A Pill Bug-Inspired Foldable Quadrotor

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Abstract— **Similar to Armadillidiidae insects that roll into a ball as a key defense against predation, we employ a foldable design as a method for a quadrotor to protect its central sensitive components upon collision. The developed prototype successfully demonstrates the desired protective fold when passively activated by a mid-flight collision.**

I. Introduction

In recent years, small flying robots have gained traction in real-world applications. Still, there remains issues related to mechanical failures or collisions of these vehicles owing to various reasons, such as pilot errors or disturbances. To date, researchers have taken an inspiration from the resilient insect wings to develop a quadrotor with a dual-stiffness frame to absorb energy and protect sensitive components in collisions [1]. In another example [2], the authors designed a wing buckle hinge, enabling a flapping-wing robot to reduce the impact upon a collision. In this work, motivated by the protective behavior of pill bugs known as conglobation [3], we propose a foldable quadrotor airframe that folds upon impact, protecting the central components from possible damage.

II. Foldable Quadrotor Design

Fig. 1A shows the 51.2-g foldable quadrotor prototype. The foldable airframe of the prototype consists of the ground plate, foldable arms, fold coupler, and fold triggers.

To achieve the desired fold function, the airframe is manufactured using the origami-inspired planar fabrication paradigm [4]. A 25-μm Kapton sheet is sandwiched between 300-μm fiberglass plates to create a rigid structure with flexural hinges. The design of the arm, shown in Fig. 1B, results in the joint kinematics with one degree of freedom. The fold coupler ensures that all the arms share a single degree of freedom, constraining four arms to fold and unfold together. In the flying state, the propeller's thrust is nominally vertical. Each propeller generates an upward force, of which the resultant torque is countered and balanced by the joint stoppers, keeping the arms in the flight configuration. Upon collision, the impact rotates the fold trigger to push part of the arms. If the force is sufficiently large, it overcomes the torque from the propellers, activating the arm folding. Once folded, the arms enclose the central part of the robot, protecting delicate parts from possible damage.

III. Mid-Flight Collision Demonstration

With the battery, onboard electronics, and commerical flight control board, the quadrotor is capable of stable flight.

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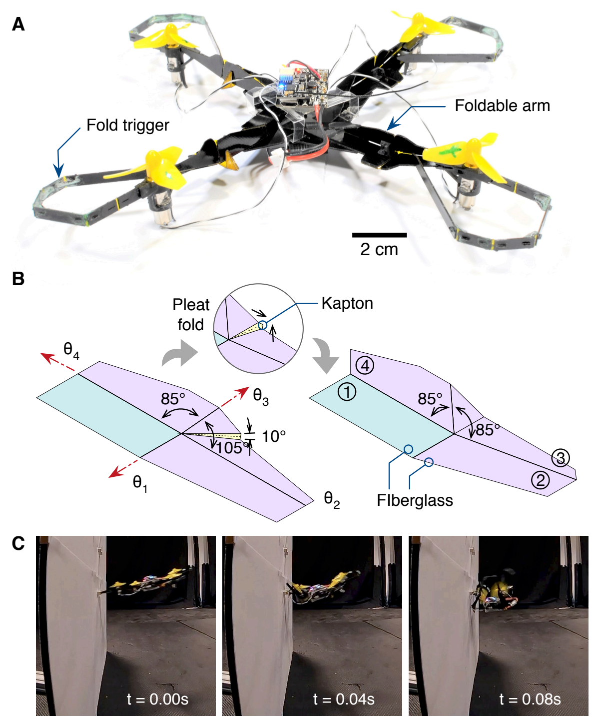

Fig. 1. (A) Photograph of the prototype. (B) Joint kinematics of the folding arm. (C) Mid-flight fold demonstration.

To demonstrate the fold activation from a mid-flight collision, the robot was remotely controlled to fly horizontally towards at the speed of $\approx$1.5 m.s^{-1} (estimated from the video footage) towards a vertical surface (acrylic plate covered by paper for improved clarity). Upon impact, the airframe completed the fold in less than 0.1 s before crashing to the ground in the folded configuration. The flight was captured by a camera at 240 Hz. The video frames are shown in Fig. 1C. The foldable structure and onboard components were intact after the crash.

References

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