A Bio-Inspired Jump-Gliding Robot for Planetary and Terrestrial Exploration

Interim Technical Report

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Abstract—**Inspired by recent studies of planetary jump robots and bio-inspired gliding mechanisms, we propose a novel robot capable of both repeated elastic-powered jumps and controlled gliding. The key innovation is the use of carbon fiber strips for energy storage and actuation, enabling jumping launches and mid-air wing deployment. So far, we detail the system architecture, mathematical modeling, and challenges encountered in the realization of this hybrid jump-gliding robot.**

Index Terms—Jump-gliding robot; elastic-powered jumping; carbon fiber; gliding mechanism.

I. Introduction

Our main goal was to design a robot capable of repeated jumps and gliding, expanding its operational range and adaptability. Our innovation lies in the integration of a carbon fiber strip-powered jumping mechanism with a deployable wing gliding system. Unlike prior robots that typically perform single-use or limited jumps, and compared to conventional flying robots, our design offers higher reliability and significantly lower energy consumption. So far, we detail the system architecture, mathematical modeling, and challenges encountered in the realization of this hybrid jump-gliding robot.

II. System Design

-Solution Selection: After comparing different jump actuation mechanisms, we found that biomimetic legged or complex multi-link jumping structures, are not suitable for our intended application. These mechanisms are generally too heavy and not conducive to achieving lightweight design and effective gliding. Based on further research, we selected the carbon fiber strip compression jumping mechanism, which best meets our requirements for both performance and weight.

-Release Mechanism: The release mechanism works by using an electromagnetic clutch* to quickly connect or disconnect the winch from the motor. During energy storage, the motor—through the engaged clutch—pulls the UHMWPE line to stretch the carbon fiber strip and store elastic energy. When the target tension is reached, power to the clutch is cut, instantly disconnecting the winch from the motor. This allows the stored energy to be released rapidly, enabling the jump, while protecting the motor from any sudden forces or backlash during the release.

-Design of Jump Energy Storage and Release: Utilizes a winch motor to tension a Ultra-high-molecular-weight polyethylene(UHMWPE) line attached to carbon fiber strips, storing elastic potential energy.

- Design of Gliding Mechanism: Wings are deployed at the apex of each jump, either by electronic control or mechanical triggering.

*An electromagnetic clutch engages or disengages power transmission between two shafts by using electromagnetic force. When current is applied, the clutch connects the shafts; when current is removed, the connection is released.

III. Modeling and Analysis

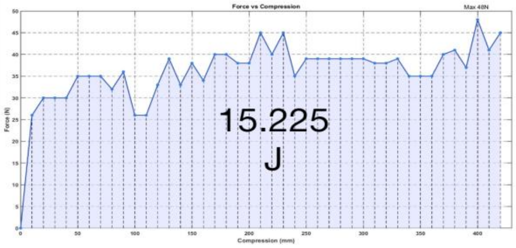
- Energy Storage:

$E_{elastic} = \int_0^{x_{max}} F(x)dx$

The above equation represents the idealized calculation of the elastic energy stored in our device, obtained by directly summing the discrete force measurements without considering energy losses. However, we found that results calculated using this method differ significantly from those obtained by the area-under-the-curve (integral) approach. In practical applications, it is more accurate to estimate the stored energy using the integral formulation shown below.

$E_{elastic} \approx \sum_{i=1}^{n-1} \frac{F_i+F_{i+1}}{2}(x_{i+1}-x_i)$

We define the stored elastic energy, $E_{elastic}$, as the total mechanical work done during the compression of the carbon fiber spring. Specifically, the force–displacement relationship is nonlinear, and the energy is computed by integrating the measured force F(x) over the full compression distance x_{max} ,where F(x) is the measured force at displacement x, and x_{max} is the maximum compression. * The area under the force–displacement curve was obtained experimentally using a digital scale and ruler (see photos below), yielding an estimated elastic energy of approximately 15.2 J.



- Theoretical Jump Height:

$$H_{ideal}=\frac{E_{elastic}}{M_{total}\cdot g}$$

The ideal jump height, H_{ideal}, is estimated by equating the measured elastic potential energy to the gravitational potential energy required to elevate the total system mass. Specifically, where $E_{elastic}$ is the experimentally measured elastic energy, M_{total} is the total mass of the jumping system, and g is the acceleration due to gravity. This equation assumes 100% conversion of stored elastic energy into vertical displacement, thus representing the upper bound of achievable jump height in the absence of energy losses.

-Jump Height:

$$H_{estimate}=\frac{E_{elastic}\cdot(1-D_{drag})\cdot(1-\beta_{xy}-\beta_{\theta})\cdot(1-x_{CoM})}{M_{total}\cdot g}$$

The jump height, $H_{estimate}$, accounts for various energy losses in the real system that are not reflected in the theoretical calculation. These losses include air drag (D_{drag}), effects from non-vertical take-off angles (β_{xy}), device rotation during take-off (β_{θ}), and the influence of the center of mass position (X_{CoM}).

where:

D_{drag} is the fractional energy loss due to air resistance during the jump

β_{xy} and β_{θ} represent losses caused by non-vertical take-off and device rotation, respectively

X_{CoM} denotes the effect of the center of mass location on the device

$$H_{estimate}=H_{ideal}\cdot\eta$$

As it is difficult to measure or model all these loss factors accurately, we also employ a simplified approach by introducing an overall efficiency factor η, defined as the ratio of actual jump height to the theoretical value based on literature [12].

* For energy estimation, a force gauge was attached to the jumping device and incrementally stretched in the vertical direction. The force readings were visualized and recorded at each interval to generate a force–displacement curve. By calculating the area under this curve using the appropriate formula (numerical integration), we obtained an estimate of the stored elastic energy in the system.

IV. Conclusion and Future Work

To date, we have conducted extensive literature review, mechanical structure design, and mathematical modeling for this design. Preliminary computational results have demonstrated the jumping capability of our proposed system; however, remains a significant technical challenge that we are actively addressing.

Ongoing efforts focus on:

- Improving mechanical efficiency and alignment,
- Optimizing the wing deployment strategy,
- Designing and testing closed-loop feedback and control,
- Validating the robot in more varied and realistic test scenarios.

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