DECOMPOSITION METHOD FOR ANALYSIS OF ROBOT VERTICAL VIBRATION MOVEMENT

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Abstract. The work is dedicated to flying or diving robot motion analysis in which the drive system is created without propellers - with fins or wings. The diving or flying robot's frame vertical slow movement is initiated by the vibrations of wings. Interaction with the fluid (air or water) is described as the elementary particle interaction forces proportional to the square of the speed of the contact surfaces. Additionally, the wing interaction forces are dependent on the speed direction to be followed by two different drag coefficients (move up or down). Motion analysis of the system is divided into two stages. In the first stage of decomposition wing rapid oscillatory motion is analyzed, assuming that the robot's body is motionless. One case, in which the transient motion of wings is given, is analyzed. In the second case the forces of rotation actuators are given. The region in which forces try to pick up the robot is fixed. In the second stage of decomposition using the obtained fluid reactions (fast moving) of the first stage slow upward movement is analyzed. In this stage hull interaction with the environment is also respected. At the end application of two rotation actuators is analyzed. The results of the proposed decomposition method can be used for flying and diving robot synthesis.

Keywords: diving or flying robot, wings vibrations, body motion, motion decomposition.

Introduction

In the robotic technique synthesizing new drive mechanisms the major role is given to biological systems to imitate the motion. For example, fish tail or fish side fins type actuators are used in underwater robot synthesis, but the insect or bird flapping wings actuators are implemented in flying robot design. In both cases, applicable mathematical models are similar, differing only in the fluid density. Mostly flying or diving robot movement is going on a medium or low speed region. However, even in these cases there are problems to describe accurately the variable structure mechanical systems center of mass motion and rotation around it, because the interaction forces with the surrounding fluid (water or air) are very complicate [1-3]. In some reports with a high-speed photo camera it has been observed that the bee-wing movement during the flight is very complex [4; 5]. It is composed movement consisting of several elementary small angles of rotation motions (Fig. 1.). It has been found that the basic movement frequency is very high, above 200 Hz. This study confirms that in rough calculation it is appropriate to use the movement decomposition, splitting fast wing movements and slow motion of the central mass. Analyzing slow motion (as the center of mass motion and rotation around it) wings and fluid interaction forces from fast movement must be added.

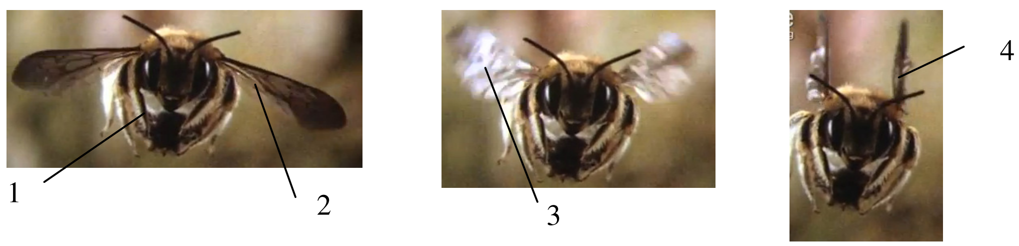

Fig. 1. **Bee-wing movement during the flight is very complex [4; 5]:** 1 – central body; 2 – lower position of wings; 3 – middle position of wings by two rotations; 4 – upper position of wings

Model of horizontal translation motion decomposition

To check up the possibility of the decomposition method, first of all a horizontal motion model was investigated with one wing that is shown in Fig. 2. The right side part of decomposition is shown in Fig. 2. Motion calculation was made by differential equations (1-3).

$$\begin{pmatrix} x_{n+1} \\ v_{n+1} \\ X_{n+1} \\ V_{n+1} \end{pmatrix} := \begin{bmatrix} x_n + s \cdot v_n \\ v_n + \dfrac{s}{m1} \cdot \left[-c \cdot x_n - b \cdot v_n - \left[B1 \cdot \left(1 - k \cdot \text{sign}(v_n)\right)\right] \cdot (v_n)^2 \cdot \text{sign}(v_n) + P1 \cdot \sin(\omega \cdot t_n) \right] \\ X_n + s \cdot V_n \\ V_n + \dfrac{s}{m1 + m2} \cdot \left[-B2 \cdot (V_n)^2 \cdot \text{sign}(V_n) - \left[B1 \cdot \left(1 - k \cdot \text{sign}(v_n)\right)\right] \cdot (v_n)^2 \cdot \text{sign}(v_n) \right] \end{bmatrix}, \tag{1}$$

$$RV_n := -\left[B1 \cdot \left(1 - k \cdot \text{sign}(v_n)\right)\right] \cdot (v_n)^2 \cdot \text{sign}(v_n), \tag{2}$$

$$\begin{pmatrix} x1_{n+1} \\ v1_{n+1} \\ x2_{n+1} \\ v2_{n+1} \end{pmatrix} := \begin{bmatrix} x1_n + s \cdot v1_n \\ v1_n + \dfrac{s}{m1} \cdot \left[-c \cdot x1_n + c \cdot x2_n - b \cdot v1_n + b \cdot v2_n - \left[B1 \cdot \left(1 - k \cdot \text{sign}(v1_n)\right)\right] \cdot (v1_n)^2 \cdot \text{sign}(v1_n) + P1 \cdot \sin(\omega \cdot t_n) \right] \\ x2_n + s \cdot v2_n \\ v2_n + \dfrac{s}{m2} \cdot \left[c \cdot x1_n - c \cdot x2_n + b \cdot v1_n - b \cdot v2_n - B2 \cdot (v2_n)^2 \cdot \text{sign}(v2_n) - P1 \cdot \sin(\omega \cdot t_n) \right] \end{bmatrix}, \tag{3}$$

where x, v – coordinate and velocity of fast wing motion (Fig. 2);
X, V – coordinate and velocity of center mass of system (Fig. 1);
m1, m2 – wing and central body masses;
c – stiffness of spring;
b – constant of inside damper;
B1, B2 – parameters of element interactions with air, including density of fluid and area interactions;
k – drag exchange coefficient;
P1, ω – amplitude and angular frequency of internal excited force;
RV1 – wing and air interaction force from decomposition model.

The results of modelling are shown in Fig. 4-7. Comments on the results are given below figures.

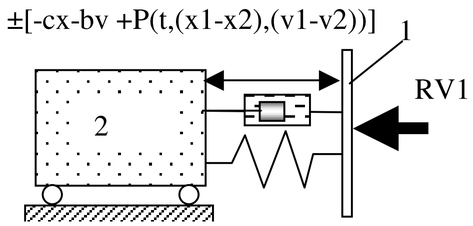

Fig. 2. **Complete model:** 1 – fluid interaction wing; 2 – central body

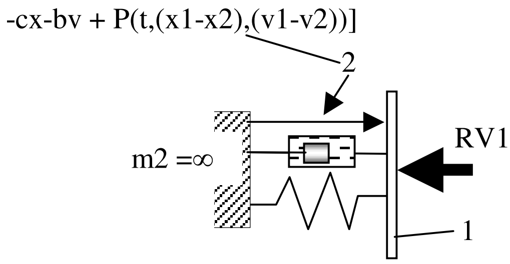

Fig. 3. **Wing fast movement scheme:** 1 – wing; 2 – one side interactions when central body m2 is motionless

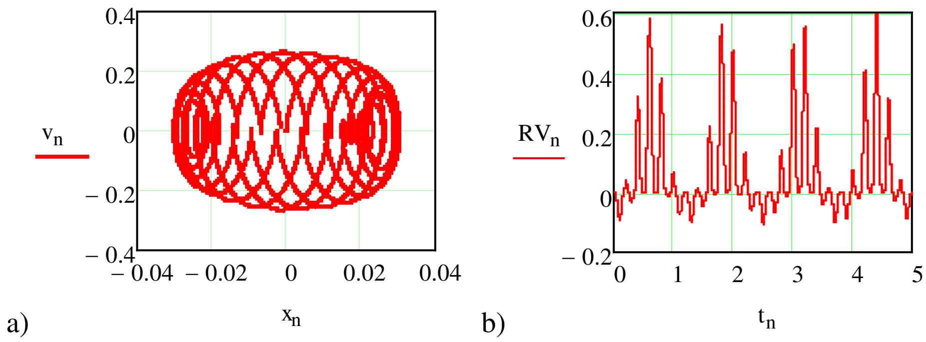

Fig. 4. **Wing modellings results:** a – wing fast motion graphic in phase plane (x, v); b – air interaction resulting force

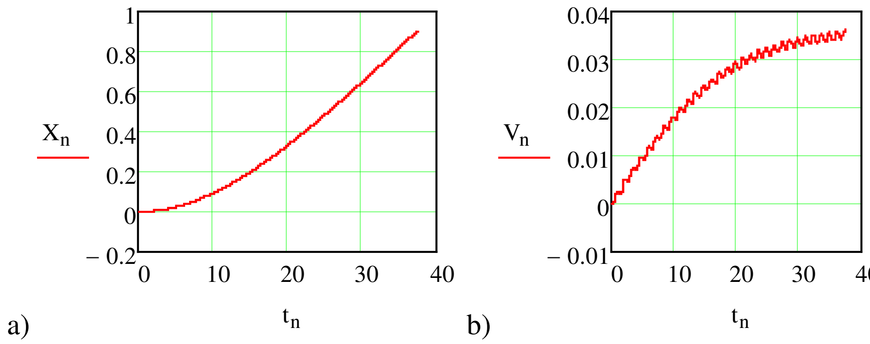

Fig. 5. **Central body motion graphics:** a – displacement X graphic as time t function; b– velocity V graphic as time t function

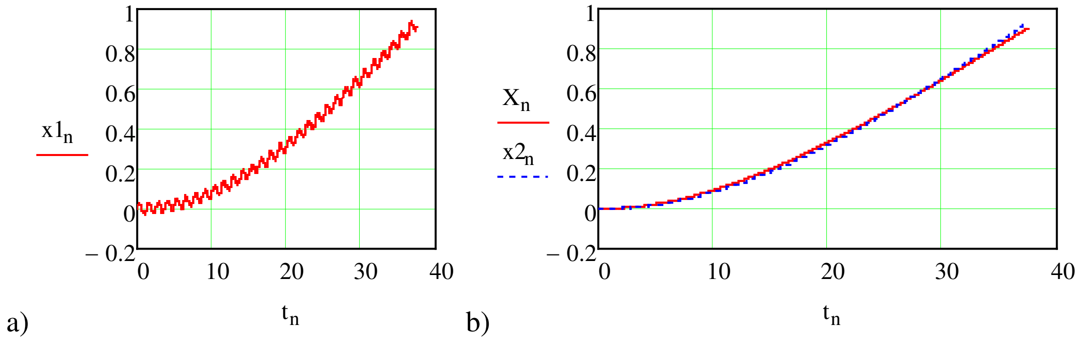

Fig. 6. **Wing and central body different motion graphics:** a – wing displacement x1 precision graphics; b – central body precision motion x2 graphics and central body decomposition motion X graphics

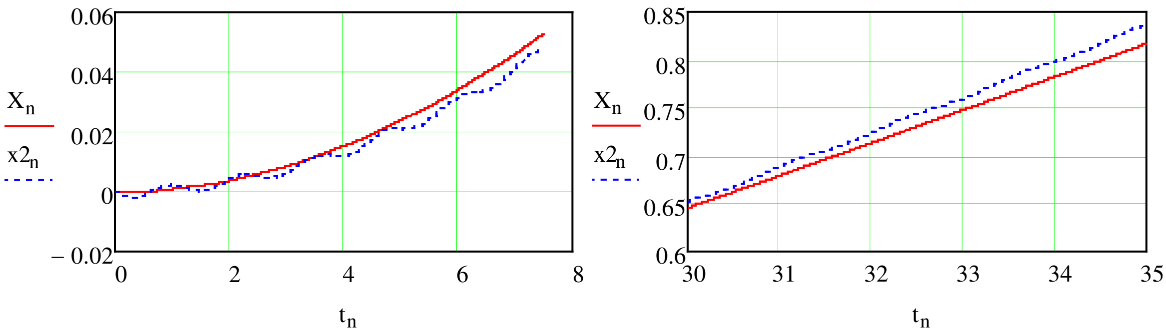

Fig. 7. **Central body different motion graphics:** central body precision motion x2 graphics and central body decomposition motion X graphics; in given task at the end of motion t = 35 seconds precision of decomposition method is about 2 %

Plane motion decomposition

The principal scheme of the model is given in Fig. 8. The decomposition model is shown in Fig. 9. Differential equations of the decomposition model are given in (4)

$$\begin{pmatrix} \varphi_{n+1} \\ v\varphi_{n+1} \\ Y_{n+1} \\ V_{n+1} \end{pmatrix} := \begin{bmatrix} \varphi_n + s \cdot v\varphi_n \\ v\varphi_n + \frac{s}{JA} \cdot \left[-c \cdot \varphi_n - b \cdot v\varphi_n - KM1 \cdot \left(1 - k \cdot \mathrm{sign}\left(v\varphi_n\right)\right) \cdot \left(v\varphi_n\right)^2 \cdot \mathrm{sign}\left(v\varphi_n\right) + M1 \cdot \sin\left(\omega \cdot t_n\right) \right] \\ Y_n + s \cdot V_n \\ V_n + \frac{s}{2 \cdot m1 + m2} \cdot \left[-B2 \cdot \left(V_n\right)^2 \cdot \mathrm{sign}\left(V_n\right) - 2 \cdot \left[KR1 \cdot \left(1 - k \cdot \mathrm{sign}\left(v\varphi_n\right)\right)\right] \cdot \left(v\varphi_n\right)^2 \cdot \mathrm{sign}\left(v\varphi_n\right) \cdot \cos\left(\varphi_n\right) - (2 \cdot m1 + m2) \cdot g \right] \end{bmatrix}, \quad (4)$$

where φ, $v\varphi$ – angle and angular velocity of fast wing motion (Fig. 9);
X, V – coordinate and velocity of central body motion (Fig. 8);

m1, m2 – wings and central body masses;
c – stiffness of rotating spring;
b – constant of inside damper;
KM1, KM2 – parameters of element interactions with air;
k – drag exchange coefficient;
M1, ω – amplitude and angular frequency of internal excited force moments;
RV – wing and air interaction force from decomposition model.

The results of modelling are shown in Fig. 10-11, comments on the results are given below figures.

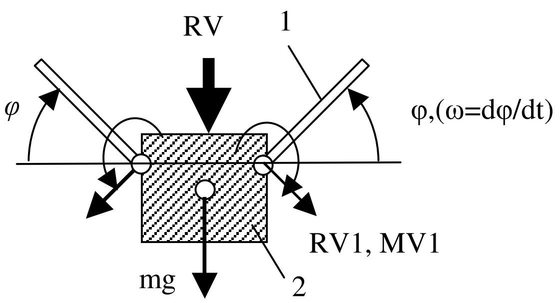

Fig. 8. **Complete motion model:** 1 – fluid interaction wing; 2 – central body with weight mg

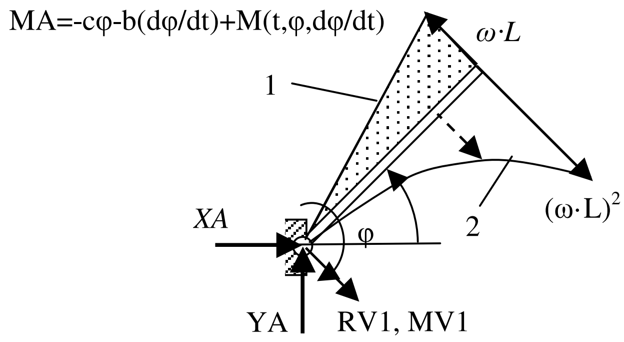

Fig. 9. **Fast wing movement decomposition scheme:** 1 – wing local point rotation velocity graphic; 2 – graphic of distributed fluid interaction forces as square function of rotation angular velocity

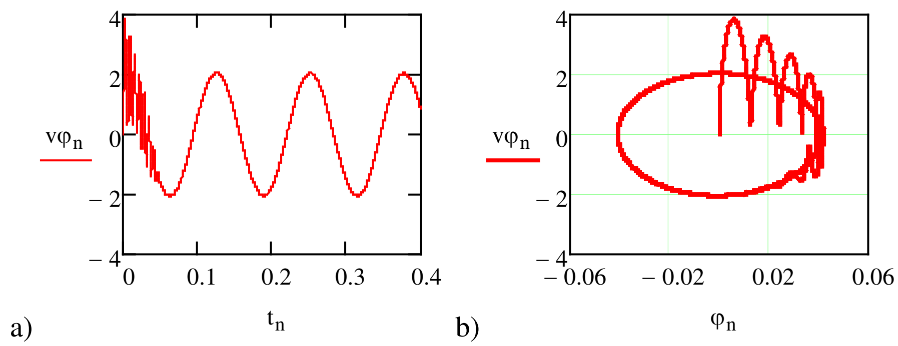

Fig. 10. **Approximation of one wing motion:** a – angular velocity as time function; b – motion graphic in phase plane

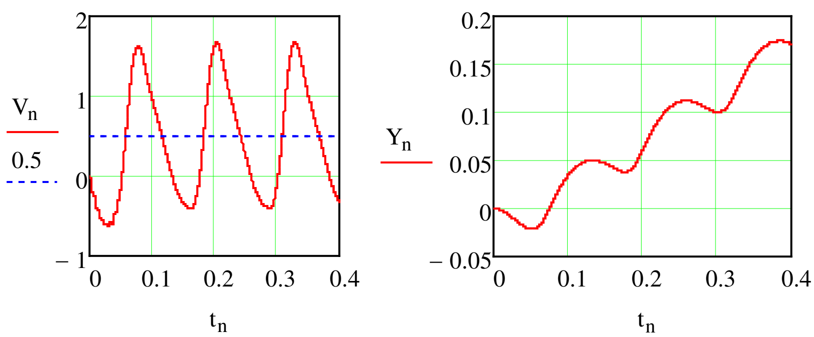

Fig. 11. **Central body approximation motion in vertical up direction:** a – central body approximation motion velocity graphics in time t; body starts to fly up because middle value of velocity is positive; b – central body approximation motion vertical displacement graphics in time t

Two actuators flying motion decomposition

According to the equations (4) the idea to use two actuators for wings and fluids interaction forces control was investigated. One actuator was for wing rotation motion excitations in vertical plane and the second one was for rotation in horizontal plane. In this case differential equation of motion using the decomposition method is (5):

$$\begin{pmatrix} y_{n+1} \\ v_{n+1}\end{pmatrix} := \begin{bmatrix} y_n + s\cdot v_n \\ v_n + \frac{s}{m}\left[-m\cdot g - D1\cdot(v_n)^2\cdot \mathrm{sign}(v_n) - D2\cdot\left(1-\Delta\cdot\sin(p\cdot t_n+\phi)\right)\cdot\left(\frac{L}{2}\cdot\alpha0\cdot\omega\cdot\cos(\omega\cdot t_n)\right)^2\cdot\mathrm{sign}\left(\cos(\omega\cdot t_n)\right)\cdot\cos\left(\alpha0\cdot\sin(\omega\cdot t_n)\right)\right]\end{bmatrix}, \quad (5)$$

where ω, p – frequencies of wing rotation around horizontal and vertical axis;
ϕ – phase between rotations;
L – length of wing;
$\alpha0$ – amplitude of vertical rotation;
D1, D2 – constants.

In this task the pick up force is calculated by equation (6). The pick up motion graphics are shown in Fig. 12.

$$RV_n := -\left[D2\cdot\left(1-\Delta\cdot\sin(p\cdot t_n+\phi)\right)\cdot\left(\frac{L}{2}\cdot\alpha0\cdot\omega\cdot\cos(\omega\cdot t_n)\right)^2\cdot\mathrm{sign}\left(\cos(\omega\cdot t_n)\right)\cdot\cos\left(\alpha0\cdot\sin(\omega\cdot t_n)\right)\right], \quad (6)$$

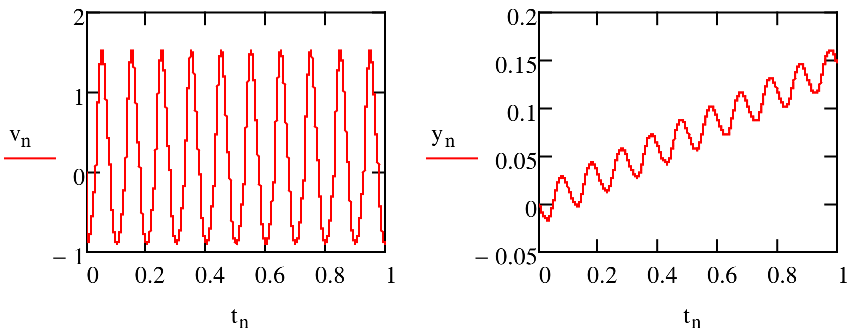

Fig. 12. **Vertical slowly motion graphics for two actuators driven system:** a – velocity graphics; b – vertical displacement graphics

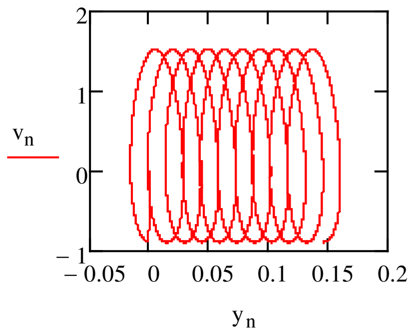

Fig. 13. **Vertical slowly motion graphics in phase plane:** velocity as a function of displacement

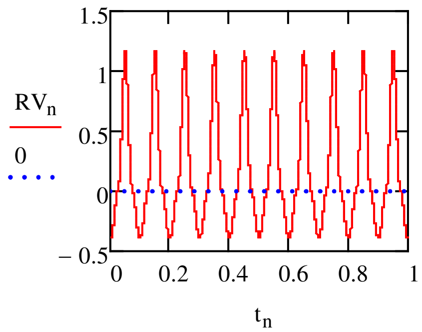

Fig. 14. **Interaction force approximation (6):** force as a function of time

Results and discussion

Robots motion analysis in fluid media by the decomposition method allows to simplify the calculation procedure. In the first stage of decomposition the central body of the robot can be observed as motionless. It allows to increasing degree of freedom for pick up forces calculation. In the second stage of decomposition full system modeling allows finding motion with appropriate enough precision. At the end of the investigations recommendations for the control system actuator synthesis can be found.

Conclusions

1. Robot motion analysis inside fluid media includes complicated interactions with three dimension forces. For technical invention of new robot control systems equations of interaction forces can be simplified.
2. In first stage of investigation the decomposition method allows to decrease the degree of freedom of the system. Founding out approximate interaction forces allows describing the robot motion and gives visible recommendations for new system synthesis.
3. From analysis of robot wings two vibration motion regime of pick up and flying regime are found out.

References

1. Clancy L. J. Aerodynamics. Publisher by Pitman. New York. London. 1975. 610. p.
2. Morrison F. A. An Introduction to Fluid Mechanics. Cembridge University Press. New York. 2013. 625. p.
3. Data Correlation for Drag Coefficient for Sphere. [online][10.12.2014] Available at: http://www.chem.mtu.edu/~fmorriso/Data CorrelationForSphereDrag2013.
4. Douglas L. Altshuler, William B. Dickson, Jason T. Vance. etc. Short-amplitude high-frequency wing strokes determine the aerodynamics of honeybee flight. Proceedings of the National Academy of Sciences of the United States of America. Vol. 102, no 50, December 13, 2005. pp. 18213-18218.
5. “Apis Mellifera: Honey Bee” a high-speed short. [online][10.12.2014] Available at: https://vimeo.com/100367111