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FEATURES OF POINTING IN SYSTEMS OF STABILIZATION BY GROUND VEHICLE OBSERVATION EQUIPMENT

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Abstract**—***The paper deals with features of pointing and tracking modes in systems of control by location of lines-of-sights of observation devices operated at the ground vehicles. The structural scheme of the studied control system is suggested. Features of two possible approaches to control pointing modes in the studied systems are considered. Analysis of the methods of pointing and their equations is carried out. The choice of the method of the proportional method of pointing or proportional navigation is grounded. Advantages of the chosen method are analyzed.*

Index Terms—Ground vehicles; pointing modes; method of proportional navigation; observation devices; gyro devices.

I. INTRODUCTION

The main tasks of the system for control by location of observation devices installed at the stabilized platform are pointing and tracking by a reference points. This process is implemented on the basis of signals of an error between direction to the reference point and line-of-sight axis of the observation device operated at the ground vehicle. It is obviously, that to track the moving reference point it is necessary to provide pointing with a rate that takes in consideration motion of both a reference point and the vehicle, on which an observation device is mounted.

Control by the location of an observation device line-of-sight during pointing may be automatic, manual and semiautomatic [1]. During automatic pointing control signals are formed and enter to the control means without an operator assistance. If pointing is manual or semiautomatic, displacements of control means are implemented by an operator. If a pointing system is controlled in a manual way, an operator takes information about parameters and location of the reference point by visual information shown at an indicator, forms control signals based on this information and moves handles of control means to decrease the pointing error. If a pointing system is semiautomatic, an operator takes information about control signals, which are formed without his assistance and moves control means.

Analysis of functions of the systems for control by location of the observation devices operated at the ground vehicles and requirements to their characteristics leads to the necessity to choose the manual mode of pointing and tracking. In this case, two approaches are widespread. The first approach may be used for previous pointing to a reference point. The second approach ensures the precision pointing and tracking of a reference point.

II. FEATURES OF TRACKING MODES

The modern systems by control stabilized platforms with useful payload (observation devices) operated on ground vehicles must be characterized with the high accuracy, small time of reference-point search and serviceability. To satisfy these rigid requirements it is necessary to develop the research-grounded structural schemes of the studied systems building.

One of such schemes is represented in Fig. 1 [2]. The main control features of the control system built by this scheme are manual pointing and tracking by a reference point in the space and automatic stabilization of the platform with the useful payload installed on it.

The scheme shown in Fig. 1 may implement both above described approaches to pointing and tracking (the main feedback by the gyro signal for the first approach is shown by the dotted line, the main feedback for the second approach – by the solid line).

For the first approach the signal from the optic-electronic system enters to an indicator and is taken by an operator, which changes direction of an observation device line-of-sight based on visual observation by means of control console. The line-of sight turns at some angle due to operation of the stabilization and tracking system. Namely stabilization is implemented by control signals based on information from the rate gyro and voltage and current of the motor armature circuit, which represent feedback signals.

For the second approach an operator chooses the tracking rate based on visual observation by the reference point. An operator forms control signals based on video representation at the indicator to decrease the pointing or tracking error. Stabilization of pointing or tracking rates is carried out on the basis of the rate gyro signals [3].

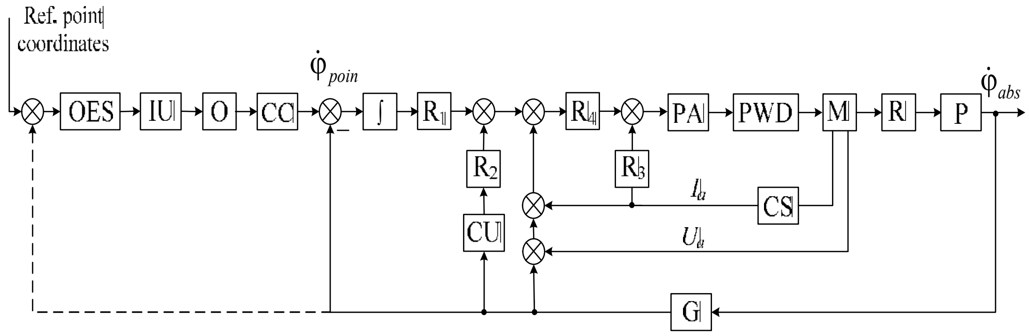

Fig. 1. Generalized structured scheme of the system by the stabilized platform control (the vertical channel): OES is an optic-electronic system; IU is an indication unit; O is an operator; CC is a control console; G is a gyro device; CU is a correction unit; CS is the current sensor; PA is a power amplifier; PWD is a pulse-width-modulator; M is a motor, R is a reducer, P is a platform with the payload; $\dot{\varphi}_{abs}$ is an absolute angular rate of the platform with a payload; $\dot{\varphi}_{poin}$ is an angular rate of the reference point tracking, which is given by an operator; I_a is a current of an armature circuit; U_a is a voltage of an armature circuit; $R_i, i=\overline{1,4}$ are adjustable coefficients

For the system described by the structural scheme represented in Fig. 1 the control signal may be defined by the following expression

$$U_{con} = K_1\left[R_1\int_0^{\Delta t}\left(K_i U - K_{1\dot{\varphi}_{abs}}\dot{\varphi}_{abs}\right)dt + R_2 K_{2\dot{\varphi}_{abs}}\dot{\varphi}_{abs}\right] + K_2(K_{1U_a}U_a + K_{1I_a}I_a) + K_3R_3K_{2I_a}I_a + K_4R_4(K_{3\dot{\varphi}_{abs}}\dot{\varphi}_{abs} + K_{2U_a}U_a + K_{3I_a}I_a), \quad (1)$$

where $K_i, K_{1\dot{\varphi}_{abs}}, K_{2\dot{\varphi}_{abs}}, K_{3\dot{\varphi}_{abs}}, K_{U_a}, K_{1I_a}, K_{2I_a}$ are the transfer constants by the signals $U, \dot{\varphi}_{abs}, U_a, I_a$.

The control law (1) is based on the general principles of PID-controller forming [4] and features of controllers for stabilization systems operated at the ground vehicles [3].

Based on requirements given to the pointing and stabilization systems operated at the ground vehicles we can believe that the vertical and horizontal channels of such system operate independently from each other. The scheme represented in Fig. 1 describes the vertical channel of the studied stabilization systems. Notice that the vertical and horizontal channels of the stabilization system differ by some features [5], [6].

1. A plant for the horizontal channel of the stabilization system represents a working module. A plant for the vertical channel of the stabilization system represents an observation equipment mounted at the working module.

2. Both channels use a motor of the same type (motors of direct current) but have difference in control organization. Control by the vertical channel is based on feedback by the voltage and current in the motor armature circuit. Respectively feedback in the horizontal channel is implemented by the signal of the current only. Such difference leads to distinctions of the structure and parameters of the vertical and horizontal channel controllers.

Systems designed by the represented schemes may operate in modes of pointing, tracking, stabilization and simultaneous tracking [2], [3].

The studied system has some features, which essentially complicate its design. Such difficulties are caused by some control contours, complex structure of the controller and the necessity to ensure the specific requirements such as the dynamic error and the angular rigidity (change of the stabilization plant angular position due to change of the external moment action [3]. At the same time the high accuracy and disturbance immunity are the basic requirements to such systems.

Main functions of studied systems are pointing and tracking of the reference point by the observation equipment line-of sight and elimination of the non-coincidence between the direction to the reference point and the line-of sight axis of the observation device. Analysis of functions carried out by the system and requirements to serviceability shows expediency of choice of the manual control for the pointing and tracking modes.

In accordance to the structural scheme represented in Fig. 1 a signal from the optic-indicator system enters to the indicator, where it is taken by an operator, which based on the visual observation by means of the control console chooses tracking rates simultaneously with the visual observation by the reference point. It is possible to improve accuracy of pointing and tracking processes by using of two ranges (large and small) rate change. There is a possibility also to switch off simultaneously the tracking rate at the instant of time of line-of-sight coincidence with the direction to reference-point. Using the visual representation of the reference-point at the indicator an operator may form control signals by means of control handles to decrease the pointing or tracking error. Stabilization of pointing or tracking errors is implemented automatically.

Depending on a frequency range of used electro-magnetic signals the radio-electronic observation systems are divided into radio and optic-electronic [7]. Basic feature of the radio system is presence of such unit as the discriminator, which forms an error signal Δx of pointing or tracking depending of the mode of system functioning. Optic-electronic systems are characterized by usage of the tele- or laser units.

The basic function of the optic-electronic system is transformation of electro-magnetic waves in the optic range into the electrical and light signals. These signals are necessary for information visualization. Optic-electronic systems are divided into passive, active and semi-active [7]. Laser devices are sources of signals for active and semi-active systems. The typical passive optic-electronic system includes the optic-electronic device, scanning mechanism, video-impulse amplifier, threshold device and unit of images forming [7]. The optic-electronic device provides reception of signals in the heat or visible optic range, elimination of the background noise and receiving of electric signals, which characterize angular coordinates of a reference point. Forming of such information is implemented with the help of the scanning mechanism. The optic-electronic device is connected with the device of the electric signal processing, which in the simplest case represents the set of the video-impulse amplifier and the threshold device. Indicator operation is ensured by a unit of the images forming.

In the general case, the field of vision of the optic-electronic device may show some images of different reference points. To provide tracking of one among these reference points, the auto-selector may be used. Parameters of the reference-point motion are represented at the indicator display as electronic cross-lines. An operator implements manipulations with console handles to ensure values of the horizontal and vertical deviations Δ_h, Δ_v close to zero [7]. Visual representation formed at the indicator is shown in Fig. 2.

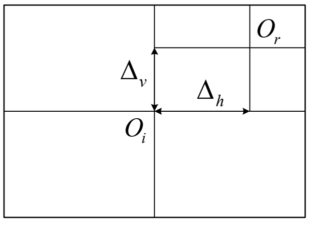

Fig. 2. Representation at the indicator of OES: O_i is the center of the indicator; O_r is the center of the reference-point

In the modern systems by control of line-of-sights of the observation device it is possible to implement pointing or tracking of the reference point by means of the TV-camera. The structural scheme of this process is represented in Fig. 3 [7].

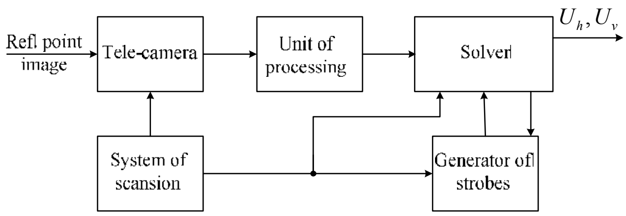

Fig. 3. The structural scheme of reference-point pointing or tracking by means of TV-camera: U_h, U_v are voltages, which correspond to the horizontal and vertical deviations

The control contour of the studied system includes an operator as a control link. Therefore the quality of the tracking processes depends on the psycho-physiological characteristics of an operator and a level of its training. An operator and controller represent the interconnected elements if the man-machine control system. Now there are many types of the human operator models, which may be used for tracking processes research. One of the most widespread model may be represented in the form of the transfer function [7]

$$W_o(s) = \frac{k(T_1 s + 1)}{(T_2 s + 1)(T_3 s + 1)} e^{-\tau s}, \quad (2)$$

where k (40…100) is the transfer constant of an operator; τ (0,13…0,2 s) is a time of delay of an operator reaction on the trajectory control signal (0,25…2,5 s); T_1 is advance time, which defines the possibility of an operator to compensate the reaction delay; T_2 (0,1 s) is the neuromuscular time constant; T_3 (0,6…2 s) is the filtration constant.

Inputs of the model (2) are trajectory control signals (error signals) and outputs – control signals formed by an operator. The model (2) is approximate because it does not take into consideration abilities of an operator to extrapolation, adaptation, active nature of his activity and discretion of perception. To consider an operator as a control system link it is necessary take into consideration that an operator is able to carry out functions of amplification with the bandwidth no more than 0,5 Hz [7].

Notice that an operator may implement both deterministic and random displacements of control handles. These actions may be simulated by means of the white noise entering to the forming filters.

In the case of the necessity the model (2) allows to simulate the dynamics of the man-machine system, represented in Fig. 1.

Dependence of control parameter (error) Δx on parameters, which characterize the cross motion of the reference point and the line-of-sight of the observation device is called an error equation or a trajectory control equation. Any pointing method is characterized by its specific error equation. The equation $\Delta x = 0$ corresponds to the ideal pointing [1], [7], [8]. Choice of a method depends on the kind of the reference point, nature of its motion and possibilities of a motion of a platform, on which the observation devices are mounted.

The most widespread pointing methods are the methods of the direct pointing, pointing with prediction and proportional pointing or proportional navigation [1], [7], [8].

Control parameters of the direct pointing method are angles of the horizontal and vertical motion φ_h, φ_v, which represent the mutually-perpendicular projections of an angle between the direction to the reference point and the observation device line-of-sight onto the horizontal and vertical planes correspondingly. In this case, the equation of the direct pointing for the manual control becomes

$$\Delta_h = \varphi_h ; \ \Delta_v = \varphi_v . \qquad (3)$$

In the general case, the equation (3) may include the scale coefficients k_{hm}, k_{vm}

$$\Delta_h = k_{hm}\varphi_h ; \ \Delta_v = k_{vm}\varphi_v .$$

The basic advantage of the direct pointing is its relative simplicity [9]. The most essential disadvantage lies in absence of prediction for location of the vector of the observation device line-of-sight turn relative to the direction to the reference point. This method it is expedient to use in the case of non-moving and slow-moving reference points.

Equations of the method for pointing with prediction by means of the manual control look like [1]

$$\Delta_h = k_{hm}(\varphi_h^* - \varphi_{hn}^*) ; \ \Delta_v = k_{vm}(\varphi_v^* - \varphi_{vn}^*) , \qquad (4)$$

where φ_h^*, φ_v^* are actual angles between the observation device line-of-sight and the direction to the reference point in the horizontal and vertical planes; φ_{hn}^*, φ_{vn}^* are necessary values of these angles.

The angles φ_{hn}^*, φ_{vn}^* in the equations (4) may be determined by means of the approximate formulas

$$\varphi_{hn}^* = -D\omega_h / k_{Dv} ; \ \varphi_{vn}^* = -D\omega_v / k_{Dv} ,$$

where D is a distance between the observation device line-of-sight and the direction to a reference point; ω_h, ω_v are the line-of sight rates in the horizontal and vertical planes; k_{Dv} is a coefficient, which depends on the closing speed, rate of a platform with the observation device relative to the ground vehicle, time of displaying of the reference point.

As a whole determination of the angles φ_h^*, φ_v^*, φ_{hn}^*, φ_{vn}^* requires information about parameters of the mutual motion of the reference point, ground vehicle and the platform with the observation devices. Determination of these parameters is implemented by the systems of determination of the reference point location. It displayed in the form of deviation of the electronic point, ring or arrow from the cross-coordinates at the indicator display. An operator implements manipulations by the control console handles to keep the values Δ_h, Δ_v close to zero.

The equation of the proportional pointing or the proportional navigation looks like [1], [7]

$$\Delta_h = Nv_{cr}\omega_h - a_h ; \ \Delta_v = Nv_{cr}\omega_v - a_v , \qquad (5)$$

where N (3…5) is the navigation constant; v_{cr} is the closing rate; a_h, a_v are accelerations of the platform with the observation device in the horizontal and vertical planes.

In accordance with the equation (5), the necessary lead angle may be achieved, when actual accelerations a_h, a_v will be equal to the necessary accelerations $a_{ht} = Nv_{cr}\omega_h$ and $a_{vt} = Nv_{cr}\omega_v$ in the horizontal and vertical planes.

The basic advantage of the method of the proportional pointing is its suitability to the external conditions, namely, changes by the heading and altitude.

The method of the proportional pointing allows to achieve the best results in the case of the reference point manoeuvring absence

$$\Delta_h = Nv_{cr}(\omega_h + \omega_{dh}) - a_h ;$$
$$\Delta_v = Nv_{cr}(\omega_v + \omega_{dv}) - a_v ,$$

where ω_{dh}, ω_{dv} are rates of the observation device line-of-sight displacement in the horizontal and vertical planes.

Analysing above represented methods of pointing, it is possible to make the following conclusions. In the case of the non-moving and slow-moving reference points the method of the direct pointing may be used. But the better results may be obtained by means of the method with the prediction. In conditions of disturbance action it is convenient to use the method of sequential predictions. Sometimes this method is called by the pursuit method. Its basic feature is usage of an additional prediction angle. Implementation of this method requires to change angles between the observation device line-of-sight and direction to the reference point in the horizontal and vertical planes φ_h, φ_v proportionally to the angular rates in the same planes ω_h, ω_v. In this case, the error equation may be represented in the following form

$$\Delta_h = k_{\varphi h}\varphi + k_{\omega h}\omega; \quad \Delta_v = k_{\varphi v}\varphi + k_{\omega v}\omega,$$

where $k_{\varphi h}, k_{\omega h}$, $k_{\varphi v}, k_{\omega v}$ are the constant coefficients.

Corresponding to the method of the proportional navigation the angular rate of tracking $\dot{\gamma}$ of the system of considered type is directly proportional to the angular rate of the line-of-sight $\dot{\lambda}$ [8], [9]

$$\dot{\gamma} = N\dot{\lambda}. \quad (6).$$

The relationship (6) makes this method the most suitable for organization of tracking processes in the studied systems.

So, advantages of the method of the proportional navigation are its simplicity and ease of use [1], [7]–[9]. As above stated, this method has such advantage as suitability to external conditions. The method is the most widespread for applications in the short and middle ranges.

Corresponding to the method of the proportional navigation the angular rate of tracking $\dot{\gamma}$ is directly proportional the angular rate of the line-of-sight. This makes the method the most suitable for organization of tracking processes in the studied systems.

CONCLUSIONS

The structural scheme of the tracking and stabilization system for control by the location of lines-of-sights of observation devices operated on the ground vehicle is suggested. The types of control by the studied system in pointing and tracking modes are considered. The error equations of the different pointing methods are analyzed and the choice of the proportional navigation method was grounded. Advantages of the chosen method for the studied system are described.

REFERENCES

[1] Design of guidance systems (1975) /under red. of Fedosov, E. A. Moscow, Mashinostroenie Publ., 296 p. (in Russian).

[2] Sushchenko, O. A. (2009). "Algorithm for ground vehicle stabilizer optimal synthesis". *Proceedings of the National Aviation University*, no. 4. Kyiv, NAU Publ., pp. 23–28.

[3] Kochergin, V. V. (1988). Servo-systems with direct current motors. Leningrad, Energoatomizdat Publ., 168 p. (in Russian).

[4] Hilkert, J. M. (2009). "Inertially stabilized platform technology" *IEEE Control Systems Magazine*, no. 1. vol. 28. pp. 26–46.

[5] Sushchenko, O. A.; Sayfetdinov, R. A. (2007). "Mathematical model of the stabilization system of the ground vehicle". *Electronics and control systems*, no. 3(13). Kyiv, NAU Publ., pp. 146–151. (in Ukrainian).

[6] Sushchenko, O. A., Sayfetdinov, R. A. (2007). "Mathematical model of ground vehicle in contours of vertical and horizontal pointing". *Proceedings of the National Aviation University*, no. 2. Kyiv, NAU Publ., pp. 32–35. (in Ukrainian).

[7] Maksimov, M. V., Gorgonov, G. I. (1982). Radioelectronic guidance systems. Moscow, Radio i svyaz Publ., 304 p. (in Russian).

[8] Siouris, G. M. (2004). Missile Guidance and Control Systems. New York. Springer-Verlag, 666 p.

[9] Chikriy, A. A. (1992). Processes controlled based on conflicts. Kyiv, Naukova dumka Publ., 384 p. (in Russian).

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О. А. Сущенко. Особливості наведення в системах стабілізації апаратури спостереження наземних рухомих об’єктів

Розглянуто особливості режимів наведення та супроводження в системах керування положенням ліній візування приладів спостереження, що функціонують на наземних рухомих об’єктах. Запропоновано структурну схему системи досліджуваного типу. Розглянуто особливості двох можливих підходів до організації керування в режимах наведення в системах досліджуваного типу. Виконано аналіз методів наведення та їх рівнянь. Обґрунтовано вибір методу пропорційного наведення або пропорційної навігації. Проаналізовано переваги обраного методу.

Ключові слова: наземні рухомі об'єкти; режими наведення; метод пропорційної навігації; прилади спостереження; гіроскопічні прилади.

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О. А. Сущенко. Особенности наведения в системах стабилизации аппаратуры наблюдения наземных подвижных объектов

Рассмотрены особенности режимов наведения и сопровождения в системах управления положением линий визирования приборов наблюдения, функционирующих на наземных подвижных объектах. Предложена структурная схема системы исследуемого типа. Рассмотрены особенности двух возможных подходов к организации управления в режимах наведения в системах исследуемого типа. Выполнен анализ методов наведения и их уравнений. Обоснован выбор метода пропорционального наведения или пропорциональной навигации. Проанализированы преимущества выбранного метода.
Ключевые слова: наземные подвижные объекты; режимы наведения; метод пропорциональной навигации; приборы наблюдения; гироскопические приборы.

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