

ON A METHOD OF TARGET DETECTION AND TRACKING USED IN AIR DEFENCE

JAN W. OSIECKI

Military Academy of Technology, Warsaw, Poland

e-mail: osewoj@wp.pl

KONRAD STEFAŃSKI

Kielce University of Technology, Kielce, Poland

e-mail: konrad@poczta.fm

The work discusses a new approach to the control of motion of the gyroscope axle with an in-built optical system responsible for detection and tracking of aerial targets emitting infrared radiation. The method, which has been presented by the authors at numerous conferences on the subject, requires using phase trajectories of control errors.

Key words: gyroscope, scanning, phase trajectories

1. General information

The work discusses the operation of a short-range anti-aircraft missile fired from a mobile launcher mounted on a vehicle or a naval ship. The launching takes place during motion of the vehicle or vessel. The study focuses on a passive self-guidance system used for targets emitting thermal (infrared) radiation, which are "seen" by a missile as light spots (at a longer distance) or light patches (at a closer distance). An object to be attacked by a missile should be intercepted by the built-in optical system before the missile is launched. It may be difficult, however, to select the precise moment of missile firing (after an image of the target is perceived in the optical system) when the launcher is moving or the base, on which the operator stands, is moving. Modern systems for scanning or searching through the space and detecting the target are used to facilitate the manual operation (Krzysztofik and Osiecki, 2000; [7]; Voigt, 1977). Scanning heads are used in ground-air and air-air missiles.

The aim of the work is to present and analyse an efficient system for space scanning used in a rocket head. After the object to be attacked is detected basing on the emitted infrared radiation, it can be tracked while the missile realises the first loop of the self-guidance process (Osiecki and Stefański, 2003, 2004).

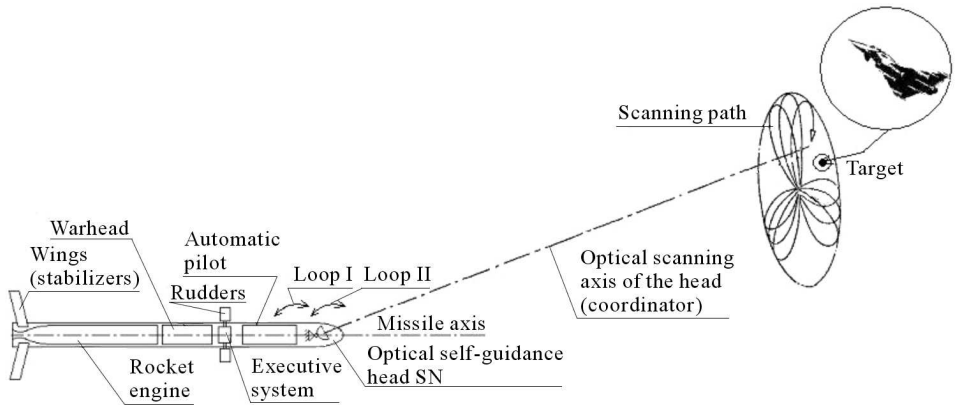


Fig. 1. The proposed system responsible for space scanning and target tracking

The proposed system responsible for space scanning and target tracking operates according to the principle shown in Fig. 1. The optical unit is mounted in the gyroscope axle with three degrees of freedom (Fig. 2: $d\Phi/dt = n = \text{const}$). The unit with the gyroscope and the control circuit is mounted on board of an aerial vehicle such as a missile or another unmanned aerial vehicle.

The system operation can be divided into three stages. Stage I is conventionally termed the space patrolling. The aerial vehicle with a scanning-tracking system on board moves in the surveillance zone with a programmed motion. The motion program will not be discussed here, as it is the subject of a separate strategy. When the target is intercepted, i.e. when it is at a presumed view position, the program responsible for scanning the space and determining the angular coordinates of the target is switched on. In stage III, the target is tracked and, if necessary, destroyed.

In stage II, the direction of the gyroscope axle is controlled according to a pre-determined program of space scanning and target tracking, both in a closed system, basing on the method described in Hsu and Meyer (1970), Osiecki and Stefański (2003, 2004), Stefański (2004), which uses the deviation trajectories tending to zero.

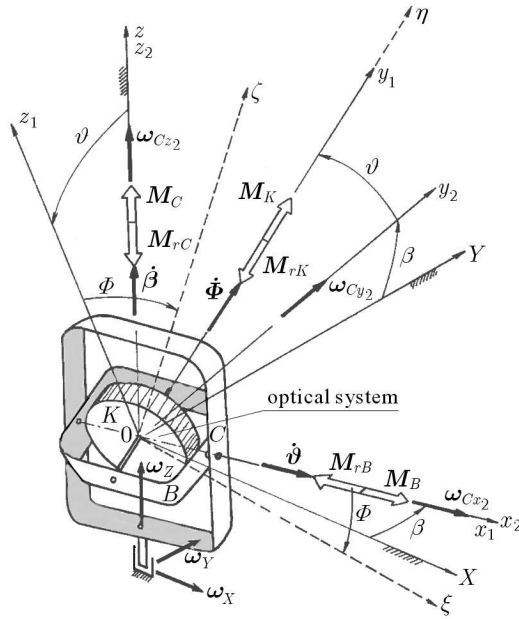


Fig. 2. A diagram of the gyroscope suspended on Cardan's joint

The equations of motion of the optical unit mounted on the gyroscope axle are given:

a) for rosette scanning (Fig. 4a)

$$\psi(t) = a \sin(\varpi_1 t) \sin(\varpi t) \qquad \eta(t) = a \sin(\varpi_1 t) \cos(\varpi t) \qquad (1.1)$$

b) for spiral scanning (Fig. 4b)

$$\psi(t) = (a - bt) \cos(\varpi t) \qquad \eta(t) = (a - bt) \sin(\varpi t) \qquad (1.2)$$

c) for multi-loop spiral scanning (Fig. 4c)

$$\begin{aligned} \psi(t) &= (a - bt) \cos(\omega t) + 0.1a \cos(80\varpi t) \\ \eta(t) &= (a - bt) \sin(\omega t) + 0.1a \sin(80\omega t) \end{aligned} \qquad (1.3)$$

The motions are realised through control applying the following system of equations describing motion of the gyroscope axle, 0η (Nizioł, 2005), see Fig. 1

$$\begin{aligned}
& J_B \ddot{\vartheta} + \frac{1}{2} J_B (\dot{\beta} + \varpi_Z)^2 \sin 2\vartheta - J_0 n (\dot{\beta} + \omega_Z) \cos \vartheta + J_B \dot{\omega}_X \cos \beta + \\
& - J_B \varpi_X \dot{\beta} \sin \beta - \frac{1}{2} J_B \varpi_X^2 \sin^2 \beta \sin 2\vartheta - J_0 n \omega_X \sin \beta \sin \vartheta + \\
& = J_B \omega_X (\dot{\beta} + \omega_Z) \cos 2\vartheta \sin \beta = M_B
\end{aligned} \tag{1.4}$$

$$\begin{aligned}
& J_B (\ddot{\beta} + \varpi_Z) \cos^2 \vartheta - J_B (\dot{\beta} + \omega_Z) \dot{\vartheta} \sin 2\vartheta + J_0 n \dot{\vartheta} \cos \vartheta + \\
& - \frac{1}{2} J_B \dot{\omega}_X \sin \beta \sin 2\vartheta - J_B \omega_X \dot{\beta} \cos \beta \cos^2 \vartheta - J_B \omega_X \dot{\vartheta} \sin \beta \cos 2\vartheta + \\
& + J_0 n \omega_X \cos \beta \cos \vartheta + J_B \dot{\vartheta} \omega_X \sin \beta + \frac{1}{2} J_B \omega_X^2 \sin 2\beta + \\
& + \frac{1}{2} J_B (\dot{\beta} + \omega_Z) \omega_X \cos \beta \sin 2\vartheta - \frac{1}{2} J_B \omega_X^2 \sin 2\beta \sin^2 \vartheta = M_C
\end{aligned}$$

and

$$M_0 = M_B - J \ddot{\vartheta} \quad M_0 = M_C - J \ddot{\beta}$$

Figure 3 shows a block diagram of the control system, which is uniform for *scanning* and *tracking* (stages II and III). At the moment the target is intercepted, the system begins either taking the target bearings or tracking it. The bearings can be taken only if the distant target practically does not move in relation to the system founded on the ground. When the tracking mode is selected, it is necessary that the switch-over be done in the system determining the signals p and r by introducing other deviations, i.e. replacing e_0 with $e_u = \vartheta - \theta_p$, e_1 with $e_{u1} = \dot{\vartheta} - \dot{\theta}_p$, e_2 with $e_v = \beta - \sigma_p$ and e_3 with $e_{v1} = \dot{\beta} - \dot{\sigma}_p$, where $\theta_p(t)$ and $\sigma_p(t)$ represent the angular coordinates of the moving target.

There exist a number of design solutions (mechanisms) as well as algorithms responsible for scanning. We shall focus on the design of a mirror lens (Fig. 1) fixed on the gyroscope axle and consider different yet uniform algorithms realising its scanning and tracking motions. The space scanning paths can be described with the general formula

$$\begin{aligned}
\vartheta &= a_1(t) \sin(\omega_1 t) + a_2(t) \cos(\omega_2 t) \\
\eta &= b_1(t) \cos(\omega_1 t) + b_2(t) \sin(\omega_2 t)
\end{aligned} \tag{1.5}$$

The formula describes the desired signals given at the input of the control system of the optical coordinator axle in the missile head. The control is realised in a closed system.

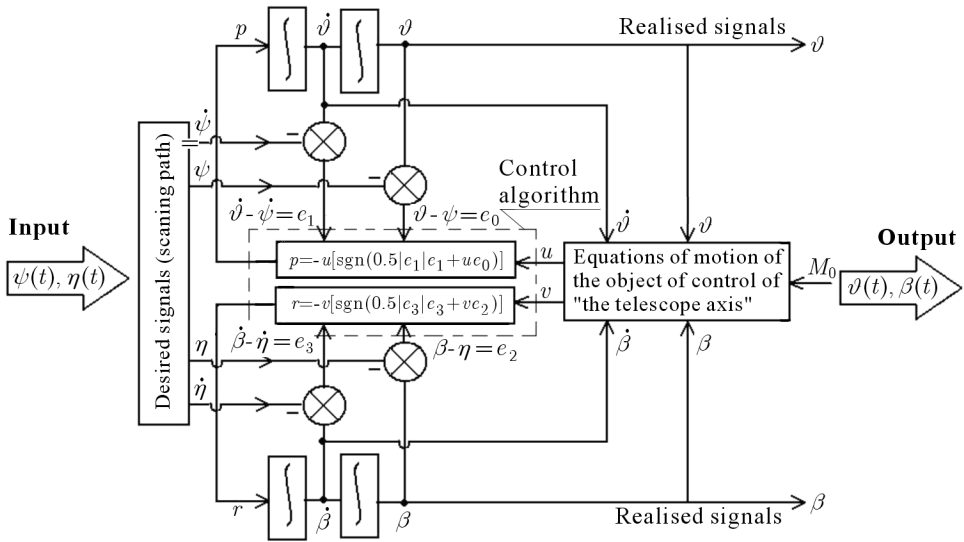


Fig. 3. A block diagram of scanning and tracing a target

Different scanning paths can be obtained, and the shape depends on the value of the following ratios: a_1/a_2 , b_1/b_2 and ω_2/ω_1 . Three exemplary shapes of scanning paths, which are axial and symmetrical [$a_i = b_i$], are shown in Figs. 4a, 4b and 4c, and these are: an Archimedean spiral, a multi-loop spiral and a *rosette*, respectively. When the scanning is performed along a rosette-shaped path, the number of the rosette leaves will be different, depending on the ratio $\omega_2/\omega_1 < 0$. When the ratio is $\omega_2/\omega_1 = n_2/n_1$, where n_1 and n_2 are natural prime numbers with regard to each other, the sum $n_1 + n_2$ is equal to the sum of the *rosette leaves*.

2. Summary and conclusion

The system proposed above uses a gyroscope with three degrees of freedom and an optical unit built in the gyroscope axle, which receives infrared signals sent by the target. Different algorithms can be applied to scan a large surveillance area. As soon as the first signals are received, i.e. the target is perceived as a light spot, the optical axis is directed towards the spot centre so that the target coordinates can be determined irrespective of the radiation energy distribution. The system of control is efficient even if the target

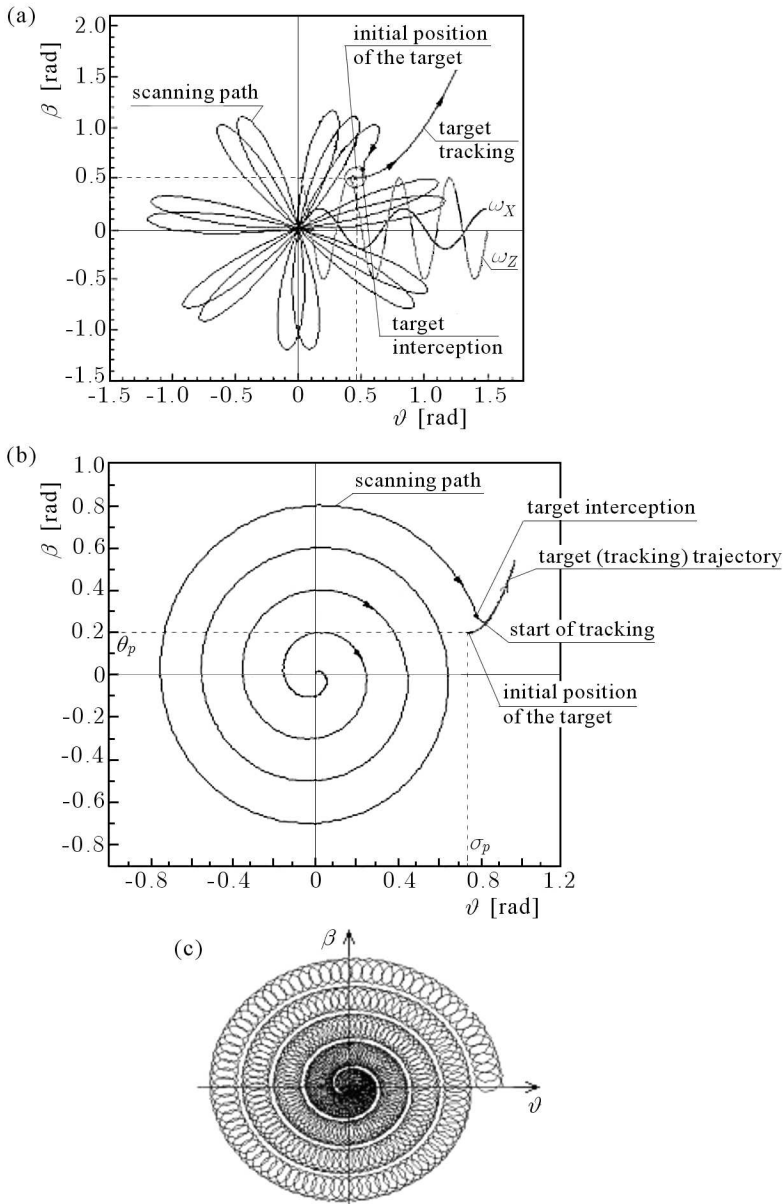


Fig. 4. Results of a digital simulation of tracing a target ($m = 0.8$ kg, $d = 0.08$ m, $M_0 = 500$ kh m^2/s^2 , $J = md^2/16$ kg m^2/s^2 , $J_0 = 2J$, $b_b = b_c = 0.001$ kg m^2/s^2 , $n = 600$ rad/s, $v_0 = 300$ m/s, $D = 500$ m, $a = b = 1.2$ rad, $\omega = 16\pi$ rad/s, $\omega_1 = 20\omega/3$, mobile base: $\omega_x = 0.2 \sin(2\pi t)$ rad/s, $\omega_z = 0.5 \cos(5\pi t)$ rad/s)

changes its position with high speed. After the spot centre is established, the system switches over to the tracking mode, which enables observation of the moving target. The system satisfies all the formulated requirements. Controlling the gyroscope axle is not complicated, the scanning time until the target is intercepted is short and the tracking is characterised by high precision.

References

1. HSU J.C., MEYER A.U., 1970, *Modern Control Principles and Applications*, McGraw-Hill B.C.
2. KRZYSZTOFIK I., OSIECKI J., 2000, On a certain mechanism of space scanning with an optical target coordinator, *17th National Conference for Researchers and Academics on the Theory of Machines and Mechanisms*, Warsaw-Jachranka, Conference Proceedings, 505-510
3. NIZIOŁ J., 2005, *Dynamics of Gyroscopes. Technical Mechanics. Vol. II: Dynamics of Mechanical Systems*, J. Nizioł (Edit.), IPPT Pan Warsaw, 474-558
4. OSIECKI J.W., STEFAŃSKI K., 2003, Applying phase trajectories to control the bearing-taking system, *9th National Conference for Researchers and Academics on the Automation and Application of Control and Communications Systems*, Gdynia, *Conference Proceedings "Automation and Application of Control and Communications Systems"*, **2**, ISBN 83-87280-60-7, 421-428
5. OSIECKI J.W., STEFAŃSKI K., 2004, The method of automatic optical space scanning and target tracking, *Scientific Bulletin of the Rzeszów University of Technology No. 213, Mechanics Bulletin No. 63, Avionics*, **2**, Rzeszów, ISSN 0209-2689, 421-428
6. STEFAŃSKI K., 2004, A space scanning system for identifying and tracking aerial targets, *5th International Conference on Armaments "Scientific Aspects of Armament Engineering"*, Waplewo, Conference Proceedings, 939-943
7. US Patent No. 4,030,807
8. VOIGT A., 1977, *Optical Scanning Apparatus with Two Mirrors Rotatable About a Common Axis*, US Patent No. 4,039,246 – Aug. 2, 1977 (assigned by General Dynamic Corporation, Pamona, Calif.)

O pewnej metodzie wyszukiwania i śledzenia celu w obronie powietrznej

Streszczenie

W pracy przedstawiono metodę sterowania ruchem osi giroskopu z umieszczonym w niej układem optycznym dla wykrywania i śledzenia celów powietrznych, emitujących promieniowanie w zakresie podczerwieni. Nawiązuje do wcześniejszych wystąpień autorów na konferencjach i przedstawia dalszy rozwój metody. Metoda sterowania polega na wykorzystaniu trajektorii fazowych uchybów sterowania.

Manuscript received April 14, 2008; accepted for print August 20, 2008