Feeding an information determine optic atmosphere turbulence into the simulation model of a seeker of homing missiles

TEODOR BALÁŽ, RADEK DOSKOČIL, MARTIN MACKO
Department of Weapons and Ammunition, Department of Air Defence Systems
University of Defence at Brno
Kounicova 65, Brno, 612 00
CZECH REPUBLIC

Abstract: Possible way of implementation of measured and computed data about atmosphere turbulence into the simulation model of an optoelectronic seeker (coordinator) of a homing missiles is described in this article. The general method allows analyzing of impact of the atmosphere turbulence on output signal of an optoelectronic tracking coordinator of homing missiles.

Key-Words: Turbulence, Atmosphere, Range, Seeker, Coordinator, Homing, Rocket, Simulation

1 Introduction

At homing rockets VSHORAD and SHORAD the optoelectronic (OE) tracking coordinators (TC) with one-gyroscope tracking actuating mechanism are use the most [3, 8] that is movably place on the board of a homing rocket. The position of the optic axis of a coordinator is controlled to follow the target all the time. It is allow to get necessary parameters for realization used guidance method (aiming angle ε and angular velocity of target $\dot{\varepsilon}$). Function chart of the OE TC with gyroscope tracking actuating mechanism for the vertical plane is in the Fig.1.

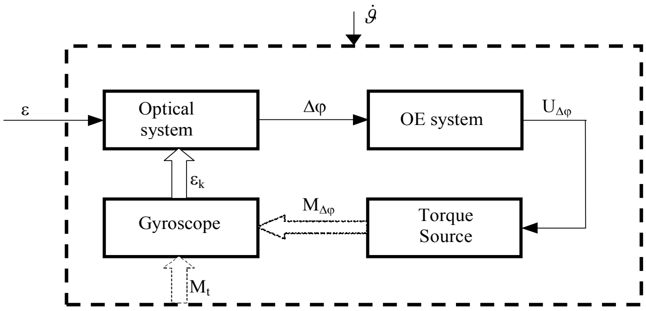

Fig.1 Function chart of the OE TC with gyroscope for the vertical plane

The measurement of desired parameters is based on the detection optic radiation to propagate in the atmosphere from interest target to OE TC. The atmosphere has an unnegligible impact on propagated radiation (Fig.2). In ideal atmosphere conditions the effect of attenuation (absorption, scattering) and turbulence on quality of image does not assume. Tasks of range of the OE TCs are solved only according to energy or geometrical formulas. The effect of attenuation and turbulence has to analyze when we research range and accuracy of the measurement of OE TCs in real atmosphere [10].

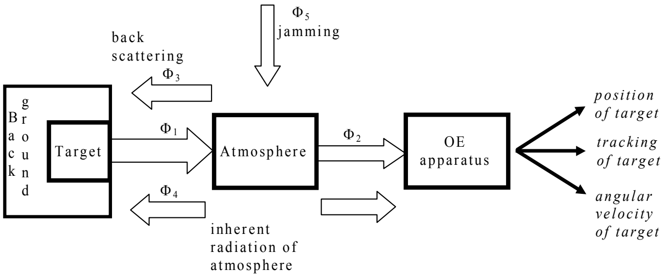

Fig.2 Chart of radiation in system of target, atmosphere and OE apparatus

The impact of attenuation and scattering of optic radiation on the resulting image created by OE system expresses especially on intensity decreasing of optic radiation during the propagation in atmosphere and on decreasing of contrast target/background. It decreases range of OE apparatus on the given target. Neither absorption nor scattering causes an angular error of aiming. Besides we are able to compensate a scattering sufficiently during measurement of a distance. Turbulence of atmosphere – chaotic change of refraction index of air can change of dimension and shape of target image, to produced fluctuation of radiation amplitude, to produced random changes of position target image and to cause random error in aiming target and in measurement angular position target, possibly angular velocity, and in the end to influence of range of TC [1,].

2 Problem Formulation

Function chart from Fig.1 is possible to transform into structural chart of OE TC with gyroscope tracking actuating mechanism, in the Fig.3, according to Laplace transformation rules [4, 7].

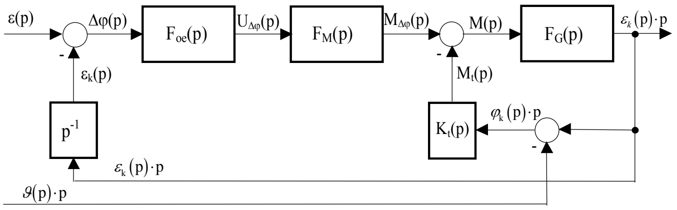

Fig.3 Structural chart of OE TC with gyroscope for the vertical plane [3]

In structural chart in the Fig.3 represent:

$F_{oe}(p)=\dfrac{U_{\Delta\varphi}(p)}{\Delta\varphi(p)}=\dfrac{K_{oe}}{1+p\cdot T_e}$ standard transfer function of OE system includes an objective; (1)

$F_M(p)=\dfrac{M_{\Delta\varphi}(p)}{U_{\Delta\varphi}(p)}=\dfrac{K_M}{1+p\cdot T_e}$ standard transfer function of a torque source; (2)

$F_G(p)=\dfrac{\varepsilon_k(p)}{M(p)}=\dfrac{1}{p\cdot L}=\dfrac{K_G}{p}$ standard transfer function of a free gyroscope; (3)

K_t friction coefficient in bearings of gyroscope.

Input information of TC about angular position (eventually angular velocity) of tracked target is represented by value of position angle ε (eventually angular velocity of change of the aiming line of target $\dot{\varepsilon}$). Goal of control is the optic axis of TC to aim to the target all the time. This situation is possible to describe by term $\varepsilon_k=\varepsilon$, and control deviation $\Delta\varphi=0\,\mathrm{rad}$ too. Longitudinal vibrations of rocket $\dot{\vartheta}$ are next input quantity ("harmful"), that influence must be eliminated. According to theory of automatic control [3, 8], when it is true a condition $K_t\to 0$, for the control deviation of TC (Fig.3) to valid formula

$$\begin{aligned}\Delta\varphi(p)&=\frac{p^2\cdot T_e\cdot T_M+p\cdot(T_e+T_M)+1}{p^3\cdot T_e\cdot T_M+p^2\cdot(T_e+T_M)+p+K_o}\cdot\dot{\varepsilon}(p)=\\&=F_{\Delta\varphi,\dot{\varepsilon}}(p)\cdot\dot{\varepsilon}(p)\end{aligned}\quad, \qquad (4)$$

where $K_o=K_{oe}\cdot K_M\cdot K_G$ is whole amplification given as product amplification of OE system, source of a torque and inverse value of a moment of momentum of the gyroscope; $F_{\Delta\varphi,\dot{\varepsilon}}(p)$ is a transfer function of a control deviation; T_e a T_M are time constants of filter cells of the electronic block and source of torque.
Then for the stabilized value of control deviation is valid

$$\Delta\varphi_{ust}=\lim_{p\to 0}\left[p\cdot\Delta\varphi(p)\right]=\lim_{p\to 0}\left[p\cdot F_{\Delta\varphi,\dot{\varepsilon}}(p)\cdot\frac{\dot{\varepsilon}_o}{p}\right]=\frac{1}{K_o}\dot{\varepsilon}_o \qquad (5)$$

where $\dot{\varepsilon}_o$ is magnitude of angular velocity jump of a change direction of target aiming line.

From carried out analysis and from terminal formula (5) follow that

- stabilized value of control deviation $\Delta\varphi$ is proportional to angular velocity of the change of direction of the target aiming line $\dot{\varepsilon}(t)$;
- TC with a partial transfer functions (1 to 3) behaves as a system with first astatism, i.e. the system has a zero stabilized deviation of position and constant deviation of velocity;
- the using of gyroscope tracking actuating mechanism leads in effective suppression of rocket longitudinal vibrations on operation of TC.

Followed conclusions are convenient for the method of proportional guidance and their modifications that used at homing rocket VSHORAD and SHORAD the most. These conclusions from analysis of TC are possible to check and enlarge with the help of the simulation model (*SledKoord1.mdl*) in interface Matlab [8] (Fig.4).

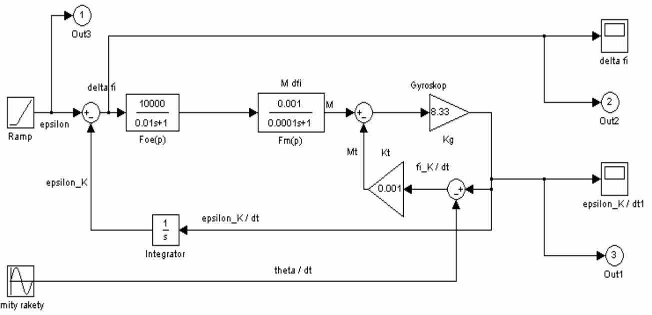

Fig.4 Chart of simulation model OE TC with gyroscope at interface MATLAB – Simulink (*SledKoord1.mdl*)

For the simulation of function [7] the OE TC of homing rockets VSHORAD and SHORAD have to determine as soon as the following parameters (here determined for the OE TC system VSHORAD Strela-2M) [8, 9]:

- gain of optic system $K_o=100$, gain of electronic system $K_e=100$, time constant of electronic system (filter) $T_e=f_r^{-1}=100^{-1}\ \mathrm{s}=10\ \mathrm{ms}$;
- gain of source of torque $K_M=0{,}001$, time constant of the source of torque $T_m=0{,}1\ \mathrm{ms}$;
- gain (a moment of momentum) of gyroscope $K_G=L^{-1}=\left(0{,}12\ \mathrm{kg\cdot m^2s^{-1}}\right)^{-1}\doteq 8{,}33\ \mathrm{kg^{-1}m^{-2}s}$, friction coefficient in bearings of gyroscope $K_t=1\cdot 10^{-3}$;
- angular velocity of target $\dot{\varepsilon}(t)=0{,}2\ \mathrm{rad\cdot s^{-1}}$;
- frequency of the longitudinal vibrations of rocket $f_r=900\ \mathrm{min^{-1}}=15\ \mathrm{s^{-1}}$, i.e. $\omega_r=94{,}5\ \mathrm{s^{-1}}$, amplitude of vibrations range $0{,}01\ \mathrm{rad}\div 0{,}2\ \mathrm{rad}$.

The results of simulation of function the OE TC, i.e. courses of signals into model *SledKoord1.mdl* (Fig.4), are showed for time range $(0 \div 1)\,\mathrm{s}$ and above mentioned parameters and for two characteristic cases (idealized $A(\dot{\vartheta}) << 0{,}1\,\mathrm{rad}$ and real $A(\dot{\vartheta}) \geq 0{,}1\,\mathrm{rad}$ situation) in diagrams in the Fig.5a and Fig.5b. (Top diagrams express a input function $\varepsilon[\mathrm{rad}] = f(t)$, the middle – function of a control deviation $\Delta\varphi[\mathrm{rad}] = f(t)$ and bottom – output function $\mathrm{d}\varepsilon_k / \mathrm{d}t\left[\mathrm{rad}\cdot\mathrm{s}^{-1}\right] = f(t)$.)

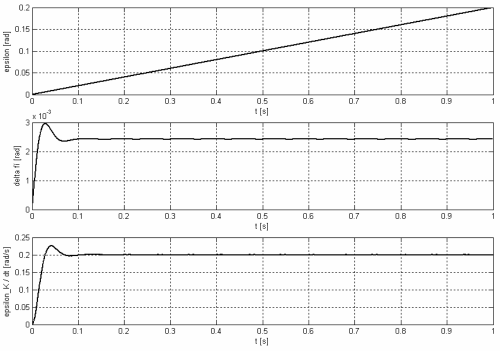

Fig.5a Signals for the amplitude vibrations $A(\dot{\vartheta}) << 0{,}1\,\mathrm{rad}$ and $K_t \to 0$

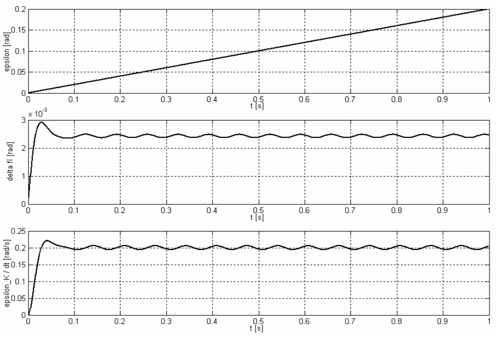

Fig.5b Signals for the amplitude vibrations $A(\dot{\vartheta}) \geq 0{,}1\,\mathrm{rad}$ and $K_t \to 0$

From top diagram in the Fig.5a follows, if the target moves constant angular velocity $\dot{\varepsilon}(t) = konst$ (i.e. $\varepsilon(t) = k \cdot t$) at vertical plane and if friction coefficient in bearings is minimal ($K_t \to 0$), and at the same time amplitude of the longitudinal vibrations $A(\dot{\vartheta}) << 0{,}1\,\mathrm{rad}$, so courses of signals correspond to theoretical assumptions. From the last diagram in the Fig.5a can read value $\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s}) \approx 0{,}2\,\mathrm{rad}\cdot\mathrm{s}^{-1} = \mathrm{konst.}$, that correspond chosen input value $\dot{\varepsilon}(t) = 0{,}2\,\mathrm{rad}\cdot\mathrm{s}^{-1}$. So that to be valid $\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s}) = \dot{\varepsilon}(t)$. Next to see, $\dot{\varepsilon}_k(t) = \Delta\varphi(t)\cdot k$, and thus control deviation $\Delta\varphi(t > 0{,}1\,\mathrm{s})$ is possible to use for measurement of value $\dot{\varepsilon}(t)$, or to be valid $\dot{\varepsilon}(t > 0{,}1\,\mathrm{s}) = \Delta\varphi(t)\cdot k$.

If conditions are fulfilled, except value of amplitude of the longitudinal vibrations of rocket, that is $A(\dot{\vartheta}) \geq 0{,}1\,\mathrm{rad}$, then courses of signals are showed on the Fig.5b. It knows that $\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s}) \neq \mathrm{konst.}$, but values vary. Course of $\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s})$ can approximately express by formula

$$\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s}) = \dot{\varepsilon}_{k\_konst} + \dot{\varepsilon}_{k\_prom}(A_{\dot{\vartheta}})\cdot\sin(2\cdot\pi\cdot f_r\cdot t),$$

where $\dot{\varepsilon}_{k\_prom}(A_{\dot{\vartheta}})$ is error amplitude of measurement of angular velocity of TC optic line, that value is function of amplitude $A(\dot{\vartheta})$. By simulation it is possible to show that a amplitude periodical variation $\dot{\varepsilon}_{k\_prom}$ a quantity $\dot{\varepsilon}_k(t > 0{,}1\,\mathrm{s})$ rises with rising a value $A(\dot{\vartheta})$. From diagrams in the Fig. 5b see that $\Delta\varphi(t > 0{,}1\,\mathrm{s}) \neq konst.$ In spite of $\dot{\varepsilon}_k(t) = \Delta\varphi(t)\cdot k$, when we implemented formula (5) the error of measurement arises the more the bigger is value $A(\dot{\vartheta})$.

Now we can ask legitimately: "***Where is the problem?***" Wee see that used mathematical model (1 to 5) does not allow to direct analysis (implementation) of impacts of atmosphere turbulence to output signal of OE TC. The model does not contain any direct optic quantities that to determine atmosphere turbulence and that to influence function of OE TC. Solution is to add some "input function" in OE TC that express change in input quantity ε produced by turbulence. For the first explanation (approach) we will use a model of course quantity ε with mean square deviation σ [1, 8], Fig.6.

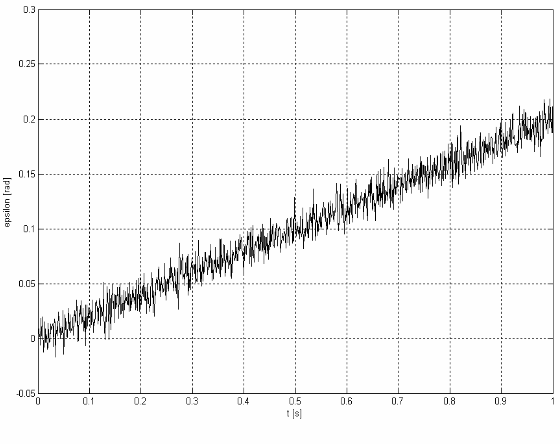

Fig.6 Model of input signal $\dot{\varepsilon}(t) \neq \mathrm{konst}$ with σ

3 Problem Solution

We will analyze the case when $\dot{\varepsilon}(t) \neq \text{konst}$ (Fig.6). It is means that the change course of angle $\varepsilon(t)$ in time is not linear rising, i.e. $\varepsilon(t) \neq k \cdot t$, but values of angle ε are dispersed about σ_ε from mean value. This model course corresponds to case when the changes are produced by propagation optic radiation in atmosphere from target.

The simulation model *SledKoord2.mdl* was formed for an investigation manner of the OE TC and his output signals include the impact of turbulence – fluctuation instantaneous position of "centre" in direction axis *x* [1, 2, 6], Fig.7. The element parameters of OE TC are the same as previous examples.

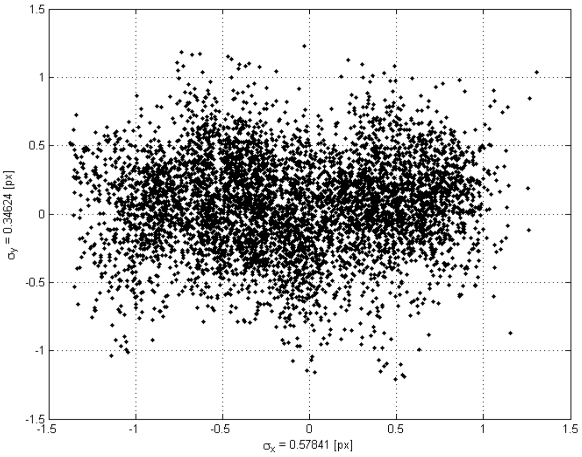

Fig.7 Model of fluctuation of instantaneous position of „centre" of target in detector plane [1]

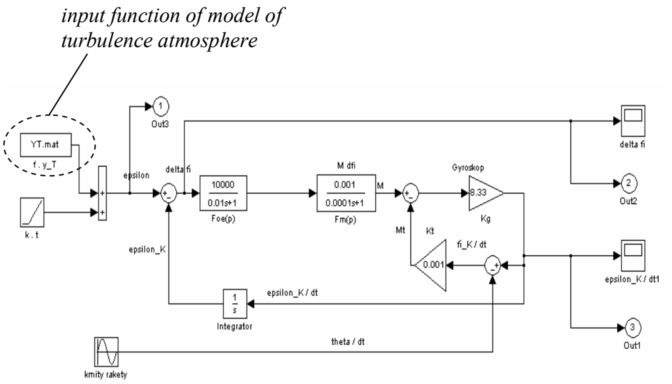

Fig.8 Chart of the simulation model *SledKoord2.mdl*

The results of simulation function the OE TC by means of model *SledKoord2.mdl* (Fig.8) with input function (YT.mat) influenced of model of real atmosphere are showed for time range $(0 \div 1)s$ in diagrams in the Fig.9a, Fig.9b and Fig.9c.

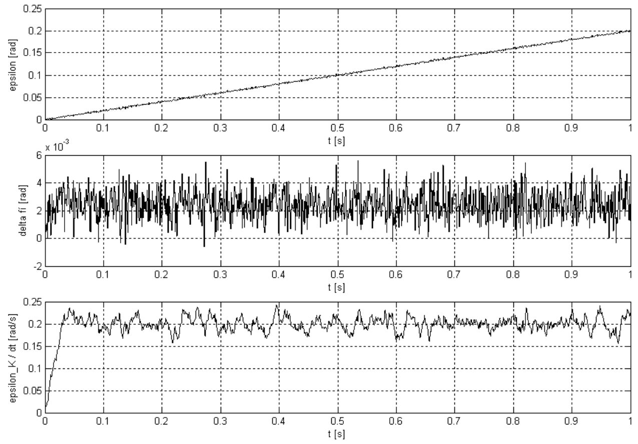

Fig.9a Signals for vibrations $A(\dot{\vartheta}) << 0,1\,\text{rad}$, $K_t \to 0$ and mean square deviation $\sigma_\varepsilon = 1 \cdot 10^{-6}$ rad

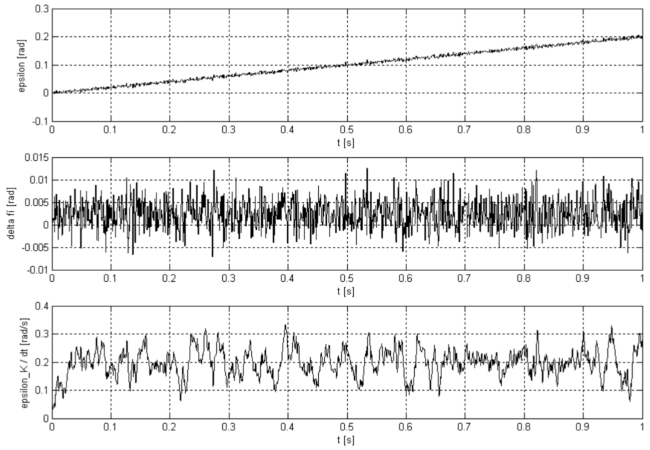

Fig.9b Signals for vibrations $A(\dot{\vartheta}) << 0,1\,\text{rad}$, $K_t \to 0$ and mean square deviation $\sigma_\varepsilon = 1 \cdot 10^{-5}$ rad

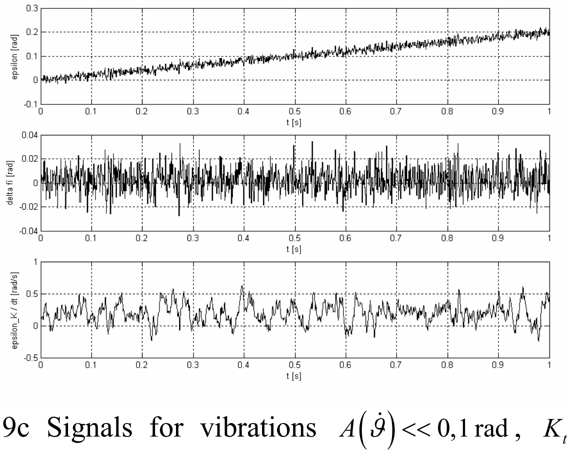

Fig.9c Signals for vibrations $A(\dot{\vartheta}) << 0,1\,\text{rad}$, $K_t \to 0$ and dispersion $\sigma_\varepsilon = 1 \cdot 10^{-4}$ rad

4 Conclusion

- From computed courses in the Fig.9a,b,c we can see that signals of deviation $\Delta\varphi(t)$ and angular velocity

$\dot{\varepsilon}_k(t)$ are impacted on atmosphere very substantially contrary to signals in the diagrams in the Fig.5a,b. And it more the bigger is value of dispersion σ_ε of input signal $\varepsilon(t)$.

- If mean square deviation approximately $\sigma_\varepsilon \le 1\cdot 10^{-5}\ \text{rad}$, implementation of filters would lead to suppression of high-frequency part of signal $\Delta\varphi$ and $\dot{\varepsilon}_k$, and his smoothing too. Course of signal would be approximately constant, i.e. $\Delta\varphi(t \ge 0{,}1\ \text{s}) \approx \text{konst}$ and $\dot{\varepsilon}_k(t \ge 0{,}1\ \text{s}) \approx \text{konst}$. Subsequently it would allow using of formula $\dot{\varepsilon}(t) = \Delta\varphi(t)\cdot k$ for realization proportional method of guidance.
- If mean square deviation $\sigma_\varepsilon \ge 1\cdot 10^{-4}\ \text{rad}$, signals of deviation $\Delta\varphi(t)$ and angular velocity $\dot{\varepsilon}_k(t)$ are impacted on atmosphere so more that using of filtration and realization proportional method of guidance would be very problematic and ineffective.

For practical applicability of this model of OE TC is necessary to replace model of “input function” ε by experimental taken data about atmospherically turbulence [6, 8]. It is next task for our job.

References:

[1] BALÁŽ, T., DOSKOČIL, R., KRIST, Z., MACKO, M. Fluctuation of Direction Points in the Field of View of the Optoelectronic Device by Turbulent Atmosphere. *Budapest: 4th International Conference New Challenges in the Fields of the Military Sciences 2006, Zrinyi Miklos National Defence University, Hungary, 2006.* ISSN: 1416-1443.

[2] BALÁŽ, T., DOSKOČIL, R., MACKO, M., ŘEHOŘ, Z. Chyba zamíření způsobená turbulencí atmosféry (Aiming error causes by atmosphere turbulence). *Liptovský Mikuláš : 12th International Scientific Conference Armament and Technics of Land Forcers 2006, Akadémie ozbrojených sil gen. M. R. Štefánika, Katedra strojárstva, Liptovský Mikuláš, Slovensko, 2006.* 7 p. ISBN 978-80-8040-309-6.

[3] HAMTIL, I., DOSKOČIL, R. *Optoelektronické koordinátory raketových systémů (Optoelectronic coordinators of rocket systems).* Brno : Vojenská akademie v Brně, 2000.

[4] HOLST, C. G. *Testing and Evaluation of Infrared Imaging Systems.* Second edition. Winter Park and Washington : JCD Publishing and SPIE Optical Engineering Press, Bellingham, Washington, USA, 1998.

[5] HOLST, C. G. *Elektro-optical Imaging system Performance.* Second edition. Washington : JCD Publishing and SPIE Optical Engineering Press, Bellingham, Washington, USA, 2000.

[6] BALÁŽ, T., DOSKOČIL, R., MACKO, M., MELŠA, P., ŘEHOŘ, Z. Experimental Determination of a Correlative Dependence of the Image Frames from Direction and Measure Line of a Passive Rangefinder in the Turbulent Atmosphere Conditions. *Trenčín: 1st International Conference Advance in Mechatronics, Alexandr Dubček University of Trenčín, Slovakia, 2006.* ISBN 80-8075-111-0, EAN 9788080751111.

[7] BOREMAN, G. D. *Modulation Transfer Function in Optical and Electro-Optical Systems.* Washington : SPIE Press, The International Society for Optical Engineering, Bellingham, Washington, USA, 2001.

[8] DOSKOČIL, R. Optoelektronický koordinátor univerzálního raketového kompletu blízkého dosahu (Optoelectronic seeker of a general SHORAD rocket system). *Brno : [Dissertation], University of Defence, 2007.*

[9] DOSKOČIL, R. Modelování optoelektronického systému s koordinátorem raketových kompletů VSHORAD (The modeling of optoelectronic system with seeker of VSHORAD rocket system). *Liptovský Mikuláš : Sborník Akademie ozbrojených sil gen. M. R. Štefánika Vojenskej akadémie v Liptovskom Mikuláši, Simulácia a modelovanie v PVO, Slovenská republika 2005.*

[10] HOUGHTON J. *The Physics of Atmospheres.* Third edition. Cambrige: Cambridge University Press, United Kingdom, 2002.