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Selected methods of control of the scanning and tracking gyroscope system mounted on a combat vehicle

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ABSTRACT

At present, remotely controlled modules of weaponry are becoming the basic equipment of modern army. The device for searching and observing air targets is one of the most significant elements of a weapon module. The device of that type in the form of the scanning and tracking gyroscope system is considered in the article. The process of automatic search of a target is carried out during the movement of a combat vehicle as well as during its manoeuvres. After a target is detected, it is tracked till it has been destroyed by the fired missile. The algorithm of control of the scanning and tracking gyroscope system, mounted on the deck of a combat vehicle, was developed. The optimized, classic PD controller, fuzzy controller PD type, fuzzy controller PID type and adaptive fuzzy controller were designed. Numerical research of the dynamics of the controlled gyroscope system and the assessment of the quality of control were conducted. The results of research are presented in a graphical form.

1. Introduction

The self-propelled artillery and rocket system (a combat vehicle with a weaponry unit in the form of compressed cannons with missiles) ensures anti-aircraft protection to military troops increasing their mobility at the same time. A quick change of a current location is an inseparable element of a strategy indispensable on a contemporary battlefield. Searching, identifying and tracking the detected air target during the movement of a vehicle are important elements of the operation of the unit. At present, more and more countries equip their armies with self-propelled units with remotely controlled weapon modules. The device for searching and observing air targets is one of the most significant elements of a weapon module. The stabilized platform is the basis of the device structure. Thermographic camera and a laser range finder are usually placed on it (Koruba, Dziopa, & Krzysztofik, 2010a). The platform allows to isolate the device from angular movements of the vehicle. Thanks to that the target image is stable and the movements of cameras are independent of external vibrations and disruptions. Moreover, the platform may perform the programmed movement on a set trajectory.

An observation device in the form of the scanning and tracking gyroscope system (STGS) is considered in the article. The gyroscope came to be used as a drive in self-guided target seekers of missiles, as an executive unit in control systems of spacecraft as well as in autonomous systems for space searching. The dynamics and stability of a nonlinear gyroscope, chaos control and synchronization, have been examined by many authors in papers (Chen, 2002; Chen & Ge, 2005; Chen, Kuo, Lin, Hsu, & Tsui, 2013; Ge & Lee, 2005; Lei, Xu, & Zheng, 2005; Roopaei, Zolghadri Jahromi, John, & Lin, 2010; Salarieh, 2008; Sargolzaei, Yaghoobi, & Yazdi, 2013; Van Dooren, 2003; Wang & Yau, 2011; Yan, Hung, Lin, & Liao, 2007; Yau, 2007, 2008a, b). A symmetrical gyroscope placed on a vibrating base with linear or nonlinear attenuation was considered. External disruptions have been adopted in a harmonic form. Gyroscope movement was described with the use of Euler's angles. For effective chaos control and the synchronization of chaotic behaviours for two nonlinear gyroscopes, various methods of control have been used, among others: delayed feedback control, adaptive control algorithm (Chen, 2002; Ge & Lee, 2005; Van Dooren, 2003), active control (Lei, Xu, & Zheng, 2005; Salarieh, 2008), fuzzy logic control (Sargolzaei et al., 2013; Yau, 2007), variable structure control (Yan et al., 2007), sliding mode control (Yau, 2008b), fuzzy sliding mode control (Yau, 2008a) and adaptive fuzzy sliding mode control (Roopaei et al., 2010). In papers (Chen et al., 2013; Wang & Yau, 2011) the sliding mode controller and fuzzy sliding mode controller which takes the gyroscope from chaotic to periodic movement were designed and examined. In paper (Polo, Albertos, & Galiano, 2008), authors used PID controller for gyroscope control and presented the procedure of determining permissible parameters of the controller with the use of the the-

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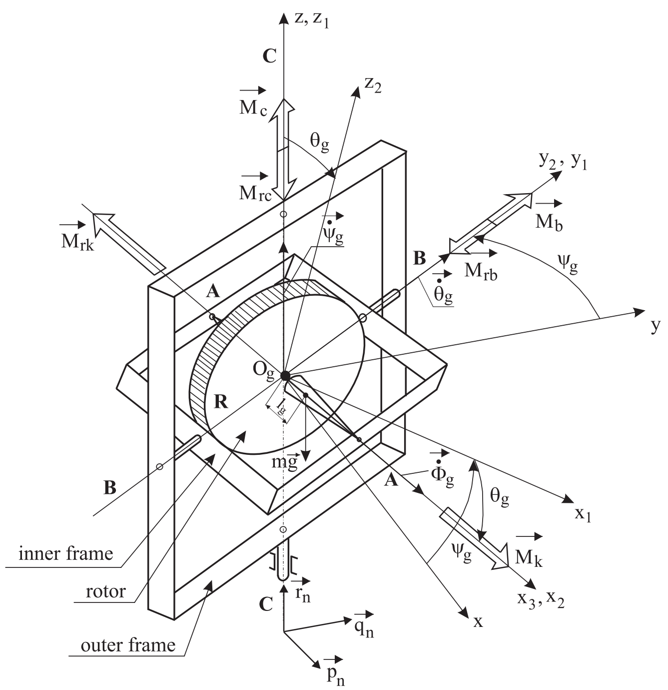

Fig. 1. General view of the gyroscope.

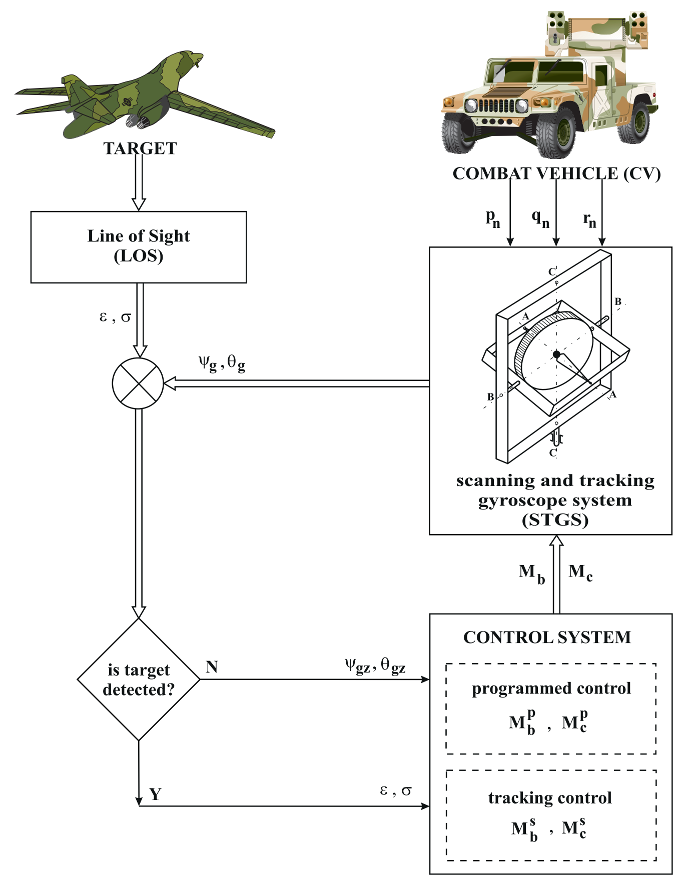

Fig. 2. The algorithm of operation of STGS mounted on the deck of a combat vehicle.

ory of bifurcation. The examples of gyroscope use in the modified optical target seeker of the homing missile and guided bomb have been discussed in papers (Gapiński & Stefański, 2014; Ogonowski & Adamski, 2014). The presented algorithm of control uses phase trajectories of control errors (Gapiński & Stefański, 2014).

The heavy scanning and tracking gyroscope, mounted on Cardan joint and placed on the deck of a combat vehicle (CV), is considered in this paper. It needs to be emphasized that as opposed to the above mentioned papers, the examined gyroscope constitutes a strongly nonlinear system considering the inertia of suspension frames and primarily the kinematic influence of the base (of CV deck) (Awrejcewicz & Koruba, 2012). While searching for a target, the system axis scans the air space on a set path, i.e. it draws the strictly defined lines in a suitably selected plane in space. Then, the infrared detector of the scanning and tracking system has the possibility of intercepting the thermal radiation emitted by the air target. After detecting the target, the gyroscopic system automatically passes to the automatic tracking of the target, i.e. from that moment its axis overlaps with the line of sight (LOS). It is significant that the process of automatic search of a target is carried out during the movement of the CV as well as during its manoeuvres. After a target is detected, it is tracked till it has been destroyed by the fired missile. Therefore, the use of the scanning and tracking gyroscope system increases the effectiveness of conducting combat tasks by anti-aircraft defence sub-units and allows to attack air targets when the vehicle is moving (Koruba, Dziopa, & Krzysztofik, 2010b; Krzysztofik, 2012; Krzysztofik & Koruba, 2012).

The problems connected with the optimum control of the gyroscope system contributed to looking for new techniques of control based on artificial intelligence methods, e.g. fuzzy logic. The use of fuzzy logic controllers (FLC) enables first and foremost passing from quantitative to qualitative description of the process. In traditional control systems the control algorithms are prepared in an intuitive way by operators based on their own experience. Using the methods of fuzzy logic, one can record the knowledge acquired during the operation and supervision of the process, or the expertise of operators constituting the intuitive algorithms of control of adjustment objects, with verbal logic to mathematical operations and use it in the process of control. The systems with fuzzy logic, thanks to expert knowledge, may also be used in processes in which nonlinearities, uncertainties as to their parameters or other unfavourable features of the control process occur. Systems with fuzzy logic are intelligent control methods in which the knowledge encoded in the rules base results from experience and intuition as well as the theoretical and practical understanding of the process dynamics. The use of fuzzy logic in controllers results from the fact that a knowledge of the process dynamics is not required to tune a controller. Fuzzy control became popular also because real control objects are nonlinear and therefore require the use of specific adjustment techniques the designing of which is usually very difficult, laborious, and sometimes impossible. For such objects, designing fuzzy controllers may be much easier, and the controllers themselves may replace classic or state controllers.

Fig. 1 shows the general view of the gyroscope, including the adopted systems of coordinates. The location of systems in relation to one another is determined by Bryant's angles θ_g, ψ_g, Φ_g.

The most general equations of dynamics of the gyroscope system were introduced with the use of Lagrange IInd kind of equations (Awrejcewicz & Koruba, 2012; Krzysztofik & Koruba, 2012):

$$\begin{aligned}\frac{d^2}{dt^2}\psi_g = \{ & -\left[J_{z_1} + J_{z_2} + J_{z_3} + \left(J_{x_2} - J_{z_2} - J_{z_3}\right)\sin^2\theta_g + ml_g^2(1+\cos\theta_g)^2\right]\frac{dr_n}{dt} \\ & + \frac{1}{2}\left(J_{z_2} + J_{z_3} - J_{x_2}\right)\left(\omega_{gz_1}\frac{d\theta_g}{dt} - \frac{d\omega_{gx_1}}{dt}\right)\sin 2\theta_g + \\ & - \left[J_{z_2} + J_{z_3} + \left(J_{x_2} - J_{z_2} - J_{z_3}\right)\sin^2\theta_g\right]\omega_{gx_1}\frac{d\theta_g}{dt} + \left(J_{z_2} + J_{z_3}\right)\omega_{gz_2}\omega_{gy_2}\sin\theta_g \\ & + J_{x_2}\omega_{gx_2}\omega_{gy_2}\cos\theta_g + J_{x_3}n_g\omega_{gy_2}\cos\theta_g \\ & + \left(J_{x_1} - J_{y_1}\right)\omega_{gx_1}\omega_{gy_1} - \left(J_{y_2} + J_{y_3}\right)\omega_{gy_2}\omega_{gx_1} + - ml_g(1+\cos\theta_g)\end{aligned}$$

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