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SHORT COMMUNICATION

Measuring Errors' Spectrum of the Artillery Radar Stations

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ABSTRACT

The simulation analysis of the measuring errors of the artillery radar stations is presented in this paper. This analysis enables the proper designing of the smoothing filters of the data for the ballistic module and determination of the components of the velocity of the target. They are derivatives of the signals representing coordinates of the target, and as such, can introduce huge errors during computations of derivatives.

Keywords: Autocorrelation, variance, spectral density of power, measurement, artillery radar station, ballistic computations, simulation analysis, digital prediction system, algorithm, error spectrum

1. INTRODUCTION

Fast development of the industrial computers, especially faster speed of computations, enables realisation of complex algorithms working in a real time. One of such algorithms is the algorithm of the digital prediction system. It has the application in the specialised computing machines realising a prediction of the location of the air object. Up to now, this task was performed in analogue systems, which in original was built with an analogue lamp computing machine, called a resolver. Replacing analogue computing machines with digital ones is necessary to recognise the input signals with their spectra and the spectra of disturbances.

In the begining, the analysis of the usefulness of different kinds of digital filters and their orders in the digital resolvers, is presented. It however applies in them, not a real signal with disturbances but uses only an ideal signal without disturbances. That is why it was advisable to perform the analysis of the spectrum of the measuring disturbances of the artillery radar stations, which in future can be applied and considered in designing of the input digital filters used both for smoothing of the input signals and also for computations of their derivatives which has an influence on the accuracy of the prediction process of the meeting point and the accuracy of the aiming process.

2. ALGORITHM OF THE ERRORS' SIMULATION

In the measurement devices applied for tracking and prediction of the position of the meeting point of the target and the shell, there are two basic sources of the errors: fluctuations of the spatial coordinates of the target and the dynamic errors of the tracking circuit[1,2]. These errors can be described with the autocorrelation function:

$$K_z(\tau) = \sigma^2(D_c)\cdot e^{-\alpha_z\tau}\cdot\cos(\beta_z\tau) \quad \text{for} \quad -1<\tau<1 \qquad (1)$$

where,

- σ^2 is the variance of the measuring error of the appropriate coordinate $[D, \varepsilon, \beta]$
- α_z, β_z – coefficients of the autocorrelation function of the appropriate coordinate. Coefficient α_z is a dumping factor and coefficient β_z is the angular frequency.

In the contemporary artillery radar stations, the following values of the above coefficients are valid[3] for the errors of a distance

$$\_\ \sigma = \begin{cases} 15 \text{ for } D_C > 2000[m] \\ 10 \text{ for } D_C \le 2000[m] \end{cases}$$

$$-\beta_z = \pi$$

$$\_\ \alpha_z = \frac{\beta_z}{1{,}63}$$

For the measurement errors of the angle coordinates

$$\_\ \sigma = \begin{cases} 15 \text{ for } D_C > 2000[m] \\ 10 \text{ for } D_C \le 2000[m] \end{cases}$$

$$-\beta_z = 2\pi$$

$$\_\ \alpha_z = \frac{\beta_z}{1{,}63}$$

For the simulation of errors the following algorithm is used[3,4]:

(a) On the basis of a known autocorrelation function $K_z(\tau)$, a spectral power density $S_z(\omega)$ is computed from the expression:

$$S_Z(\omega) = \int_{-\infty}^{\infty} K_Z(\tau)\cdot e^{-j\omega\tau} d\tau \qquad (2)$$

Introducing the Eqn.(1) to the above expression Eqn.(2) one gets:

$$S_z(\omega) = \alpha_z\sigma^2\left[\frac{1}{\alpha_z^2+(\beta_z-\omega)^2}+\frac{1}{\alpha_z^2+(\beta_z+\omega)^2}\right] \qquad (3)$$

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(b) After transformation of the Eqn.(3) to the common denominator and computing the square root of the numerator and the denominator relative to ω, this equation can be presented in the following form

$$S_z(\omega) = \frac{B(j\omega)\cdot B(-j\omega)}{A(j\omega)\cdot A(-j\omega)} \qquad (4)$$

(c) If from the Eqn.(4), one cuts out the negative imaginary part, one will get the spectral transmittance of the analogue filter [Eqn.(5)] and after putting $j = s$ and a few transformations the operational transmittance of the filter [Eqn.(6)]

$$G(j\omega) = \frac{B(j\omega)}{A(j\omega)} = \frac{(j\omega + \sqrt{\alpha_z^2+\beta_z^2})\cdot 2\sigma^2\alpha_z}{\left(j\omega+\alpha_z + j\beta_z\right)\left(j\omega+\alpha_z - j\beta_z\right)} \qquad (5)$$

$$G(s) = \frac{2\sigma^2\alpha_Z}{\sqrt{\alpha_z^2+\beta_z^2}} \cdot \frac{\frac{1}{\sqrt{\alpha_z^2+\beta_z^2}}s+1}{\frac{1}{\alpha_z^2+\beta_z^2}s^2 + 2\frac{\alpha_Z}{\alpha_z^2+\beta_z^2}s+1} \qquad (6)$$

(d) Introducing to the input of the filter exhibiting the transmittance [Eqn.(6)] the random signal described with the normal distribution N(0,1) one will get in the output of this filter the random signal with the known autocorrelation function. It means the signal of the measurement errors.

3. RESULTS OF THE SIMULATIONS

Simulation of the measurement error of the spherical coordinates was performed with the program MATLAB. The example distribution of the simulated distance errors as a function of time is presented in Fig. 1. Figure 2 presents the changes of the azimuth error as a function of time.

Next, the spectral analysis of the measuring errors of distance and angle coordinates was performed. In Figs 3 and 4, the spectra of the distance errors and the azimuth

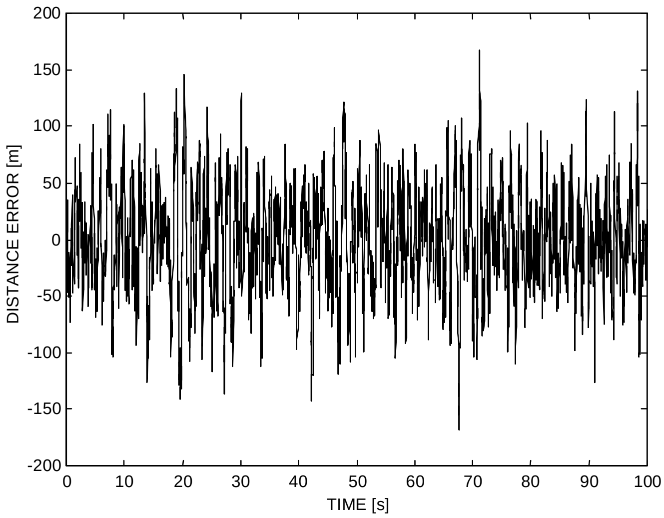

Figure 1. Distribution of the distance errors versus time of observation.

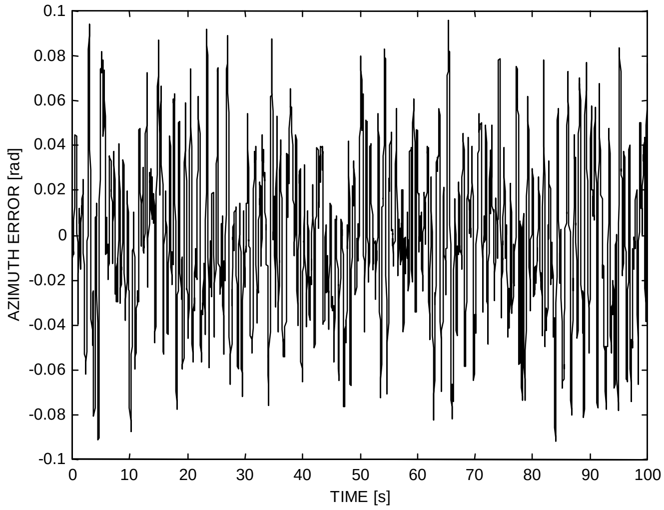

Figure 2. Distribution of the azimuth errors versus time of observation.

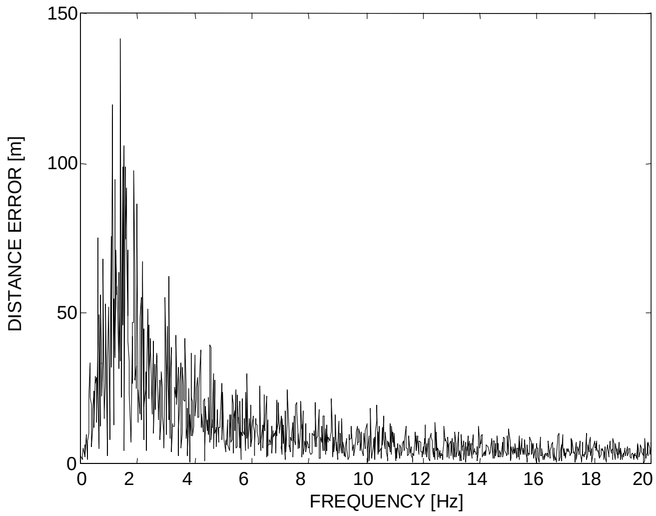

Figure 3. Spectrum of the distance error versus the frequency.

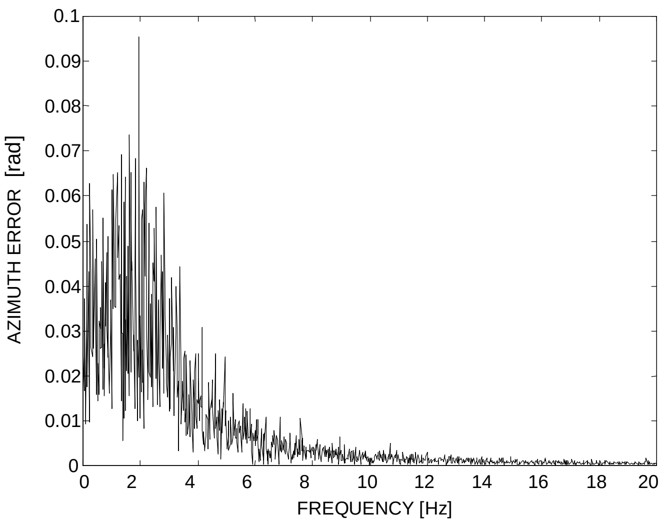

Figure 4. Spectrum of the azimuth error versus the frequency.

errors for the sampling frequency f=50 Hz are shown.

As it is seen in Figs 3 and 4, the spectrum of the measurement errors is the base for the statement that the signal of the measurement error is the signal of low frequency and its upper limit is the frequency about 5 Hz. This situation is disadvantageous as the useful signal is also the signal of the low frequency and disturbances of the frequency 1 Hz have the highest influence on the process of aiming. Next, the simulation of the process of ballistic computations was performed with the compliance of the measurement disturbances without their filtering for different trajectories of the flight of the target. The time of the flight of the shell to the meeting point of the target and the shell, at the target moving around a circle of the radius r =1000 m at the height 1000 m with a constant velocity 200 m/s when the disturbances are taken into account is presented in Fig. 5. Time of the flight without disturbances is a constant value and equals to 1.41s.

Time of the flight of the shell for the radius r = 3000 m at the same height and the velocity is shown in Fig. 6. In this case, the time of flight without disturbances equals to 4.096 s.

Figure 7 shows a percentage relative error of the time of flight for two radii of the moving target (a) r =1000 m (b) r = 3000 m.

In Fig. 8, the diagram of the time of flight to the meeting point bearing measuring errors, for the course of flight of the target around the circle and the hypothesis about its movement on the surface of the cylinder is presented. The diagram should be a solid line, however measuring disturbances cause that it's not possible to determine the real time what results in the errors of the aiming process.

4. CONCLUSIONS

Presented diagrams of the simulations of the signals spectra of errors performed for different trajectories of the target flight and the hypothesis about the movement of

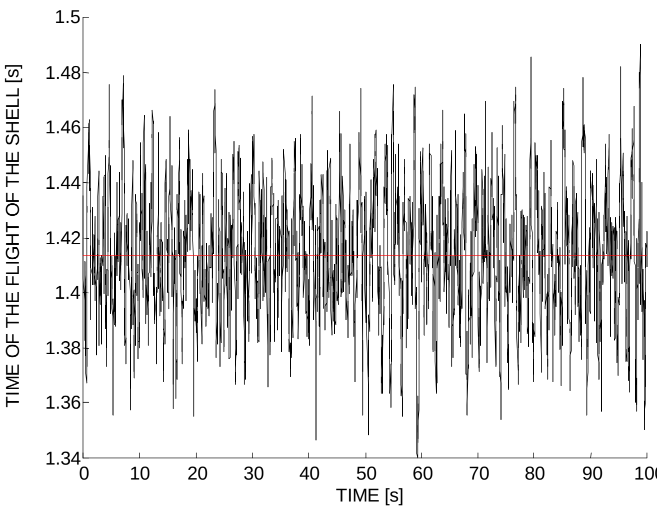

Figure 5. Computed time of the flight of the shell to the meeting point for r = 1000 m.

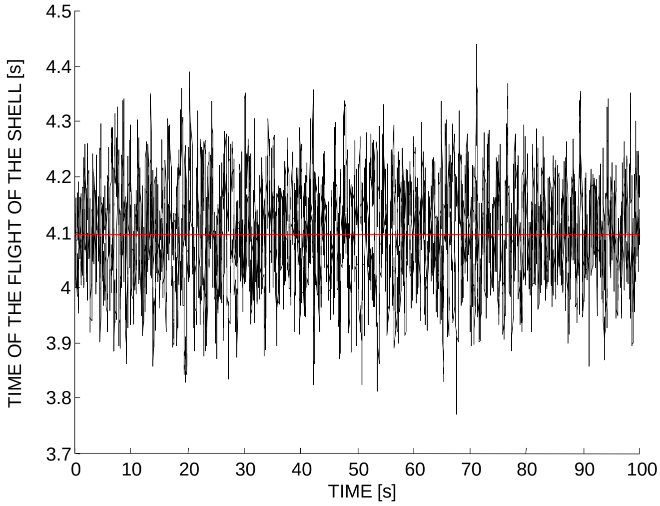

Figure 6. Computed time of the flight of the shell to the meeting point for r = 3000 m.

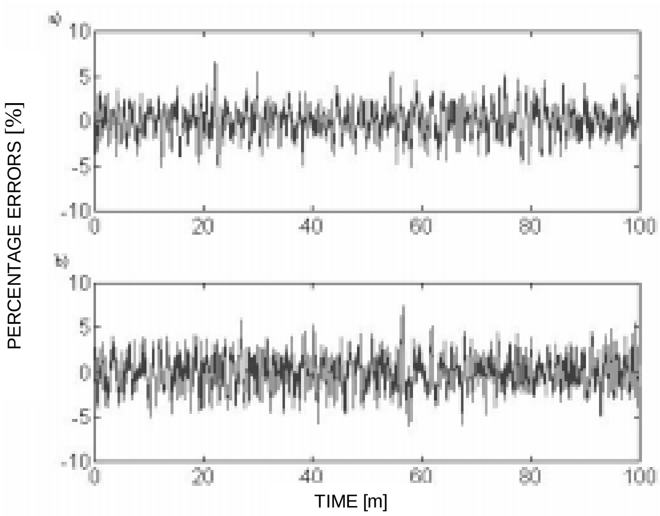

Figure 7. Percentage relative error of the time of flight of the shell versus time of observation.

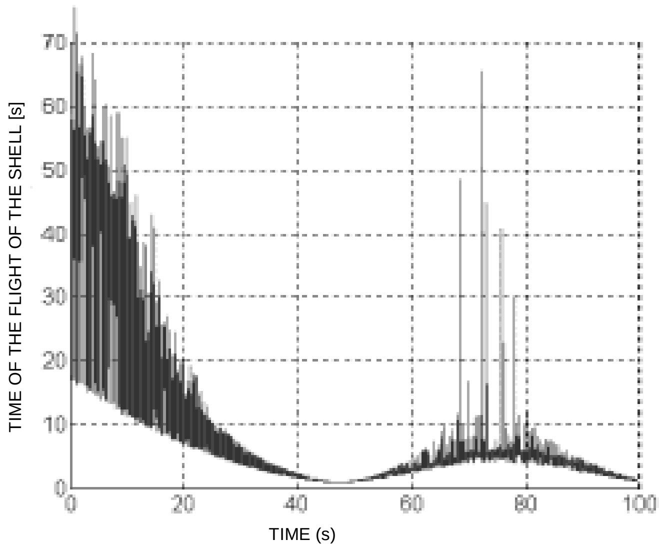

Figure 8. Time of flight to the meeting point bearing measuring errors versus time of observation.

the target allows to draw the following conclusions.

From the whole spectra of the measuring disturbances the most essential are those which are in the transmission band of the drive of the gun and additionally, for which the essential difficulties with their damping can happen in the input filters of the resolver. They are disturbances with the upper limit frequency at the level of 1 Hz.

Additionally at the interaction of the errors of coordinates of the target, changing in time, additional errors of the components of the velocity vector, and the acceleration vector appear. The results of their interaction are such strong disturbances of the process of aiming that without damping of vibrations of the components of the velocity vector and components of the vector of acceleration, shooting is practically impossible.

Disturbances of the process of aiming are in proportion to the time of the shell flight and the frequency of the measuring errors.

The analysis presented in the paper will give the base for the proper design of digital filtering circuits for signals of the coordinates of the target. It will enable the change of the approach to the input circuits preparing data for the ballistic modulus to minimise shooting errors and minimise the delay of the measuring signals.

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Dr Wieslaw Madej obtained his PhD (Control Theory) from the Military University of Technology, Warsaw, Poland, in 1993. Currently, he is working at the Koszalin University of Technology as the academic teacher (adjunct). His areas of interest are: Control theory, digital systems, and programmable logic controllers.