FORECASTING FOR THE HAZARDOUS ASTEROIDS APPEARANCE. N. I. Perov[1,2]. [1]State Autonomous Cultural and Education Organization named after V.V. Tereshkova. 150000, Yaroslavl, Ul. Chaikovskogo, 3, Russian Federation. E-mail: perov@yarplaneta.ru. [2]State Pedagogical University named after K.D. Ushinskii. 150000, Yaroslavl, Ul. Respublikanskaya, 108, Russian Federation.

Introduction: For unpertubed motion of the Solar system's bodies there is collection of modes for the determination of epochs, corresponded for the minimal distances between the two bodies [2]. These arbitrary unpertubed trajectories may be determined, for example, from optical observations with using one and the same algorithm without singularities [3].

Below in the frame of the pairwise two body problem ("the Sun and a particle" and "the Sun and the Earth"), with taking into account the motion of line of apsides and line of nodes [1], the minimal distance between the Earth and a small body is determined.

The Based Equations: Let's denote a_1, a_2 are the semimajor axes of the orbits of the Earth and the asteroid; e_1, e_2 are the eccentricities of the considered orbits; i_1, i_2 are the inclinations of the orbital planes in respect of the ecliptic plane for the given epoch; ω_1, ω_2 are the arguments of the perihelia of the Earth and the asteroids; Ω_1, Ω_2 are the longitudes of the ascending nodes of the considered planes; v_1, v_2 are the true anomalies of the bodies [1], [4], [5].

The relationship for searching of minimal distance r_{12} between the Earth and the small body we represent in the form (1)

$$r_{12}^2 = (\mathbf{r}_1-\mathbf{r}_2)^2 = \min. \qquad (1)$$

Here, $\mathbf{r}_1$ and $\mathbf{r}_2$ – the heliocentric vectors of the positions of the Earth and the asteroid.

In line with the theory [1], the following assumptions were made.

$$r_1 = \frac{p_1}{1+e_1\cos(v_1)}, \qquad (2)$$

$$p_1 = a_1(1-e_1^2), \qquad (3)$$

$$x_1 = r_1(\cos(v_1+\omega_1)\cdot\cos(\Omega_1) - \sin(v_1+\omega_1)\cdot\sin(\Omega_1)\cdot\cos(i_1)), \qquad (4)$$

$$y_1 = r_1(\cos(v_1+\omega_1)\cdot\sin(\Omega_1) + \sin(v_1+\omega_1)\cdot\cos(\Omega_1)\cdot\cos(i_1)), \qquad (5)$$

$$z_1 = r_1(\sin(v_1+\omega_1)\cdot\sin(i_1)). \qquad (6)$$

The same equations (2)–(6) we put for the second body, using index "2".

In order to take into account the variations of the quantities of ω_1, ω_2, Ω_1, Ω_2, we represent these parameters in the forms

$$\omega_1=\omega_{10}+ k_1d_1, \qquad (7)$$

$$\omega_2=\omega_{20}+ k_2d_2, \qquad (8)$$

$$\Omega_1=\Omega_{10}+K_1d_1, \qquad (9)$$

$$\Omega_2=\Omega_{20}+K_2d_2. \qquad (10)$$

Here k_1, k_2, K_1, K_2 are empirical constants. d_1, d_2 are variable values, with imposed a constraint on the ascending nodes (The closest approaching of the considered bodies takes place in the ascending nodes, which are equal).

$$\Omega_1= \Omega_2, \qquad (11)$$

or

$$d_2 = (\Omega_{10}+K_1d_1- \Omega_{20})/K_2. \qquad (12)$$

The index "0" references to the initial data sets of ω_1, ω_2, Ω_1, Ω_2.

The quantities of r_{12}, x, y, z, and the first derivatives we find with using equalities (1) – (12) and the based equations we write as (13)

$$\frac{dr_{12}^2}{dv_1} = 0; \quad \frac{dr_{12}^2}{dv_2} = 0; \quad \frac{dr_{12}^2}{dd_1} = 0. \qquad (13)$$

For the process of calculating we use the system "MAPLE'15".

Example: Let's find the numerical values of v_1, v_2, and d_1 for the epoch of the Earth and the asteroid 2019 SU3 approaching. The initial orbital elements for the Earth and the asteroids are referred to the date 27, April, 2019 [1], [4], [5]. The unit of length is 1 AU. We put mass of the asteroid is less than mass of the Earth.

Using the empirical relation of ω to Ω for the planets of the Solar system [1] we may eliminate some singularities for the computations (for instance, if resonance in motion of the bodies is possible). So, put

$$k_1 = \sqrt{2}, K_1 = -1, k_2 = \sqrt{3}, K_2 = -1. \qquad (14)$$

Numerical and analytical investigations of two body's motion along heliocentric orbits in the interval of the several revolutions show there are local and global minimums of the distance r_{12} between the bodies. **(Fig. 1).**

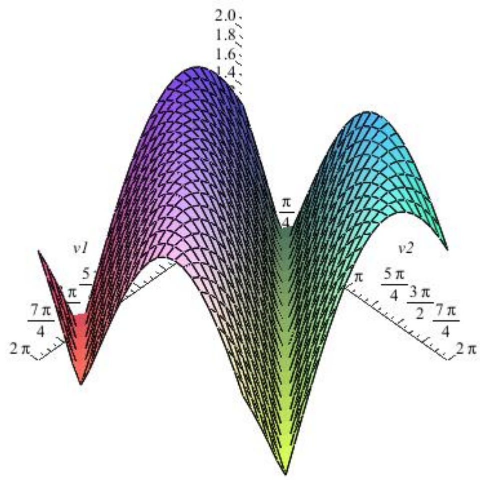

Fig.1. The distance $r_{12}=r_{12}(v_1,v_2)$ between the Earth and the asteroid 2019 SU3 is measured in AU. d_1=0.0173501769 rad. The true anomalies v_1 и v_2 take values in the interval from 0 to 2π rad.

The formulae (1) – (13) permit to determine the distance r_{12}, and plot the graph of the function $r_{12}=r_{12}(d_1)$. (**Fig. 2), (Fig. 3).**

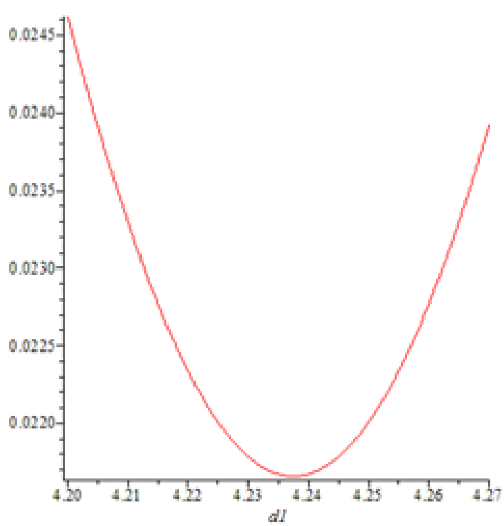

Fig.2. One of the local minimums of the functions r_{12} is the distance $r_{12}=r_{12}(d_1)$ between the Earth and the asteroid 2019 SU3 is measured in AU. d_1 is measured in rad. v_1=0.05981311596 rad, v_2= 0.008946200265 rad.

Conclusion: The advanced way gives scope for take into account the motion of perihelia and ascending nodes of celestial bodies. Estimation of the perturbations offers to determine the global minimum of r_{12} between the Earth and the hazardous bodies with the smaller error (**Fig. 3).**

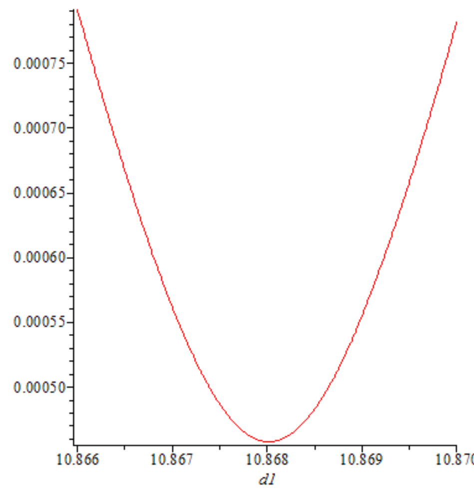

Fig.3. The global minimum of the function r_{12} (r_{12} is the distance between the Earth and the asteroid 2019 SU3 measured in AU). d_1 is measured in radians. v_1=1.6822015501976 rad, v_2=5.807095699091 rad.

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