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Design Specification for the 2026 Jilin Province Undergraduate Innovation and Entrepreneurship Competition

Butterfly Wings, Vivid and Lively

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Abstract
This project designs a four-wing independent-drive bionic butterfly named "Butterfly Wings". Using the large white-mantle butterfly as its prototype, it uses four 6 mm hollow-cup motors to drive four separate wings made of PET film and carbon fiber rods, with flexible linkages, micro spur gears and a crank-rocker mechanism producing reciprocating flapping. After verifying flapping speed, motor torque and battery selection, a miniature control board supports manual, automatic-coordination and status-feedback modes, adjusting each wing independently to achieve hovering, turning and gliding. The model achieves differentiated, independent four-wing motion while remaining lightweight and reliable, and is applicable to science popularization, cultural-creative exhibitions and confined-space monitoring.

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I. Introduction

Micro-winged aircraft inspired by insect flight offer compact size, low noise and high maneuverability. Butterflies, whose four wings coordinate to produce hovering, sharp turns and low-speed gliding, are ideal bionic prototypes. Existing designs (UC Berkeley, Tsinghua, Delft, Shanghai Jiao Tong University) mostly use a shared-wing linkage in which the wings move only in unison, so they cannot reproduce the nuanced motion of a real butterfly and support only simple synchronized flapping. This project therefore proposes a four-wing independent actuation scheme that gives each wing a dedicated actuation and transmission unit, enabling decoupled control, hovering and agile turning.

I.Design Requirements

1.1 Motor Selection

The objective is to faithfully replicate a real butterfly with independent, flexible flapping, requiring a motor that is lightweight, fast-responding, smooth and energy-efficient. The coreless hollow-cup motor is chosen: eliminating the iron core halves weight and volume, gives rapid start/stop for high-frequency flapping, removes the tooth-slot effect for smooth low-vibration operation, and avoids core losses for higher efficiency.

A 6 mm, 3.7 V miniature brushed hollow-cup motor drives each wing. A four-motor scheme controls the fore and hind wings of each side separately, enabling differentiated flapping and agile turning; coaxial embedded mounting fits the lightweight skeleton, and frequency is adjusted directly by motor speed, simplifying the structure (Figure 1).



Figure 1

1.2Wing Design

The wing design pursues independent four-wing actuation, bionic morphology, lightweight high stiffness and low-disturbance flight. The larger fore wings mainly generate lift and the smaller hind wings assist posture, each motor-driven. A lightweight, ductile PET film surface deforms naturally to improve aerodynamics, while fine carbon fiber rods give strength at minimal weight.

The rounded, low-drag contours mimic real butterfly wings with optional bionic textures, and the wings attach detachably for maintenance. Following the competition specifications, the wings are about 240 x 340 mm with a single-wing area of about 0.0179 m^2, balancing lift and maneuverability.

1.3 Selection of Drive Mechanism

The transmission mechanism converts the motor rotation into wing flapping and must be lightweight, precise, smooth and allow independent wing motion. This design uses a flexible connecting rod plus a miniature straight-gear set: two-stage spur-gear reduction converts high speed/low torque to low speed/high torque, the gear shaft drives the rod into reciprocating motion, and the wing pivot oscillates for rhythmic flapping.

Each pair of wings has its own gear-and-flexible-link assembly with a dedicated hollow-cup motor, so the four wings are controlled separately, enabling differentiated flapping and single-wing thrust for turning.

The two-stage reduction uses gear pairs of module 0.8, tooth numbers 10 and 25, face widths 4 and 3 mm and a 20-degree pressure angle, driving a crank-rocker mechanism (a = 7.5 mm, b = 27.5 mm, c = 10 mm, d = 26.8 mm; see Figure 2).

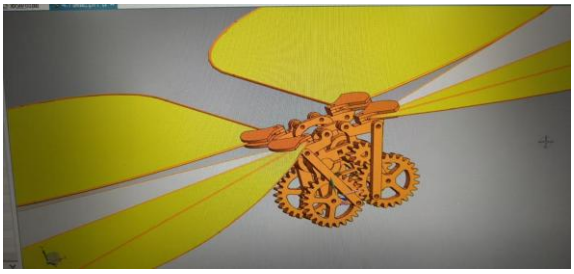


Figure 2

1.4 Wing Speed Calculation

Wing-flapping speed affects lift and stability. With n1 = n2 = 270 r/min, U = 7.4 V, L1 = 0.177 m and L2 = 0.165 m, and a transmission ratio of 1 the flapping frequency equals the motor speed, so both wings give 270 r/min = 4.5 Hz.

Using v = 2 x pi x L x f, the fore-wing tip speed is about 5.00 m/s and the hind-wing tip speed about 4.66 m/s, matching the design requirements.

1.5 Check motor torque

Torque verification checks that motor output exceeds the aerodynamic drag torque. With F = C x rho x v^2 x S / 2, C = 0.8, rho = 1.293 kg/m^3 and b = 0.05 m, the fore-wing force F1 = 0.1145 N and the hind-wing force F2 = 0.0927 N, giving resisting moments M1 = 0.0101 N.m and M2 = 0.0076 N.m.

The motor rated torque of 0.03 N.m exceeds both resisting moments with margin for friction and aerodynamic fluctuation, so the torque check passes and the motor can stably drive the wings.

1.6 Battery Selection

Following voltage compatibility, lightweight and adequate endurance, a self-assembled 7.4 V, 1 A lithium battery is selected to minimize overall mass.

II. Design Background

Butterflies fly stably, quietly and efficiently with lightweight bodies and agile wings, ideal for miniature bionic aircraft. However, most current bionic butterflies use a dual-wing linkage or four-wing synchronous mechanism whose wings move only in unison, limiting postures and maneuverability, so a four-wing independently controllable design is valuable.

2.1 Design Purpose

Grounded in bionics and integrating micro-mechanical systems and electronic control, the design builds a miniature device that simulates a real butterfly flight. Its objectives are to replicate the independent coordinated flapping of four wings, develop a lightweight structure, achieve precise independent control for maneuverability, provide science-popularization tools, and broaden application scenarios.

2.2 Working Principle

The device uses a miniature lithium battery for power. The hollow-cup motor's high-speed rotation is reduced by the gear set, then converted by the flexible rod and crank-rocker into wing flapping. The control module coordinates the four motors for independent or differential motion (hovering, turning, gliding), and a lightweight frame with a thin flexible membrane minimizes weight and drag.

III. Design of the Bionic Butterfly Model

3.1 Model Innovations

The model breaks the conventional "dual-wing linkage" paradigm: its core innovation is independent control of all four wings. Each wing has its own actuation mechanism, so the four wings adjust frequency and angle separately: the fore wing flaps at high frequency for lift while the hind wing fine-tunes for balance or direction, enabling hovering, slow flight and rapid directional shifts.

Structurally it combines a lightweight, resilient skeleton with an ultra-thin flexible wing membrane to prevent fracture while minimizing weight and drag, and a simple control program achieves coordinated four-wing motion without a complex system (Figure 3).

3.2Model Demonstration

The basic model is illustrated in Figure 3.

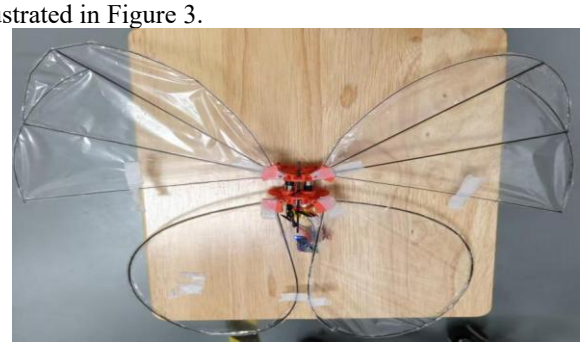


Figure 3

IV. Bionic Butterfly Control System

4.1 Research Ideas

The design replicates the actual flight of butterflies by first observing how the fore and hind wings contribute to lift, stability and control, then building a four-wing independent scheme through structural design, control-system development and test optimization, following independent control, coordinated linkage and easy operation.

4.2 Research Process

The control system uses a miniature main-control board connected to a power supply, four independent drive modules, sensors and a remote control. Its software implements three modes: manual control (setting each wing angle/frequency, e.g. reducing one wing to turn), automatic coordination (predefined hovering/gliding/turning parameters) and status feedback (auto-tuning on tilt or vibration), plus overload protection. The full aircraft was optimized through multiple test flights.

V. Application Value and Prospects

5.1 Application Value

With independent four-wing drive and high bionic fidelity, the design has value in science popularization (live demonstrations of flapping, hovering and turning for museums and schools), film and cultural-creative work (realistic in-flight dynamics and creative assets), and specialized monitoring, where its compact, silent, low-disturbance form reaches narrow spaces such as greenhouses, museums and pipelines.

5.2 Development Prospects

Through material and control iteration, including lighter membranes and autonomous navigation/obstacle-avoidance, it can evolve from manual operation to autonomous flight. Its market can expand into interactive exhibitions, educational kits and IoT indoor monitoring; as part of the low-altitude economy it can extend to disaster-site inspection, rescue and pollination, moving from a display model to a practical device.

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