Optimal Overall Layout Design of Multi-Rotor Vehicles Based on BEMT and PSO Algorithm

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論 文 名　：Optimal Overall Layout Design of Multi-Rotor Vehicles Based on BEMT and PSO Algorithm
(BEMT と PSO アルゴリズムに基づくマルチローター機の全体最適レイアウト設計)

区　　分　：甲

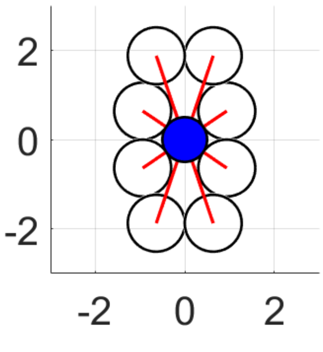
論　文　内　容　の　要　旨

In the design of multi-rotor vehicles, it is very important to predesign the overall multi-rotor layout from the perspectives of fluid dynamics, flight dynamics, and control performance. Although the configuration and layout have a great influence on the flight performance of multi-rotor aircraft, for example, how many rotors are there, what is the appropriate size of rotors, how to determine the position of rotors, how to determine the parameters of blades, etc., the designs by major companies around the world are different from each other, and there is currently no unified guiding principle. It should be noted that a proper design depends on different flight requirements (payload, cruise speed, flight altitude/distance, etc.), flight area (urban, mountain, or sea), and expected missions. Therefore, the proper configuration of multi-rotor vehicles will naturally vary according to specific flight requirements, conditions or 'design philosophy'. On the other hand, most of large multi-rotor aircraft for manned or cargo transportation use fossil fuel as energy, CO_2 emission becomes an issue of widespread concern. Therefore, due to energy saving and emission reduction, electric vertical take-off and landing (eVTOL) aircrafts are somewhat expected to replace traditional jet aircraft, as eVTOL aircrafts are expected to reduce not only CO_2 but also noise and maintenance cost. Moreover, they allow greater flexibility in the layout of rotors because the motors and batteries are smaller and lighter than traditional mechanical systems, and they can be distributed at separate positions. However, due to the lower energy density of lithium batteries than fossil fuel, current electric multi-rotors have very short flight endurance. In order to solve this problem, the overall layout of the multi-rotor should be optimized to improve the flight efficiency.

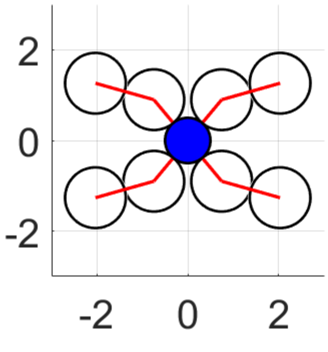
Based on the above background, this paper takes eVTOL as the object, and proposes a kind of guidance method for the optimal layout design of multi-rotor vehicles. The theories mainly used are Blade Element Momentum Theory (BEMT) and Particle Swarm Optimization (PSO). BEMT is a combination of blade element theory and momentum theory. PSO is an evolutionary computation algorithm which shares personal information to all so that the whole can converge from disorder to order.

This study discusses the parameter configuration of PSO and optimal layout design of multi-rotor vehicles through PSO. First, a rotor dynamics model based on BEMT is introduced, which shows the calculation process of rotor thrust and power. This model is the theoretical basis of the study. The calculation of the lift, drag and power of the multi-rotor, as well as the parameter calculation of the rotor, wing and propeller of the compound multi-rotor, all refer to this model. Then, since PSO simulation requires a balance between accuracy and time-consuming calculations, the proper parameter settings of the PSO algorithm are discussed, mainly considering particle number and iteration number. Finally, by using the PSO algorithm, on the one hand, at the hovering state, some results of proper multi-rotor layouts are shown according to different rotor numbers, take-off weights, blade numbers, and rotor angles. On the other hand, at the cruising state, this study discusses a kind of compound multi-rotor vehicle configurations and analyze the influence of the overall layout of multi-rotors on flight performance. Aiming at the longest cruising distance, some results of proper layouts are shown according to different rotor size, rotating speed, wing area, propeller size, rotating speed, as well as flight speed.

As an example, typical results are shown in Figures 1 and 2. In these figures, the black circle represents the rotor, the blue part is the airframe, and the red straight line is the arm connecting the rotor and the airframe. There are two propellers, which are fixed to the wings and pointed forward. From the front view of the aircraft, the green circles represent the propellers. As examples, this study considers two octorotor connections. One layout is that all the rotors are arranged around the airframe and directly connected to the airframe, which is denoted as 'direct connection', as shown in Figure 1(a). Another layout is that the rotor is connected to the rotor and then connected to the airframe, which is denoted as 'indirect connection', as shown in Figure 1(b). From the simulation results, all the octorotor connection methods selected by PSO are 'indirect connection'. Moreover, Figure 2 shows the simulation results of optimizing the compound multi-rotor aircraft by PSO with the maximum cruising distance as the objective function. In this fugure, the orange rectangles represent the wings.



(a) direct connection



(b) indirect connection

Figure 1 Two layouts of octorotors

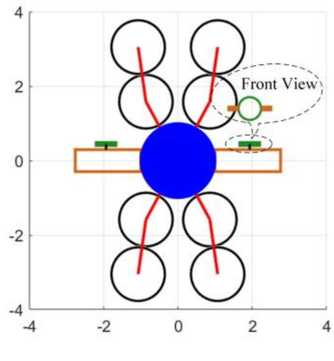


Figure 2 Optimal layout of compound octorotors.

The simulation results show that the method proposed in this study can be applied as a guideline for the layout predesign of multi-rotor vehicles. The application of BEMT can accurately calculate the dynamic parameters of each component, and the application of PSO makes it possible to use the computer to find optimal results in a large area with high efficiency and high dimension. It is worth mentioning that the optimization index varies with different tasks, and this study only proposes some general methods as guidelines for multi-rotor aircraft layout design. The results of the study suggest that these methods have some significance.

〔作成要領〕

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