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Valery Chepizhenko[1]
Viktoriya Volkogon[2]

APPROACHES TO FORMALIZATION OF MOTION DYNAMICS OF ARTIFICIAL FORCE FIELD METERS

National Aviation University
1, Kosmonavta Komarova ave., Kyiv, 03680, Ukraine
E-mails: [1]chiv@nau.edu.ua; [2]sonechkovika@mail.ru

Abstract

Purpose: *The aim of our study is to analyze virtual measurers with different functioning principles. In our case they are: a mathematical pendulum without quality factor, with quality factor and meter of force field gradient.* ***Methods:*** *This article reviews two main approaches for gradient or artificial force field measuring: gradient method and mathematical pendulum.* ***Results:*** *The results of our experiment proved that usage of the mathematical pendulum with quality factor is more effective than without it. We classified potential field methods concerning field types. Present approaches possess a number of shortcomings.* ***Discussion:*** *The paper considers modern approaches of solving conflict situations in airspace (traffic conflict). We carried out analysis of virtual indicators formalization with different functioning principles (mathematical pendulum, meter of force field gradient).*

Keywords: aircraft; dynamic models; force field potential; gradient; mathematical pendulum.

1. Analysis of the research and publications.

Currently there are a lot of methods which are based on force field potential peculiarities.

– Potential Field Approach;
– Artificial Potential Fields;
– Virtual Force Field;
– Vector Field Histogram та ін.

These methods are designed for different classes of dynamic objects, such as:

– Piloted Aircraft;
– Unmanned Aerial Vehicles (UAVs);
– Wheeled Mobile Robots;
– Autonomous Underwater Vehicles (AUVs). [1]

In research works [2, 3] was classified potential field methods concerning field types: uniform field (Fig.. 1, a); perpendicular field (Fig. 1. b), tangential field (Fig. 1, c), random field (Fig. 1, d), field of attraction (Fig. 1, e), repulsing field (Fig. 1, f), combination of attraction and repulsing (Fig. 1, g), canyon box world (Fig. 1, h). The following approach does not take into consideration characteristics of physical nature inserted in methods and doesn't allow making their systematic analysis.

2. Articulation of the problem

Present approaches possess a number of shortcomings. They are the following: 'lacuna' (when being in the force field a robot is unable to exit) and 'plateau' (in each point, force is evenly distributed and a robot is unable to find a way to move to) etc.

As methods possess a number of shortcomings, a problem of their excluding comes into existence, to make artificial force field work more effective to solve conflicts [4].

3. Outstanding parts of the problem which the following paper is dedicated to.

In each model of robot's movement there is a sensitive element which reacts on gradient change, direction or amplitude of force field. There is no a universal method at present time.

The «Free Flight» method for problem solving only was developed in research work [1]. Formulation of new concepts such as S&A, A³, as well as development and usage of Unmanned Aerial Vehicles (UAVs) which use off-line mode need higher flight safety requirements.

4. Formulation of the problem

The aim of our study is analysis of virtual measurers with different functioning principles. In the following case they are: a mathematical pendulum without quality factor, with quality factor and meter of force field gradient.

5. Fundamental research data description with complete motivation of research results

Two main approaches for gradient or artificial force field measuring are gradient method and mathematical pendulum. An analysis of these methods for solving conflicts will be carried out.

The mathematical pendulum in force field will be reviewed. [5] The mathematical pendulum is a mechanical system which consists of mass point fixed in nonstretch thread or bar in gravitational field. Such pendulum can be a heavy sphere with weight *m,* fixed in thread, length of which *l* is much bigger than size of sphere. If deflect it by an angle φ from vertical line, it will fluctuate under gravity force F_{mg}.

Fig. 1 shows the mathematical pendulum in MatLab environment, where F_{np} is a force of thread elasticity; m_1 is a pendulum weight; $m_ц$ is a target weight (which is dynamically regulated depending on the (x_i, y_i)) of other objects; m_{2-7} are other objects.

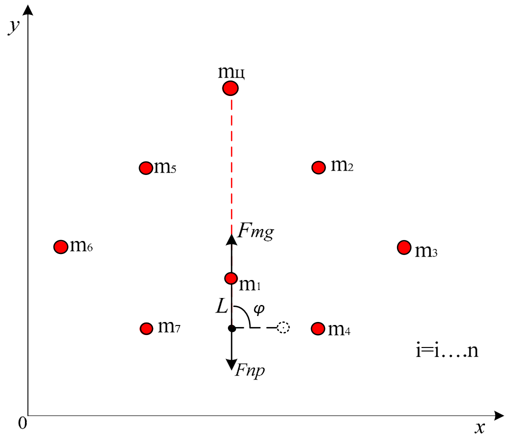

Fig. 1. Mathematical pendulum in MatLab environment

Fig.2 shows mathematical pendulum in artificial force field

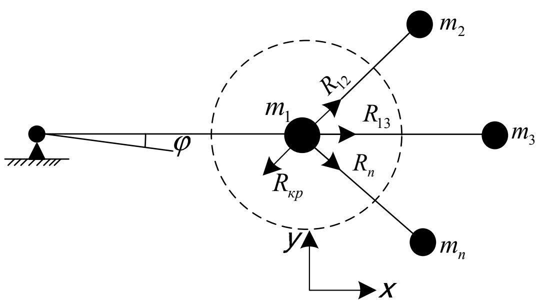

Fig. 2. The mathematical pendulum in artificial force field

Equation of damping pendulum (movement along axis X):

$$\frac{d^2x_1}{dt^2}+2\gamma\frac{dx_1}{dt}+\omega_0^2x_1=0$$

where γ- constant of damping; ω_0 - own oscillator frequency

The speed of damping associated with quality factor of oscillation system. Quality factor characterizes quality of oscillation system, as the bigger quality factor of oscillation system, the less power inputs in system per one oscillation. Quality factor of oscillation system Q is connected with logarithmic decrement of damping d.

The main parameter of damping is oscillation quality factor.

$$Q=\frac{\omega_0}{2\gamma}$$

For critical damping certain condition must be carried out

$$Q=0{,}5 \Rightarrow \ \omega_0=\gamma$$

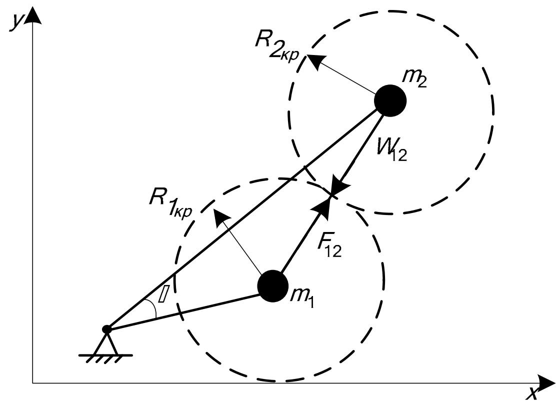

Fig. 3. Interaction of pendulum with one gravity body

F- gravity force which specifies target movement of object; *W*- buoyant force which specifies the process of conflict solving with other objects; m_1 – pendulum weight; m_2 – target weight; (is dynamically regulated depending on (x_i, y_i) of other objects; $R_{1кр}$ – critical pendulum radius; μ - damping coefficient.

$$m_1\frac{d^2x_1}{dt_2}=F_{12}-W_{12}+\mu\frac{dx_1}{dt_1}$$

Where μ - damping coefficient

Next formulas show how to compute forces of interaction m_1 and m_2

$$F_{12}^x=\frac{Gm_1m_2}{R_{12}^\alpha}\cdot\left|\frac{x_1-x_2}{R_{12}}\right|$$

$$W_{12}^x=\frac{Gm_1m_2}{R_{12}^\beta}-\frac{x_1-x_2}{R_{12}}\cdot R_{кр}^{(\beta-\alpha)}$$

where α i β – natural numbers, α > β

Having applied formula to the equation and reducing it the following equation was developed.

$$\frac{d^2x_1}{dt^2}-\mu\frac{dx_1}{dt}-Gm_2\left[\frac{|x_1-x_2|}{R_{12}^{\alpha+1}}-\frac{|x_1-x_2|R_{кр}^{(\beta-\alpha)}}{R_{12}^{\beta+1}}\right]=0$$

Using received equation own oscillation frequency can be found.

$$\omega_0^2 x_1 = -Gm_2 \left[\frac{|x_1 - x_2|}{R_{12}^{\alpha+1}} - \frac{|x_1 - x_2| R_{кр}^{(\beta-\alpha)}}{R_{12}^{\beta+1}} \right]$$

For one body ω_0

$$\omega_0 = \sqrt{-\frac{\mathrm{Gm}_2}{\mathrm{x}_1} \left[\frac{|x_1 - x_2|}{R_{12}^{\alpha+1}} - \frac{|x_1 - x_2| R_{кр}^{(\beta-\alpha)}}{R_{12}^{\beta+1}} \right]} =$$

$$\sqrt{-\frac{\mathrm{Gm}_2 |x_1 - x_2|}{\mathrm{x}_1} \cdot \frac{R_{12}^{(\beta+1)} - R_{12}^{(\alpha+1)} \cdot R_{кр}^{(\beta-\alpha)}}{R_{12}^{(\alpha+1)} \cdot R_{12}^{(\beta+1)}}}$$

Gradient of field is an important parameter which characterizes artificial force field. The gradient shows how fast a scalar quantity can change in different point of the field.

Gradient introduces as a vector quantity of a scalar field in each point of which refers to the definite scalar. Gradient is a vector which by its movement shows the direction of fast increasing of quantity φ, its meaning varies from one point of space to another (scalar field) [8]. According to the size it is equal to the growth rate of its quantity in this direction.

In other words gradient is a rapidity of physical quantity change, not in time but in a space direction.

For artificial gravity field gradient measurement the virtual meters are proposed. They represent a dynamic system which looks like mathematical pendulum. The following formulas were used to compute an artificial gravity field gradient.

$$F_\Sigma = (F_F^+ + F_F^-);$$

$$\frac{\Delta F_{\Sigma x}}{\Delta\varphi} = Grad_x; \quad \frac{\Delta F_{\Sigma y}}{\Delta\varphi} = Grad_y;$$

$$Grad_\Sigma = \sqrt{\Delta F_{\Sigma x}^2 + \Delta F_{\Sigma y}^2};$$

при $R_{12} \succ R_{кр\_goal} + R_{кр\_pend}$

Constant axis location BB in each instant of time identifies an angle of direction of artificial gravity field gradient

$$\frac{d^2\varphi}{dt^2} = f(\frac{d\varphi}{dt}, \varphi, p) = gradU_\Sigma;$$

Where p – virtual meter parameters

Artificial gravity field gradient lines can be comprehended as lines of force which characterize energy distribution. In other words if field of gravitational potential is set and in each instant of time suspension centers are known, the gradient lines show conflict-free movement trajectory which will be realized by dynamic objects in poly conflict.[6,7]

At research of approach efficiency concerning dynamic models formalization of virtual meters of artificial force fields the following efficiency criteria were used.

1) calculation time;
2) positioning accuracy
3) amount of operations needed for calculation

Three experiments were carried out using the mathematical pendulum without quality factor, with quality factor and meter of force field gradient. During these experiments meaning of target radius $R_{іц}$, pendulum radius $R_м$ and target weight changed under conditions $m_ц = 1$, $\varphi_0 = 20^0$:

$$F, W = f(R_м, R_{іц}, m_ц)$$

In first experiment target radius $R_{іц}$ changed under conditions $R_м = const$, $m_ц = const$:

$$R_{іц} = [R_{іц\min} ... R_{іц\max}],$$

де $R_{іц\min} \geq 2R_{кр}$ при $R_{крц} = R_{кр\_изм}$;

$$R_{іц\min} \geq (R_{крц} + R_{кр\_изм}) \text{ при } R_{крц} \neq R_{кр\_изм}.$$

Fig.4 shows dependence of calculation time and force field gradient on target radius.

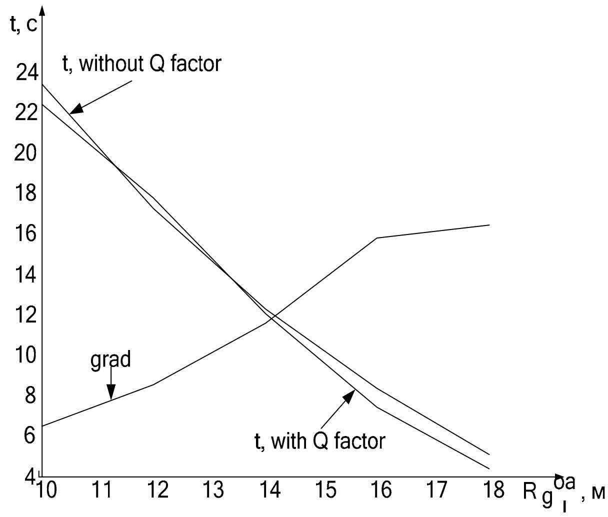

Fig. 4. Calculation time and force field gradient d ependence on target radius.

The results of first experiment proved that in a case of target radius growth calculation decreases and force field gradient increases.

In second experiment meaning of pendulum radius $R_м = \mathrm{var}$, changed on conditions that $R_{іц} = const$, $m_ц = const$.

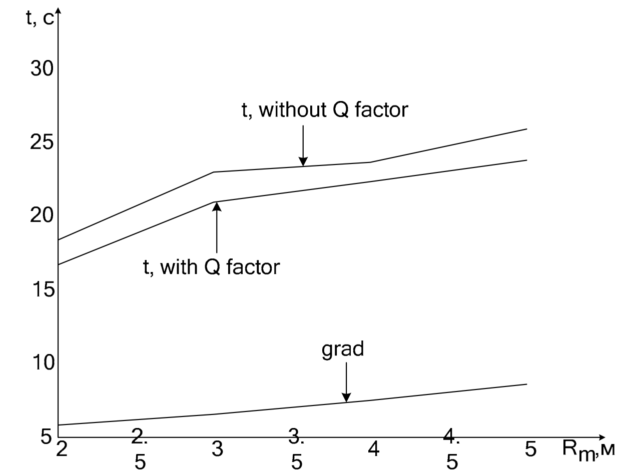

Fig.. 5. Dependence of calculation time and force field gradient on pendulum radius.

If meaning of pendulum radius increases the calculation time and force field gradient increase as well. In a case of quality factor the calculation time is lower than without quality factor.

The third experiment proved the change of target weight $m_{ц} = \text{var}$ on conditions that $R_{iц}, R_{м} = const$. Fig. 6 shows diagrams calculation time and force field gradient dependence on target weight.

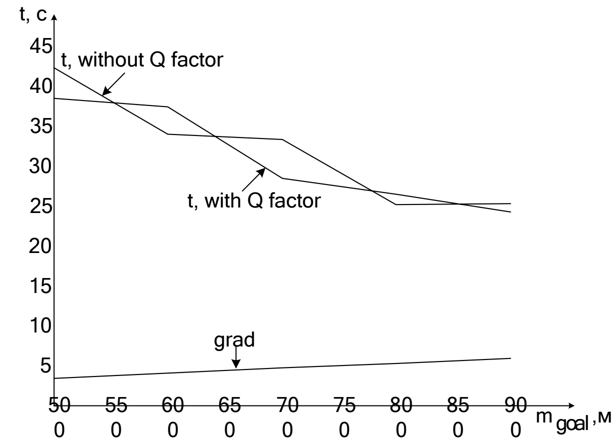

Fig. 6. Diagrams show dependence of calculation time and force field gradient on target weight.

If target weight increases, calculation time decreases and increases meaning of force field gradient.

6. Conclusions

The carried out analysis of virtual indicators formalization with different functioning principles (mathematical pendulum, meter of force field gradient) showed:

– Usage of the mathematical pendulum with quality factor is more effective than without it.

– General shortcoming of methods is expenditure of time and calculation expenditure for gradient defining near particular points (minima and discontinuity of a function).

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В.І. Чепіженко[1], В.О. Волкогон[2]. Дослідження підходів формалізації динаміки руху вимірювачів штучних силових полів
Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]chiv@nau.edu.ua; [2]sonechkovika@mail.ru

Мета: Метою нашого дослідження є аналіз віртуальних вимірювачів з різними принципами функціонування. У нашому випадку це: математичний маятник без добротності, з добротністю та вимірювач градієнту силового поля. **Методи:** У статті було розглянуто два основні підходи, які існують для вимірювання градієнта або штучного силового поля: градієнтний метод та математичній маятник. **Результати:** Результати нашого дослідження показали, що використання математичного маятника с добротністю є ефективнішим ніж без добротності. Було класифіковано потенційні польові методи по виду полів. Підходи, які існують на даний час мають ряд недоліків. **Обговорення:** Розглянуто сучасні підходи до розв'язання конфліктних ситуацій у повітряному просторі. Проведено аналіз особливостей формалізації віртуальних вимірювачів з різними принципами функціонування (математичний маятник, вимірювач градієнту силового поля). Наведено результати моделювання названих вище підходів, дано їх порівняльну оцінку.

Ключові слова: градієнт; динамічні моделі; літак; математичний маятник; потенційне силове поле.

В.І. Чепіженко[1], В.О. Волкогон[2]. Исследование подходов формализации динамики движения измерителей искусственных силовых полей
Национальний авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]chiv@nau.edu.ua; [2]sonechkovika@mail.ru

Цель: Целью нашего исследования является анализ виртуальных измерителей с различными принципами функционирования. В нашем случае это: математический маятник без добротности, с добротностью и измеритель градиента силового поля. **Методы:** В статье были рассмотрены два основных подхода, которые существуют для измерения градиента или искусственного силового поля: градиентный метод и математической маятник. **Результаты:** Результаты нашего исследования показали, что использование математического маятника с добротностью является более эффективным чем без добротности. Были классифицированы потенциальные полевые методы по виду полей. Подходы, которые существуют в настоящее время имеют ряд недостатков. **Обсуждение:** Рассмотрены современные подходы к решению конфликтных ситуаций в воздушном пространстве. Проведен анализ особенностей формализации виртуальных измерителей с различными принципами функционирования (математический маятник, измеритель градиента силового поля). Приведены результаты моделирования вышеупомянутых подходов, дана их сравнительная оценка.

Ключевые слова: градиент; динамические модели; математический маятник; потенциальное силовое поле; самолет.

Chepizhenko Valery. Doctor of Engineering. Professor.
Director of the Air Navigation Institute, National Aviation University (Ukraine).
Education: Kiev Higher Military Aviation Engineering School (1990).
Research area: synergetic aircraft polyconflict resolution methods, methods of integrated dynamics and technical maintenance of an aircraft in the CNS/ATM environment.
Publications: 60.
E-mail: chiv@nau.edu.ua

Volkogon Viktoriya. Post-graduate student.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2013).
Research area: free flight aircraft and resolution of conflict situations in a free flight.
E-mail: sonechkovika@mail.ru