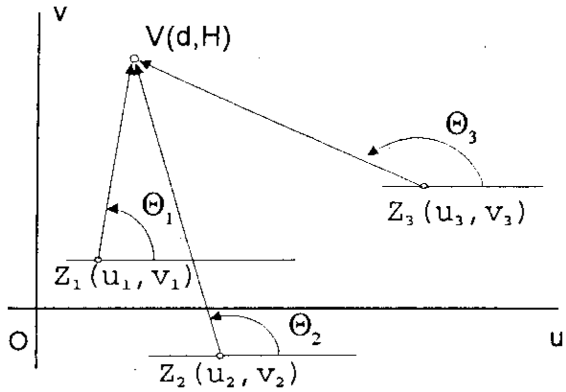

Fig.1 Geometrical configuration of the system

The individual i[th] finder Z_i locates the transmitter into the point S_i. Measuring errors are described by zero-mean Gaussian random variables $\Delta\Theta_i$ and Δr_i (see [2], [4]). The distance measuring error is usually expressed in percents k_r of the distance. The angle error is represented by a factor k_Θ expressing the azimuth deviation in degrees. Applying the 3σ rule for Gaussian random variables, we obtain formulas

$$\sigma_{\Delta r} = \frac{k_r . r_i}{3.10^2} \quad ; \quad \sigma_{\Delta\Theta} = \frac{k_\Theta . \pi}{3.180} \quad , \qquad (1)$$

Values $k_r = 15\%$ and $k_\Theta = 3°$ are usual in practice.

Let us assume values x_1, x_2 of random variables ξ_1, ξ_2 with the uniform distribution in (0,1). It is known from the probability theory that a random variable η with values

$$y = \sqrt{-2.\ln x_1} \,.\, \cos(2\pi x_2) \qquad (2)$$

has a zero-mean Gaussian distribution with the variance $\sigma_y^2 = 1$.

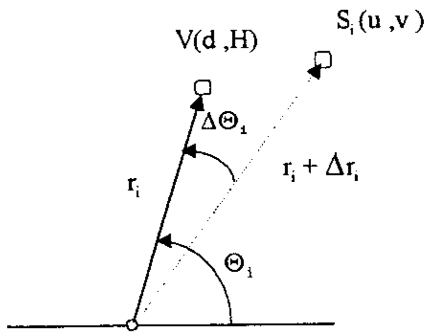

Fig.2 i^{th} finder location result

Methods of generating values of uniformly distributed variables in (0,1) are well known and they are suitable for computer programming. We have written the Turbo Pascal function GAUSS that returns values y using the formula (2). We are now able to calculate random coordinates S_i of repeated measurements of individual finders of the system and to determine appropriate estimates of the transmitter position using evaluating algorithms of the analyzed system.

3. Distance-measuring system

We demonstrate now a model of system which evaluate the position of the located transmitter like a gravity center of a polygon with vertices $S_1(u_{s1}, v_{s1}), \dots, S_N(u_{sN}, v_{sN})$, where N is the number of used finders $Z_1(u_{z1}, v_{z1}), \dots, Z_N(u_{zN}, v_{zN})$.

The simulation program realizes following steps :

1. We select the transmitter with Cartesian coordinates (d,H) . Local polar coordinates of finders are determined as follows

$$r_i = \sqrt{(d-u_{zi})^2 + (H-v_{zi})^2}$$
$$\Theta_i = \tan^{-1}\frac{H-v_{zi}}{d-u_{zi}} \tag{3}$$

2. Variances are calculated following (1) for given parameters of used finders.

3. We generate two numbers y_{i1} , y_{i2} using function GAUSS. We calculate coordinates from formulas:

$$\Delta r_i = \sigma_{\Delta r_i}.y_{i1} \quad , \quad \Delta\Theta_i = \sigma_{\Delta\Theta_i}.y_{i2} \quad ,$$
$$u_{si} = |(r_i+\Delta r_i).\cos(\Theta_i+\Delta\Theta_i)| + u_{zi} \quad , \tag{4}$$
$$v_{si} = |(r_i+\Delta r_i).\sin(\Theta_i+\Delta\Theta_i)| + v_{zi}$$

4. Estimated coordinates of the located transmitter are

$$u_T = \frac{1}{N}\sum_{i=1}^{N} u_{si} \quad , \quad v_T = \frac{1}{N}\sum_{i=1}^{N} v_{si} \tag{5}$$

5. The obtained point (u_T , v_T) is plotted in a suitably selected window of the coordinate system Ouv.

6. The steps 3, 4, 5 are repeated M times, where M is a number of simulated measurements.

In Fig.3 are presented the simulation results. Small circles denote the proposed position of the located transmitter. Each point of a cluster surrounding this circle represents one individual result of the simulated position with respect to measurement errors. Obtained patterns characterize the accuracy of the location of a selected transmitter.

4. Angle-measuring system

Each finder of an angle-measuring system can measure only azimuths $\Theta_1, \dots, \Theta_N$ of the located transmitter. The so called *probability center* will be used as an evaluating algorithm. First, we determine points of intersection S_{ik} of two straight lines p_i and p_k which are given by azimuths Θ_i ,Θ_k and positions of finders Z_i , Z_k . Fig.4 illustrates this situation .

Coordinates of the mentioned point of intersection can be obtained with the use methods of the analytic geometry in the form

$$u_{ik} = \frac{u_i\sin\tilde{\Theta}_i - u_k\sin\tilde{\Theta}_k - v_i\cos\tilde{\Theta}_i + v_k\cos\tilde{\Theta}_k}{\sin\tilde{\Theta}_i - \sin\tilde{\Theta}_k},$$
$$v_{ik} = \frac{-u_i\sin\tilde{\Theta}_i + u_k\sin\tilde{\Theta}_k + v_i\cos\tilde{\Theta}_i - v_k\cos\tilde{\Theta}_k}{\cos\tilde{\Theta}_i - \cos\tilde{\Theta}_k}, \tag{6}$$

where $\tilde{\Theta}_i = \Theta_i - \Delta\Theta_i$, $\tilde{\Theta}_k = \Theta_k - \Delta\Theta_k$.

We define now weighting coefficients

$$m_{ik} = \frac{\sin^2(\tilde{\Theta}_i - \tilde{\Theta}_k)}{\varepsilon_i^2.\varepsilon_k^2} \quad , \quad \varepsilon_i = r_i.\sigma_{\Delta\Theta_i} \; , \; \varepsilon_k = r_k.\sigma_{\Delta\Theta_k} \; . \tag{7}$$

Coordinates of the so called probability center are given by for

$$x_T = \frac{1}{W}\sum_{i=k}^{N}\sum_{k=1}^{N} u_{ik}.m_{ik} \; ; \; y_T = \frac{1}{W}\sum_{i=k}^{N}\sum_{i=1}^{N} v_{ik}.m_{ik} \; ,$$
$$W = \sum_{i=k}^{N}\sum_{k=1}^{N} m_{ik} \; . \tag{8}$$

The only difficulty is that values of r_i in (7) are unknown before coordinates of the transmitter are calculated from (8). It can be easily overcome by an iterative procedure.

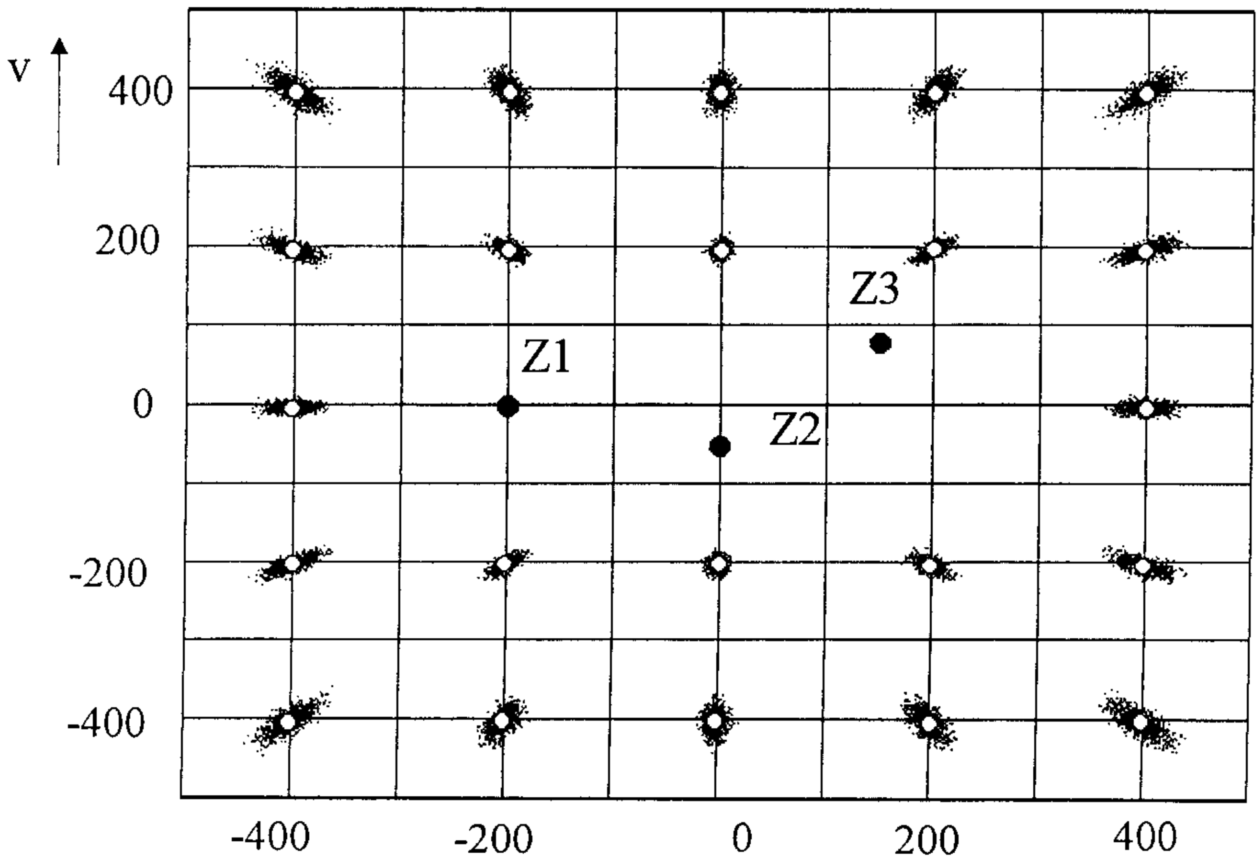

Fig.3 Distance-measuring system simulation results for k_r = 15%, $k_\Theta = 3^o$

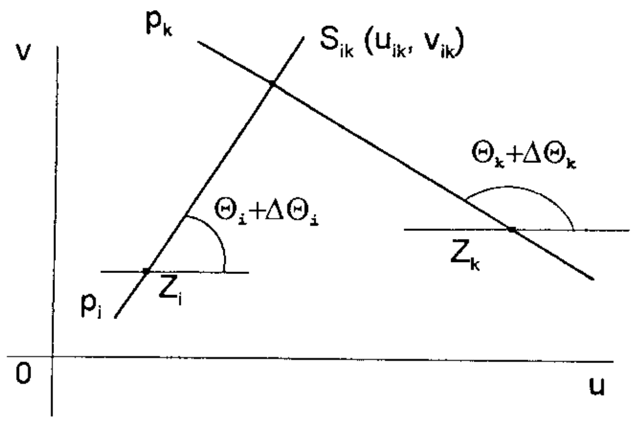

Fig.4 Determination of points S_{ik}

We select initial values of all r_i = 100 km . From calculated x_T, y_T will be obtained new values of distances from (3) and calculations will be repeated. It is sufficient to use three iterations for negligible error in practice .

The simulation program this system runs in following steps :

1. Azimuths Θ_i are calculated from (3).
2. For i = 1,...,N, y_i are obtained with the use of the function GAUSS and $\sigma_{\Delta\Theta}$ calculated from (7) . Values of are determined from (1).
3. Points of intersection (u_{ik} , v_{ik}) are calculated from (6).
4. Coefficients ε_i and weights m_{ik} are obtained from (7).
5. Finally, formulas (8) yield the probability center (u_T , v_T) as an estimate of the transmitter position .
6. Distances r_i are calculated from the first part of (3). The sequence of steps 4, 5, 6 is repeated three times.
7. Resulting point (u_T , v_T) is plotted in the window of the coordinate system Ouv.
8. The described procedure of running steps 2,..,7 is repeated M times, where M denotes a number of simulations of the same measurement.

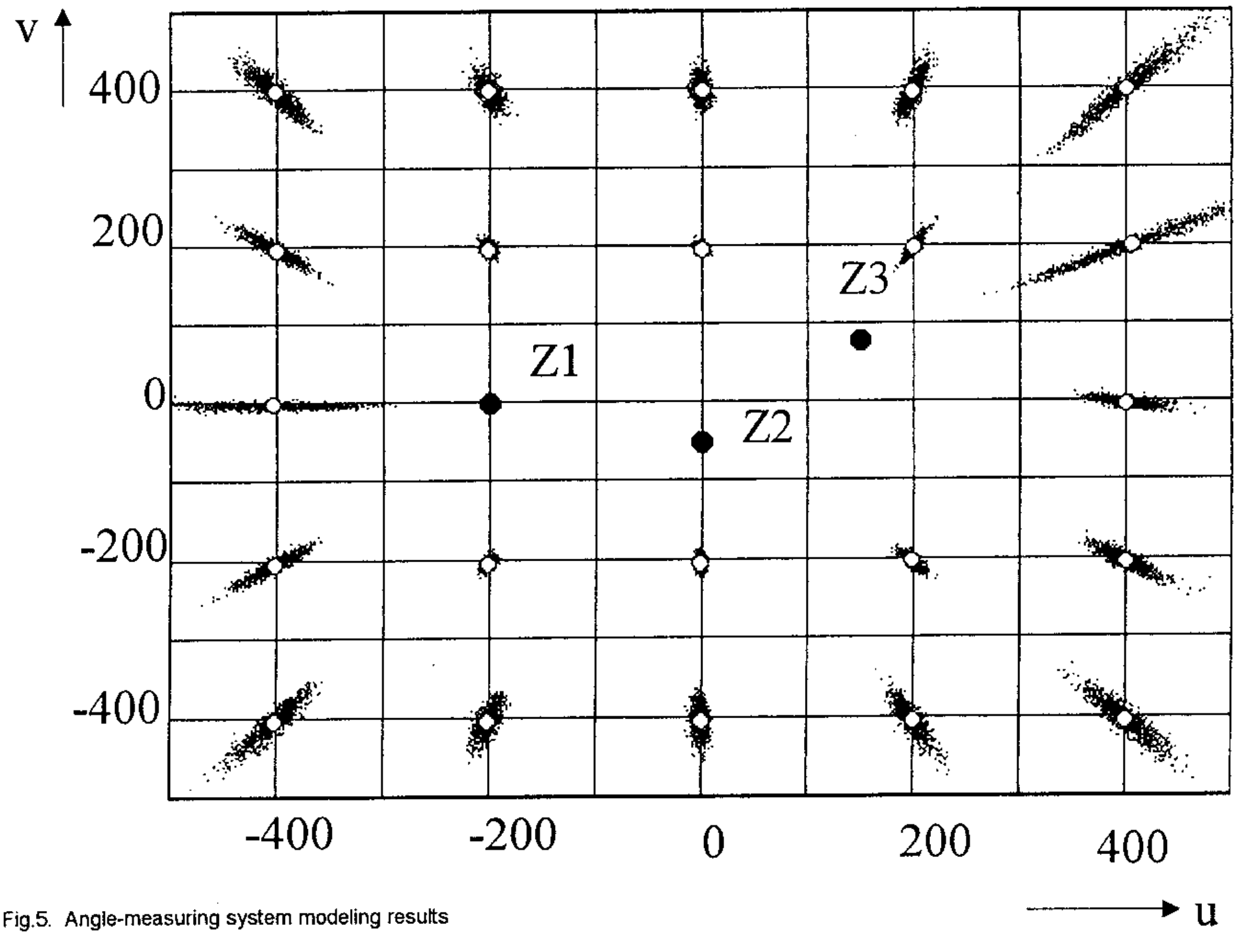

Fig.5. Angle-measuring system modeling results

Modeling results under same conditions as in the case of the above discussed distance-measuring system are shown in Fig.5, and they are interpreted in the same manner as in Fig.3.

5. Conclusions

Computer simulation models of radio direction finding systems performance is described. Two examples of practical interest illustrate the possible use of these models, which can be easily modified for other interesting estimation algorithms of a radio transmitter position. The results may be also used for educational purposes.

6. References

[1] GETHING,P.J.D. : Radio direction finders.Peregrinus, London 1978.

[2] BOND,D.S. : Radio direction finders. McGraw Hill, New York 1944.

[3] KEEN,R. : Wireless direction finding. ILIFFE, London 1949, 4th edition.

[4] HAVLÍK,J.-PELIKÁN,K. : Distance-measuring radio direction finding system analysis. Submitted to Slaboproudý obzor-Electronic Horizon.

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