SYSTEM OF VISUAL MONITORING OF PAYLOAD SEPARATION PARAMETERS

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One of the most important problems in the control of the process of separation of the payload and launch vehicle is a visual control. It important in order to determine the presence of collisions, and monitor the parameters of detachement as well. One of such parameters is the velocity of separation, as well as the angular speed. At the moment there are no sufficiently simple and effective systems (in Russia) able to solve the problem of visual control of the process of separation of such objects.

The proposed system [1] consists of two cameras mounted on the payload and rocket respectively, modem for data transmission, with compression capabilities and video processing module based on the embedded DSP. For the purpose of video recording in the absence of natural light, there are colored light-emitting diodes along the circumference of the top side of satellite and the launch vehicle[2,3]. At the same time camcorder captures not a whole image of the object, but only the outlines. This requires less power, and simultaneously simplifies analysis of the motion of the object [3]. We define the basic requirements for video recording system from the perspective of the analysis of motion parameters.

We consider two variants of the motion of the payload:

1 Uniform removal without rotation

2 Uniform rotation about a fixed longitudinal axis.

1 Uniform removal without rotation

With a uniform disengagement of the satellite from the launch vehicle, the size of object image decreases smoothly. The size of the image can be calculated as:

$$h = p_h \cdot h_p \tag{1}$$

where p_h – the number of pixels per whole image at particular time;

h_p – the height of a single pixel of the matrix, m.

Then the size of one pixel can be calculated by formula:

$$h_p = \frac{n}{p} \tag{2}$$

where n – matrix size m;

p – number of pixels in the matrix.

On the basis of (1) and (2), as well as the relations between the size of the object H and distance L with the focal length f [4,5,6], we obtain:

$$L = \frac{H f \cdot p}{p_h \cdot n} \tag{3}$$

Let's consider two distances L_1 и L_2 for which the numbers of pixels per object are equal respectively to p_{h1} и p_{h2}. Then we can find the change of distance between objects ΔL. Since the objects are moving off, $L_2 > L_1$.

$$\Delta L = L_2 - L_1 = \frac{H f p \, p_{h1} - H f p \, p_{h2}}{p_{h1} p_{h2} n} \tag{4}$$

In rectilinear uniform motion of the instantaneous velocity of mutual recession can be calculated according to the formula:

$$V = \frac{\Delta L}{\Delta t_{\hat{e}}} \tag{5}$$

where $\Delta t_к$ – time interval between frames, on which the image of the object decreased by $p_{h1} - p_{h2}$ pixels, sec.

Minimal speed, which the system can catch, we propose to calculate using following:

$$p_{h1} - p_{h2} = 1$$

$$p_{h2} = p_{h1} - 1$$

These equations describe differences between two frames. It should be one pixel at least.

Then the formula (5) takes the form:

$$V = \frac{\Delta L}{\Delta t_{\hat{e}}} = \frac{H \cdot f \cdot p}{(p_{h1} - 1) \cdot p_{h1} \cdot n \cdot \Delta t_{\hat{e}}} \tag{6}$$

From the formula (6) it can be seen that a minimal speed for the case where $p_{h1} = p$. Thus, the expression (6) takes the form:

$$V_{\min} = \frac{H \cdot f}{(p - 1) \cdot n \cdot \Delta t_{\hat{e}}} \tag{7}$$

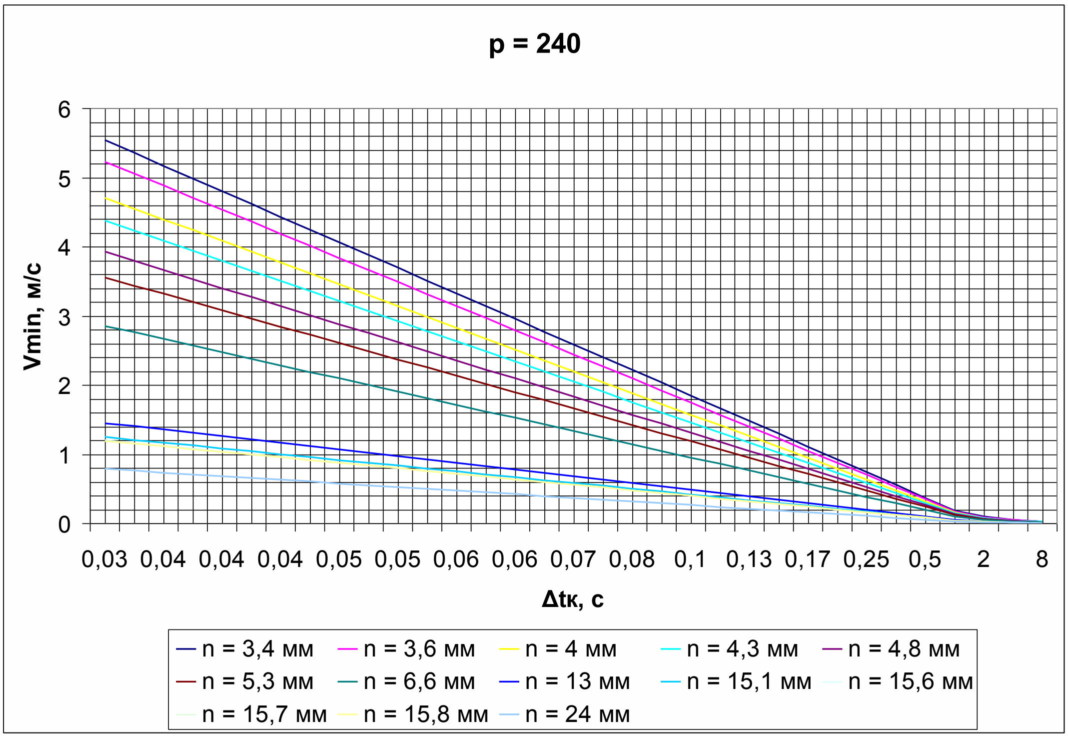

Fig. 1 - The dependence of the recorded minimal speed V_{min} on time between frames $\Delta t_к$ for various matrices with the number of pixels p = 240

Fig. 1-3 show curves which are based on (7) for selecting the resolution of the matrix depending on the magnitude of the required minimal speed recorded V_{min} , and at a particular time between frames $\Delta t_к$.

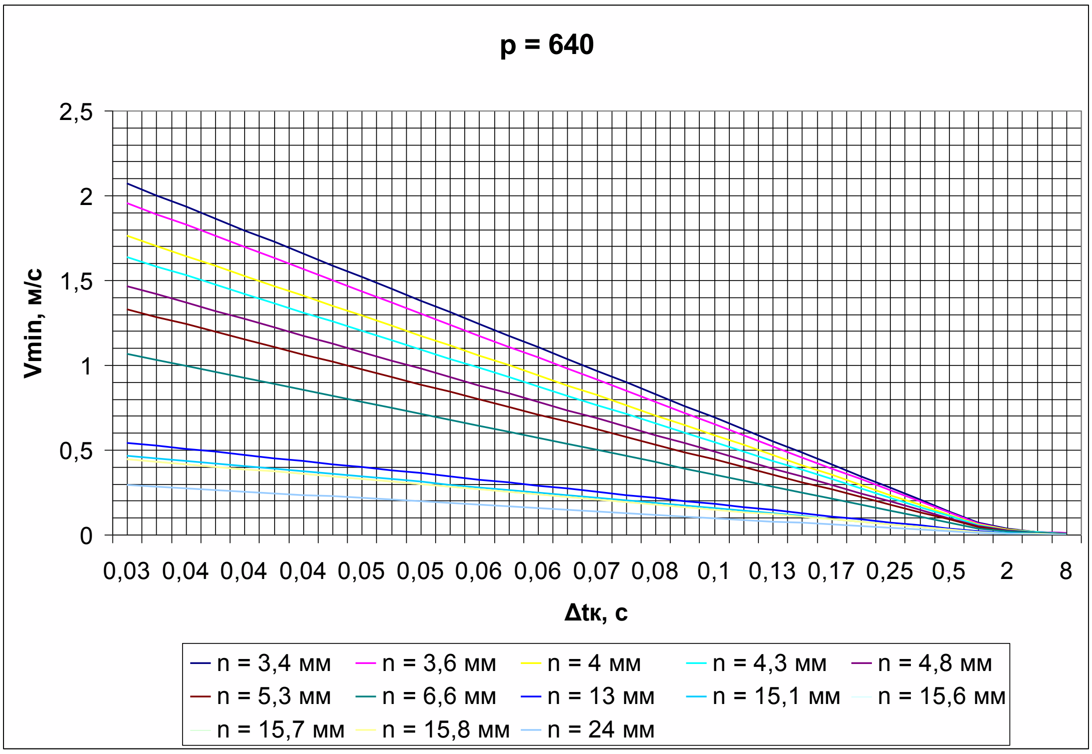

Fig. 2 - The dependence of the recorded minimal speed V_{min} on time between frames $\Delta t_к$ for various matrices with the number of pixels p = 640

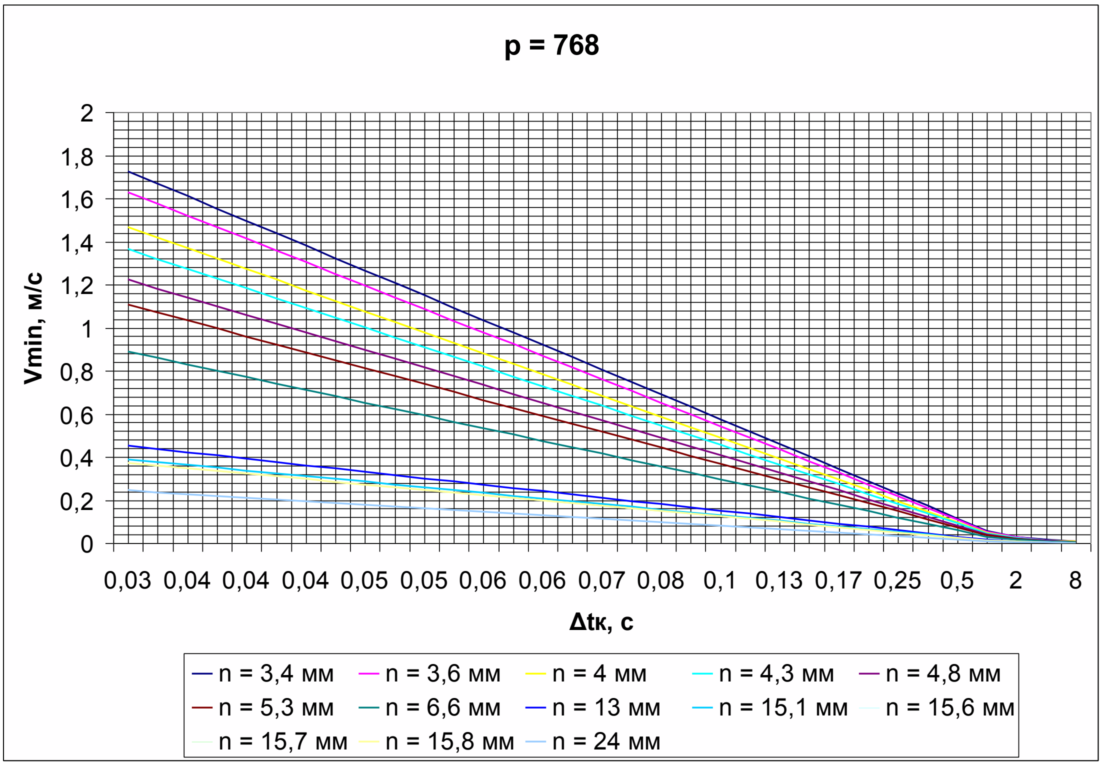

Fig. 3 - The dependence of the recorded minimal speed V_{min} on time between frames $\Delta t_к$ for various matrices with the number of pixels p = 768

Thus, the existing video camera system allows registration of the detachment process of payloads with a minimal speed of 0.04 m / s.

2 Uniform rotation about a fixed longitudinal axis

Fig. 4 shows a schematic image of a separating payload. There are LEDs mounted on the front part of it. The distance between LEDs is A. The direction of rotation is indicated by the arrow.

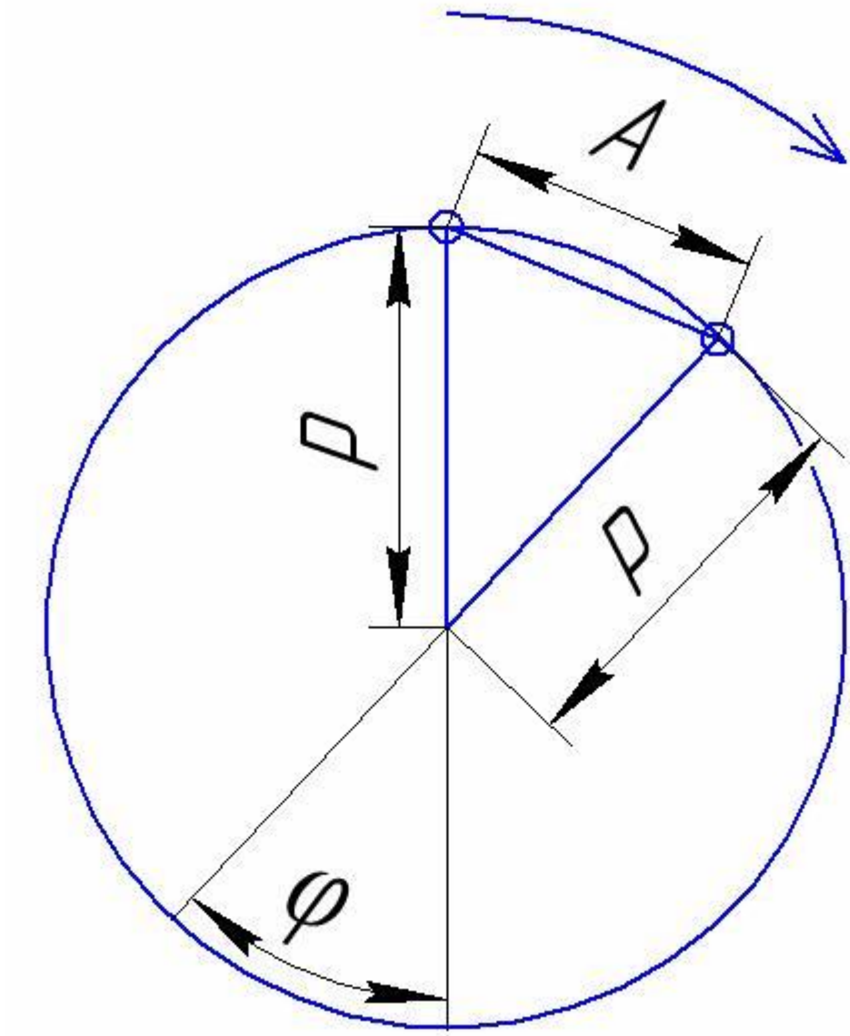

Fig. 4 - Schematic representation of the rotation model payload

Let's assume that if payload rotates at the angle of φ, the image of LEDs is shifted by the distance A in pixels. The area of such isosceles triangle can be calculated as follows:

$$S = \tfrac{1}{2} \cdot p^2 \cdot \sin(\varphi) \tag{8}$$

$$S = \tfrac{1}{2} \cdot A \cdot \sqrt{(p + \tfrac{1}{2} \cdot A)(p - \tfrac{1}{2} \cdot A)} \tag{9}$$

Let's equate the right-hand sides of formulae (8) and (9) and express the angle φ:

$$\varphi = \arcsin\left(\frac{A \cdot \sqrt{(p + \tfrac{1}{2} \cdot A)(p - \tfrac{1}{2} \cdot A)}}{p^2}\right) \tag{10}$$

The angular velocity is calculated by the formula:

$$w = \frac{\arcsin\left(\dfrac{A \cdot \sqrt{(p + \frac{1}{2} \cdot A)(p - \frac{1}{2} \cdot A)}}{p^2}\right)}{\Delta t_{\hat{e}}} \qquad (11)$$

where w – the angular velocity of the satellite, deg / s;
$\Delta t_к$ – the time between two frames, which corresponds to movement A of LED.

The minimal speed, which can be caught by the system, we can find if we assume A = 1. Then the formula (11) takes the form:

$$w_{\min} = \frac{\arcsin\left(\dfrac{\sqrt{p - 0.25}}{p^2}\right)}{\Delta t_{\hat{e}}} \qquad (12)$$

Fig. 5 shows the dependence of minimal detectable angular velocity w_{min} the time between frames $\Delta t_к$ for different numbers of pixels p.

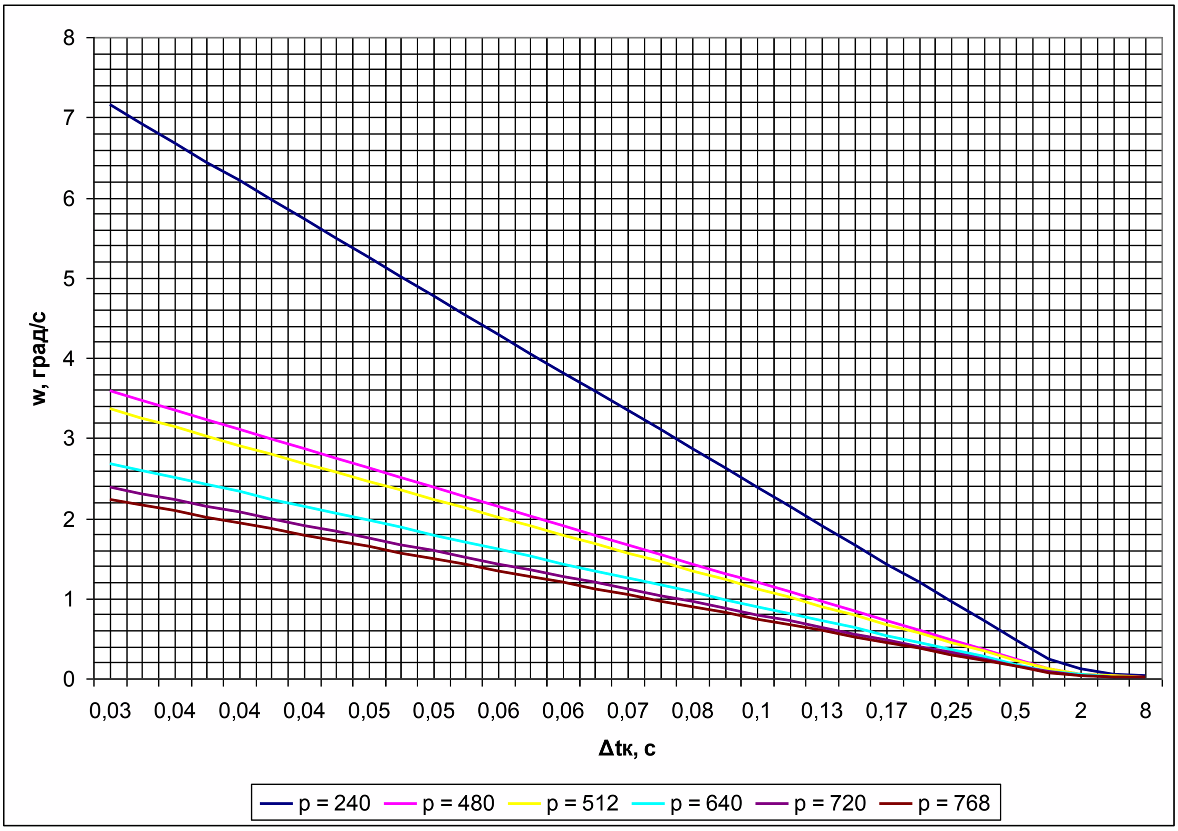

Fig. 5 - The dependence of the minimum angular velocity w_{min} on the time between frames $\Delta t_к$ for different numbers of pixels p

Thus, the minimal detectable angular velocity in the proposed system will be about 0.2 degrees / sec.

On the basis of these results it can be concluded that the proposed system allows to record the movement of the detachable part of the launch vehicle with suitable parameters for such a system.

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