

Kinematic Analysis of Micro Air Vehicle Flapping Wing Mechanism

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Abstract: Micro air vehicles (MAVs) have the potential to revolutionize our sensing and information gathering capabilities in areas such as environmental monitoring and homeland security. Bionic robotics research have been focused on the development of flapping wing machines from the natural flight mechanisms of insects or birds such as dragonflies, doves, hawk moths and bats, which are well known for their high degree of maneuverability and quite flights. They can also fly at very low forward speed, making them suited for obstacle avoidance in indoor operations. A planar four bar linkage as a typical and simple mechanism is used to simulate the flapping motion of a bird. In the present work flapping wing of MAV is idealized as single crank double rocker type linkage. Mathematical models of the flapping angle and angular velocity of two wings are established. This provides theoretical basis for mechanism design. A MATLAB code is generated for the single crank double rocker linkage. Burmester’s circle points and center points theory is to be used in design of four linkage. ADAMS and MATLAB softwares are to be used for the analysis and simulation of flapping wing mechanism model.

Keywords: Micro Aerial Vehicle, Virtual Prototyping Technology (VPT).

I. INTRODUCTION

A simple mechanical flapping mechanism is proposed by R. Madangopal et al, 2005(1) based on ideas obtained from the study of insect and bird flight. Beginning with kinematic model of the mechanism and rigid body dynamic model is described in which equations of motion are derived. Finally the expressions for lift, thrust and aerodynamic moment are derived from aerodynamic model. S.H. McIntosh et. al. 2006(2), describes the ornithopter design, the mechanism it uses to create biaxial rotation of the wing using only a single actuator, a theoretical model to predict its dynamics and aerodynamics, and comparison of the results with experimentally collected wing force-torque data. Michael A.A. Fenelon et al, 2010(3) proposed the design of an active flapping wing mechanism that replicates flapping patterns of dragonflies is obtained by using modified slider-crank (MSC) mechanism which operates using a rotary actuator and generates four distinct flapping patterns. Two steering mechanisms are demonstrated and differential steering is achieved by inclining individual stroke or flapping planes; this feature imparts multi-mode flight capability. Single-crank-double-rocker mechanism is the simplest realization of flapping motion with high efficiency, light weight, easy miniaturization, etc. However, during the flight, it often tilts toward the left or the right and even falls off, these disadvantages are mainly caused by the incomplete symmetry of the wings movement. To solve this problem, Mathematical models of the flapping angle and angular velocity of two wings have been established by Chao Wang et. al., 2010(4), and then an optimal design for improving the symmetry of the flapping motion has been carried out.

There are three problems that have to be considered in the synthesis of planar four-bar linkages, they are branch, order and crank problem. Different methods have been proposed by Jing-Shan Zhao et. al., 2014(5), to solve the problem. Simple extensions of the analysis offer a detailed picture of the movements of both driving crank and followers. Complex number method is applied to the dimensional synthesis of planar triads for six exact positions and motion generation. For four specified task positions for the design of planar four-bar linkage, Burmester curve equations can be represented by displacement matrix method. The synthesis of a planar four-bar linkage is discussed to generate a coupler-line envelope, tangent to three, four and five prescribed link positions, and to coordinate the coupler line movements with two, three and four input-link positions. The wing morphing concepts can be classified into three major types: planform alternation, out-of-plane transformation, and airfoil adjustment. In the planform alternation category, wing area manipulation techniques such as the resizing of span and chord length are discussed by author. Approaches to alter the wing sweep are also included in the planform morphing category. In the outof-plane transformation category, A.Y.N. Soflaet. al., 2010(6) had included the chord and span-wise camber changes. The most notable approach in this category is the twisting of the wing. The airfoil adjustment category summarizes the designs that

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change the wing profile (e.g. thickness) that do not significantly change the wing camber.

Adaptive wing schemes of varying complexity are outlined, including the adaptation of complete wings (airfoils), the adaptation of individual components, such as variable-camber leading and trailing edges and local contour bumps, and the adaptation of components in combination, examples being contour bumps in the shock region in conjunction with a trailing-edge flap or the combination leading-edge/trailing-edge flap, respectively. Emphasis is placed on aerodynamics and aerodynamics benefits. E. Stanewsky., 2001(7) also considered examples of possible structural realizations and penalties associated with an aircraft installation of control and adaptation schemes. Kirill V. Rozhdestvenskyet. al., 2010(8) aimed to review the aerodynamics of flapping wings, covering the history and relevant classical work, biological “analogies”, mathematical models, and theoretical and experimental results. The author first discussed biological observations that allow one to define the most important factors governing the performance of flapping-wing propulsors. Author also presented a classification of flapping-wing propulsors from the engineering point of view. MetinSitti 2003(9) considered mainly the stroke amplification and compact thorax mechanism design issues using a four-bar mechanism with two flexible links and an integrated piezoelectric unimorph actuator at the input link. The author, detailed analysis was realized for a micromechanical flapping wing mechanism based on a compliant four-bar structure, and a high stroke flapping mechanism is developed.

S.A. Ansari 2006(10) addressed the basics of insect flight, particularly their kinematics. The author also discussed the aerodynamic phenomena that make insect-like flapping flight possible and identify the key elements that need to be included in a representative aerodynamic model. Sean H. McIntosh 2006(11), described the ornithopter design, the mechanism it uses to create biaxial rotation of the wing using only a single actuator, a theoretical model to predict its dynamics and aerodynamics, and comparison of these results with experimentally collected wing force-torque data. K. KurienIssac et al., 2007(12) considered mechanical bird which is similar to the pigeon in size and weight, the reason for choosing the pigeon as model is that pigeons are good fliers, and can rise up nearly vertically from the ground and maneuver well in air. The size of the pigeon does not demand microlevel subsystems and, hence, it may be possible to design and develop such a system with existing technology. The author first described the mathematical model of the system. Then author described the optimization problem. CezaryGalin et al., 2007(13) gave a brief summary of the predicted aerodynamic forces acting on the flapping wing and the flapping mechanism itself was described. The description consists of loading analysis, wing design description, strength analysis and the frames design.

Taku Yokoyama et al., 2008(14) presented an innovative variable-wing mechanism based on flapping motion of birds. This mechanism proposed is to realize the complicated flapping motion of birds such as flapping, spanning, leading and feathering by using only a single actuator. The author shown the utility of the new variable wing mechanism by comparing the motion generated by the new mechanism with the typical flapping motion of pigeons. Robert J. Wood, 2008(15), emulous goal of creating an insect-sized, truly micro air vehicle is addressed by first exploring biological principles. These principles gave insights on how to generate sufficient thrust to sustain flight for centimetre-scale vehicles. The author had shown how novel manufacturing paradigms enable the creation of the mechanical and aeromechanical subsystems of a micro robotic device that is capable of Diptera-like wing trajectories and the results are a unique microrobot: a 60 mg robotic insect that can produce sufficient thrust to accelerate vertically. Thien-Tong Nguyen et al., 2008(16) investigated the mechanisms of lift enhancement in insect flight experimentally by visualization of air flows around flying insects recorded by high speed camera. Various kinds of insects such as beetles had been investigated and video images of flapping wing motion of these insects were analyzed to find their various flapping mechanisms. The most common and simple flapping wing motions are along inclined stroke planes with thin figure-eight trajectory and can be applied for robotic flapping wing mechanisms. The wing kinematics for 2D model is described in detail.

II. FLAPPING WING MECHANISM

The schematic of driving mechanism is shown in Fig.1 below. $\gamma$ is the stagger angle, $l_1$ is the crank length, $l_2$ is the linkage length, $l_3$ is the rocker length, $l_4$ is the distance between the fulcrum O and O1, and $\alpha$ is the distance between the crank and OO1.

![Fig.1. The schematic of driving mechanism.](image)

The angular velocity of crank can be written as follows:

$$\omega = \frac{\pi n_1}{20 i}$$  \hspace{1cm} (1)

Where $n_1$ is the motor speed, $i$ is the total transmission ratio.

The flapping angle and angular velocity of the right rocker are denoted by $\varphi_1(\alpha)$, $\omega_1(\alpha)$, respectively, while the flapping angle and angular velocity of the left rocker are denoted by $\varphi_2(\alpha)$, $\omega_2(\alpha)$, respectively. Using the method of instantaneous
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In contrast to the graphical approach, Freudenstein developed an analytical approach for analysis and design of four-link mechanisms as shown in Fig.2. He presents an equation which relate the rotation angles $\Phi$ and $\psi$ in terms of the link lengths $a$, $b$, $c$ and $d$. The scalar equation, which is now known as the Freudenstein equation, essentially is the condition for the assembly of the links (also called the loop-closure constraint) in a four-link mechanism at a given $\Phi$. We follow the development of the Freudenstein equation using fig.3.

Fig.3. Four bar mechanism.

The frame is normalized to unity and the other lengths are denoted by $b$, $c$ and $d$, and the input and output angle are $\Phi$ and $\psi$, respectively. Freudenstein obtained a simple scalar equation.

\[
R_1 \cos \Phi - R_2 \cos \psi + R_3 = \cos (\Phi - \psi)
\]

(3)

Where,

\[
R_1 = 1/d
\]

(4)
\[
R_2 = 1/b
\]

(5)
\[
R_3 = (l + b^2 - c + d^2)/(2bd)
\]

(6)

Equation (3) is known as the Freudenstein Equation and is readily applicable to kinematics analysis of four-bar mechanisms – from known links lengths and the input angle $\Phi$, the output angle $\psi$ can be found. Equation (3) can also be directly used for three precision point synthesis for a function generating four-link mechanism. Given three values of input $\Phi_i$, $i=1, 2, 3$, and the corresponding three values of output $\psi_i$, $i=1, 2, 3$, one can substitute these angle pairs in equation (3) to obtain three linear equations in $R_{i1}, R_{i2}$ and $R_{i3}$. Once $R_{i1}, R_{i2}$ and $R_{i3}$ are obtained from the solution of the linear equations, one can easily obtain the link lengths $b$, $d$, and $c$ from equations (4), (5) and (6), respectively. For designing with larger number of precision points, Freudenstein introduced two new variables $p_i$ and $q_i$ denoting the rotation angles from unspecified and arbitrary starting positions $\Phi_s$ and $\psi_s$. Setting $\Phi = \Phi_s + p_i$ and $\psi = \psi_s + q_i$, equation (3) now can be written as

\[
R_{i1} \cos(\Phi_s + p_i) - R_{i2} \cos(\psi_s + q_i) + R_{i3} = \cos(\Phi - \psi)
\]

The above equation (7) can be used for four and five precision point synthesis. Freudenstein developed a detailed solution for function generation with four and five-precision point synthesis for a four-link mechanism.

III. RESULTS

Results Showing Rocker-Crank mechanism shown in bellow Fig. 4.

![Fig. 4. Rocker-Crank mechanism.](image)

A single crank double rocker is considered for the analysis. Since the mechanism is a combination of two crank-rocker linkages, the MATLAB code is written for only one pair of crank-rocker linkage. The flapping angles of the mechanism for the respective input crank angles have been calculated. The single crank double rocker mechanism is modelled in MSC ADAMS software and its motion is simulated by using Matlab program, the optimal structure of the landing gear mechanism is selected.

IV. CONCLUSION

The kinematic analysis is performed on the single crank double rocker type flapping wing mechanism and the flapping angles of the mechanism are obtained for the input crank angles. A MATLAB code is generated for this purpose, taking a single crank rocker linkage into account. The single crank double rocker mechanism is modelled in ADAMS software and the flapping motion of the mechanism is simulated.

V. REFERENCES

[4] Li Ming, Hao Xiang-Yu, Han Xue-Feng And Jia Hong-Guang “Aircraft landing gear simulation using multidomain modeling technology” International Conference of Information Technology, Computer Engineering and Management Sciences 2011.
[6] Li Fu, Chaoan Yang, Dongzheng Wang and Wei Hu “The Overview of Aircraft Landing Gear Co-Simulation Based on
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