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APPLICATION OF COMPUTER VISION SYSTEMS IN AUTOMATIC LANDING CONTROL SYSTEMS

In this paper, one of the possible applications of computer vision systems (CVS) - system of automatic landing of a plane is presented. We have theoretically proved the opportunity of CVS application that uses algorithms of watching normalization, for realization of starting and landing process control.

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Landing of a modern air liner is a complex and responsible process demanding special approach and higher attention of a crew, and also of ground services. The system of automatic landing with the use of CVS can be offered to help the crew and it also can be used as a system of landing in emergency situations. The system of automatic landing is a part of the automated control system of flights at the airport.

Let's consider the process of plane automatic control at landing approach which begins with the flight height of 400-500 meters and comes to an end with a stop on a takeoff strip. The movement of the plane is performed on a rigid or flexible trajectory. In the first case the required path of movement (glidepath) is set by means of the devices placed on the ground, based on radio landing aids. And in the second case the information about plane position in relation to touchdown point is shown with the help of onboard devices. The radio automatic instrument landing approach system with the help of devices [1,2] consists of the onboard and ground equipment. The ground equipment consists from a glide slope beacon, course beacon, near, middle and distant beacon marker indicators. Transmitters of beacon marker indicators are placed in a direction of the central line of flight strip at the distances of 60 m, 1600 m and 7200 m accordingly. The plane commences descent being at the height of 300-400 m, i.e. the landing approach system starts working at while passing a distant marker indicator [3]. The advantage of such system is the opportunity of communication with the flight controller, and the disadvantage on the other hand is a complexity of the radio aids, not capable to work with narrow beams of radio echo signals reflected from the earth at the plane’s approach to the ground at small heights and distances from a flight strip.

Airplane control with the help of CVS that is being discussed in this article begins from the moment a plane passes a distant marker indicator - 7200 m.

The first stage in the working (functioning) process of automatic landing system based on CVS is a stage of capture of the plane during the moment of its appearance in its visibility range. Capture of the plane is carried out by a controller, who indicates it on a display screen, displaying a field in sight of the camera or automatically with the use of algorithms of recognition and segmentations. A tracing frame is placed in the plane image and the process of tracking begins. Till the moment the plane enters the field of vision, CVS fulfills the storage of field in sight to exclude a background from the image in the process of tracking. It allows increase jamming resistance of the system.

In [3] we describe a flight controller of a plane landing on glidepath. Glidepath is the radio beam coming our from a glide-path beacon that is located the near the strip at an angle 2-3^0. During landing control with the help of CVS, video camera of a system must be fixed in such a way, that a sight line inclination (angle) θ is 2-3^0 and, thus, there will be a glide slope line represented, matching with the sight line. CVS camera must be set at the same place with a beacon marker indicator. The plane will be at the height 16-25 m at the cross point with this beacon marker indicator.

While landing autopilot controls the aircraft in such a way that a velocity vector of its center of mass in a fixed mode is directed along the glide path. When the plane does not move along the glide path, its image and the center of tracing frame will be deflected with respect to the viewing field center of CVS. For CVS control the control signal is formed on basis of mismatch signal determined with the help of information about deflection of tracing frame center from the viewing field center of CVS. The situation described in fig. 1 happens at the time point t_0 – automatic landing control captures an aircraft. Fig. 1 shows that the tracing frame center is deflected with respect to the beginning of coordinates in plane $\mathbf{X_0Y_0}$. We connect points **B** and **C** (intersection of coordinate system $\mathbf{X_sY_s}$ in tracing frame with the axes $\mathbf{X_0}$ and $\mathbf{Y_0}$) with image center in CVS camera where sight line passes, and we get angle β – course deflection from line of sight in vertical plane and angle γ – course deflection in horizontal plane. We denote the distance in pixels from the tracing frame center to the axis $\mathbf{X_0}$ by η, and to the axis $\mathbf{Y_0}$– ζ. Values of tracing frame deflection from the viewing field center can be determined as far as we always know coordinates of tracing frame center.

To solve the problem of plane landing on a glide path we need to create control law that will reduce to zero the existing course and therefore tracing frame displacements. And CVS will control the process of plane approach to the glide slope line.

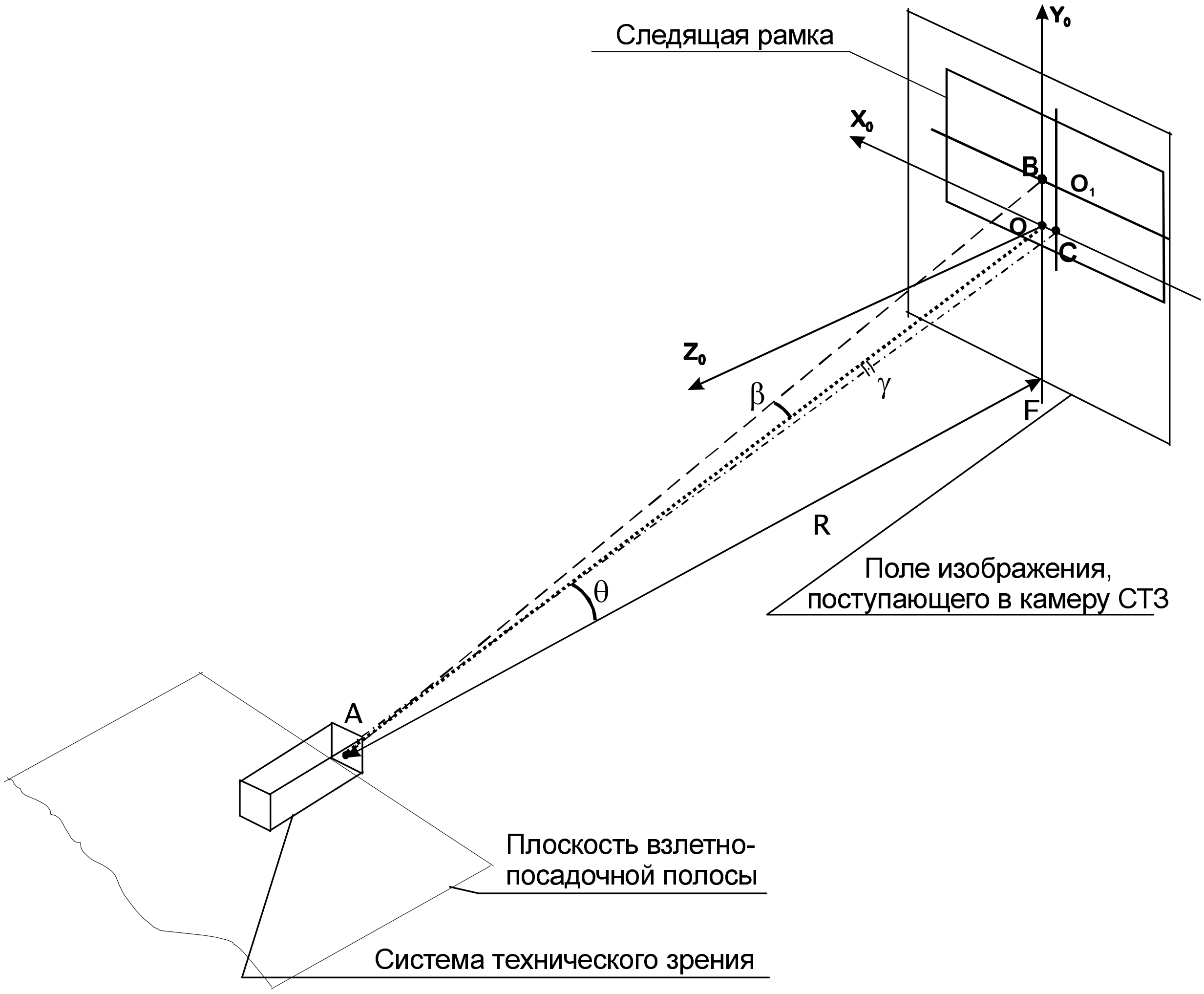

Fig. 1 – Location of CVS, flight strip and image plane at the work of guidance system of plane navigation on a strip

Determined mathematical model of plane movement [3] looks as follows

$$\begin{cases} m\dot{v} = T\cos\alpha - c_x S\dfrac{\rho v^2}{2} - mg\sin\theta, \\ mv\dot{\theta} = T\sin\alpha + c_y S\dfrac{\rho v^2}{2} - mg\cos\theta, \\ I\ddot{\vartheta} = M_z(\alpha, \dot{\alpha}, \dot{\vartheta}, v, H, \delta), \\ \dot{H} = v\sin\theta, \qquad \theta = \vartheta - \alpha, \\ \dot{m} = -\mu, \end{cases} \tag{1}$$

where **m** – mass of a plane

v – speed of the plane,
T – jet thrust,
α – angle of attack,
I – second moment of the plane with respect to the axis z,

c$_x$ c$_y$– known functions of number $M = \frac{v}{a}$ and of angle of attack α, **a(H)** – speed of sound on (at) the given height,

S **– wing area,**

ρ – air density, known as a function of height **H** at the constant temperature,

δ – deflection area of elevator,

μ – fuel consumption,

θ – inclination (slope) angle of the curve (path), угол наклона траектории,

ϑ — pitch angle.

These are fundamental equations by the development of object (plane) control equations at all stages of flight. For the landing stage on a glide path in [3] we get a simplified equation by means of equation linearization (1). This is a simplified equation of disturbed motion at minor deviations of vector direction of mass center speed of a plane from a glide path.

$$\ddot{\eta} = -k\Delta\delta \,, \tag{2}$$

$$k = \frac{m_z^\delta}{m_z^\alpha}(c_y^\alpha + c_x)\frac{S\rho v^2}{2m} \,.$$

where η — value of mismatch of current and required height of the plane flight,

$\Delta\delta$ - deflection area of elevator

m_z^δ - coefficient of moment of force that appears because of the elevator deflection on angle δ with respect to the axis **z**,

m_z^α - coefficient of moment of force that appears at attack angle deflection from the necessary value,

c$_x$ – coefficient frontal resistance along the axis of the plane,

c_y^α - derivative of rising force at attack angle deflection from the necessary value on angle $\Delta\alpha$.

Equation (2) is linearized mathematical model of object (plane) control.

Value $\Delta\delta$ is determined from (1) by solving this system in movement dimensional inaccuracies of an aircraft from required parameter values. At the same time the output coordinate η must be measured in flight. We also measure the value of control function $\Delta\delta$ (deflection area of elevator). In order to construct control system, we need to close the control object with back-coupling (back action), where η becomes an input function and $\Delta\delta$ an output function. The function connecting $\Delta\delta$ with an input coordinate η is called control law.

Applying the principles of synthesis of control systems under conditions of uncertainty described in [5], we construct an adaptive control system for a control object described with an equation (2). An undetermined parameter will be coefficient k, which takes in account aircraft parameters. In this case we have only one undetermined parameter, which simplifies the task in comparison with example described in [5].

Let's signify $v_z = \dot{\eta}$, A= $-$k , u=$\Delta\delta$ and therefore $\dot{v}_z = \ddot{\eta}$, $\dot{v}_z = -k\Delta\delta$, then the equation (2) will have the form

$$\dot{v}_z = Au, \tag{3}$$

$$\frac{\dot{v}_z}{u} = A.$$

Then we differentiate this equation with respect to time and we get

$$\frac{d}{dt}\left(\frac{\dot{v}_z}{u}\right) = 0,$$

or

$$\frac{\ddot{v}_z u - \dot{v}_z \dot{u}}{u^2} = 0.$$

We assume that at infinity u^2 equals zero, i.e. $u \neq 0$.

$$\ddot{v}_z u = \dot{v}_z \dot{u}, \quad \ddot{v}_z = \frac{\dot{v}_z \dot{u}}{u} = \xi. \tag{4}$$

Let's signify the right side as ξ and we get a new equation of object control

$$\ddot{v}_z = \xi. \tag{5}$$

In this equation the control function is determined with the help of Bellman method from minimum condition of control quality functional

$$I = \int_0^\infty \left[\alpha x^2 + \alpha_1 x_1^2 + \alpha \xi^2\right] dt.$$

Let's substitute (5) with a system of equations $\dot{v}_z = x_1, \dot{x}_1 = \xi$ and $v_z = x$, then we get an optimal linear law of control

$$\xi = \mathrm{K}_1 \dot{\mathrm{v}}_{\mathrm{z}} + \mathrm{K}_0 \mathrm{v}_{\mathrm{z}}. \tag{6}$$

By equating expressions (3) and (5) we get the equation of adaptive regulator

$$\dot{v}_z \frac{\dot{u}}{u} = K_1 \dot{v}_z + K_0 v_z,$$

or

$$\dot{v}_z \dot{u} = u(K_1 \dot{v}_z + K_0 v_z),$$

$$\dot{u} = \frac{u}{\dot{v}_z}(K_1 \dot{v}_z + K_0 v_z). \tag{7}$$

If we come back in (7) to designations (3) we get

$$\Delta\dot{\delta} = \frac{\Delta\delta}{\ddot{\eta}}(K_1 \dot{\eta} + K_0 \eta). \tag{8}$$

Take notice that $\frac{\Delta\delta}{\ddot{\eta}} = \frac{1}{A} = -\frac{1}{k}$ in (8), where k is an undetermined coefficient, which takes in account the characteristics of an aircraft, so that the denominator does not equal zero. We find the coefficients K_1 and K_0 in (8) by solving the system of Riccati equations as in [3]. So we get control law of elevator, which connects the value of deflection area of elevator δ with the value of flight altitude deflection η from required height. With the help of this control law we can determine the value of deflection area of elevator at any time point.

To find the original value of a quantity η we use a mismatch value in pixels η_k, which is determined in the viewing field of CVS as a distance from the center of a tracing frame to the axis X. These values are connected with each other through some scale coefficient μ

$$\eta=\mu\eta_k.$$

The value of a scale coefficient μ can be determined using laws of optics and assuming that the objective lens of CVS video camera is presented with one lens. The value of mismatch on the image η_k will be the image of value η. Using the known equations of the lens

$$\frac{\eta_k}{f} = \frac{\eta}{R}\,',$$

it follows that

$$\eta = \frac{R}{f}\eta_k = \mu\eta_k\,, \tag{9}$$

where R is a distance to an aircraft.

f – is a distance from objective lens to the CCD matrix (to the image).

So we have determined the value of scale coefficient μ. Now we rewrite (8) taking in account the aforementioned (9) and get

$$\Delta\dot{\delta} = \frac{\Delta\delta}{\mu\ddot{\eta}_k}(K_1\mu\dot{\eta}_k + K_0\mu\eta_k) = \frac{\Delta\delta}{\ddot{\eta}_k}(K_1\dot{\eta}_k + K_0\eta_k)\,.$$

The scale coefficient is reduced. We determine the first and second derivatives η_k as projection of speed and acceleration on the axis Y_0 accordingly and get

$$\dot{\eta}_k = \frac{\Delta\eta_k}{\Delta t}\,,\ \ddot{\eta}_k = \frac{\Delta\eta_{k1} - \Delta\eta_{k0}}{\Delta t^2},$$

so that

$$\Delta\dot{\delta} = \frac{\Delta\delta}{\ddot{\eta}_k}(K_1\dot{\eta}_k + K_0\eta_k) = \frac{\Delta\delta\Delta t^2}{\Delta\eta_{k1} - \Delta\eta_{k0}}\left(K_1\frac{\Delta\eta_{k1}}{\Delta t} + K_0\eta_k\right). \tag{10}$$

where $\Delta\eta_{k0}$ – change of deflection of tracing frame center from the axis X_0 on the previous step (time point t_0),

$\Delta\eta_{k1}$ – change of deflection of tracing frame center from the axis X_0 on the current step (time point t_1),

η_k – deflection of tracing frame center from the axis X_0.

The coordinate system X_0Y_0 is placed in the center of CVS viewing field. Increments of value η_k are values of tracing frame deflection, which are determined at each step as it is described in [4]. Value η_k itself is determined as a distance between the center of a tracing frame and axis X.

Equation (10) shows the connection between the parameters we get by normalizing a tracing frame, and deflection area of elevator. This equation does not contain such values as distance to an aircraft or the height of its flight. This gives an opportunity to refuse from extra detecting devices in the system of automatic landing and to reduce miscalculations. Value $\Delta\delta$ is measured with the help of detection device aboard and is transmitted to autopilot. The system of automatic landing control also sends signal to autopilot – value of tracing frame deflection from the center of viewing field. Autopilot is works according to (10). We can get the equation of rudder angle in the same way.

Equation (8) can be transformed with the help of the methods described in the article [5] into a discrete form on basis of finite-difference operators. That will help to conduct calculations on computer and to implement this equation on a special processor. In this case we also measure the value of mismatch η_k with the help of CVS as before and we substitute derivatives with finite-difference operators.

It is necessary to control the approach of an aircraft image and therefore the approach of a tracing frame to the center of viewing field. The match of tracing frame center with the center of viewing field will serve as a criterion for work intermission of control system aboard. But CVS must track the aircraft till it passes successfully the nearest beacon marker indicator a place, where CVS is fixed.

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