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

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Abstract

Planetary exploration often requires robotic platforms capable of traversing diverse and challenging terrain. Traditional wheeled and legged robots, while robust on flat surfaces, struggle with obstacles and rugged landscapes. 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 both high-velocity launches and mid-air wing deployment. We detail the system architecture, mathematical modeling, experimental results, and challenges encountered in the realization of this hybrid jump-gliding robot.

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

I. INTRODUCTION

Environmental and planetary exploration demands robots capable of overcoming complex terrain and obstacles. Previous work on planetary jumpers demonstrates the potential for using elastic energy to achieve remarkable leaps, especially under low—gravity or low—atmosphere—density conditions, such as those on other planets or moons. Inspired by this, our 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,our system aims for repeatable actuation, controlled by a micro—controller with IMU feedback. This configuration is intended not only to enable long—range traversal on Earth—like terrain but also to demonstrate feasibility for planetary exploration.

II. SYSTEM DESIGN

A. System Overview

The robot consists of the following core modules:

- Jump Energy Storage and Release: Utilizes a winch motor to tension a fishing line attached to carbon fiber strips, storing elastic potential energy.
- Control System: A micro-controller (Arduino) manages the jump and gliding mechanisms, with feedback from an onboard IMU for closed-loop control.
- Gliding Mechanism: Wings are deployed at the apex of each jump, either by electronic control or mechanical triggering.
- Power Supply: Provided by an onboard battery.

Block diagrams and schematics are provided in the Appendix.

B. Mechanical Design

The jump mechanism uses carbon fiber strips as springs. A 1000:1 micro metal gearmotor (6V) tensions the strip via a winch. Energy is released via an electromagnetic clutch, achieving rapid actuation.

The gliding mechanism is connected to the body and can be deployed either electronically (servo, motor) or via a mechanical release at peak jump height.

C. Electronics and Signal Flow

The micro-controller coordinates all actuators and collects sensor feedback from the IMU, which provides acceleration and orientation data.

The control algorithm manages the winch, clutch, and wing deployment timing based on jump state and feedback.

III. MODELING AND ANALYSIS

A. Jump Dynamics

− Energy Storage:

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

− Theoretical Jump Height:

$H_{ideal} = \frac{Eelastic}{Mtotal*g}$

−Actual Jump Height:

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

where eta accounts for losses.

B. Gliding Aerodynamics

After jump actuation, the wings deploy, enabling unpowered gliding. IMU feedback is used to potentially regulate deployment timing or stabilize posture.

C. Signal Architecture

The main control board issues commands to all actuators (winch, clutch, wings) and receives IMU signals. Closed−loop feedback is used for improved postures timing and reliability.

IV. PROTOTYPE AND EXPERIMENTS

A. Prototype Development

The jumping module is assembled with carbon fiber strips, a micro winch, The gliding module is currently under development; several concepts (servo-driven or mechanically triggered) are under evaluation.

B. Experimental Results

The measured jump height was significantly lower than theoretical predictions. For example, the system achieved a maximum jump of approximately 3.45 m, compared to an ideal calculated height of 6.7 m, highlighting losses in real-world actuation.

The integration of jumping and gliding systems is ongoing; initial tests confirm functional jumping, but robust, repeatable hybrid operation remains challenging.

V. DISCUSSION

A. Key Challenges

The main technical hurdle is achieving efficient, repeatable rigid-body jumps using the carbon fiber mechanism. Losses from friction, alignment, and energy dispersion reduced real-world performance. Integration of jump and glide actuation with feedback control is non-trivial and requires further iteration.

B. Lessons Learned

The jump height gap between theory and experiment points to energy loss in mechanical and electrical subsystems. Effective signal coordination and feedback are essential for reliable jump-glide transitions.

VI. CONCLUSION AND FUTURE WORK

We have developed a prototype hybrid jump-gliding robot featuring a novel carbon fiber energy storage and actuation system. Initial experiments validated core jumping capability, though achieving ideal performance and robust hybrid operation remains a work in progress.

Ongoing efforts focus on:

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

ACKNOWLEDGMENT

We thank Professor Shao, Professor Pablo, the SUTD FabLab staff and STUD Dyson staff for their guidance, support, and feedback throughout this project.

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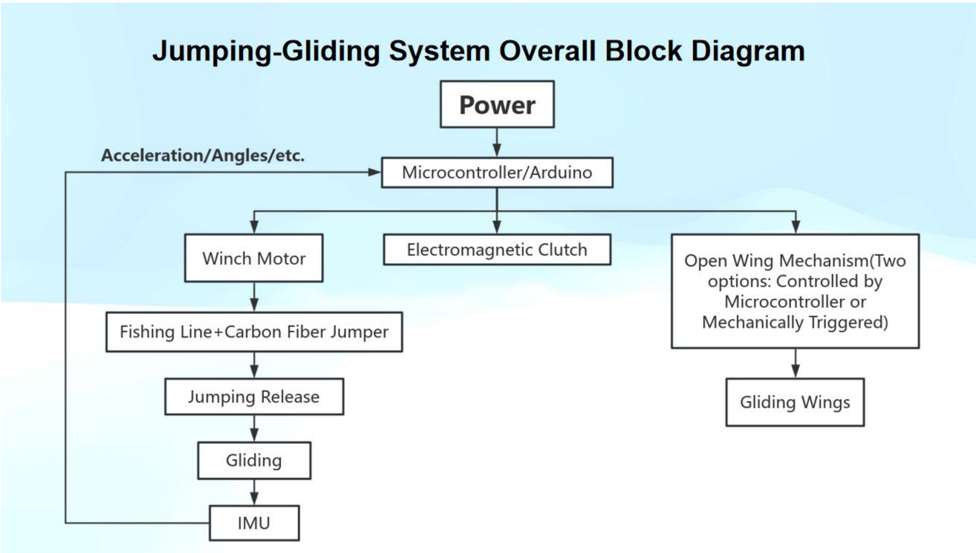
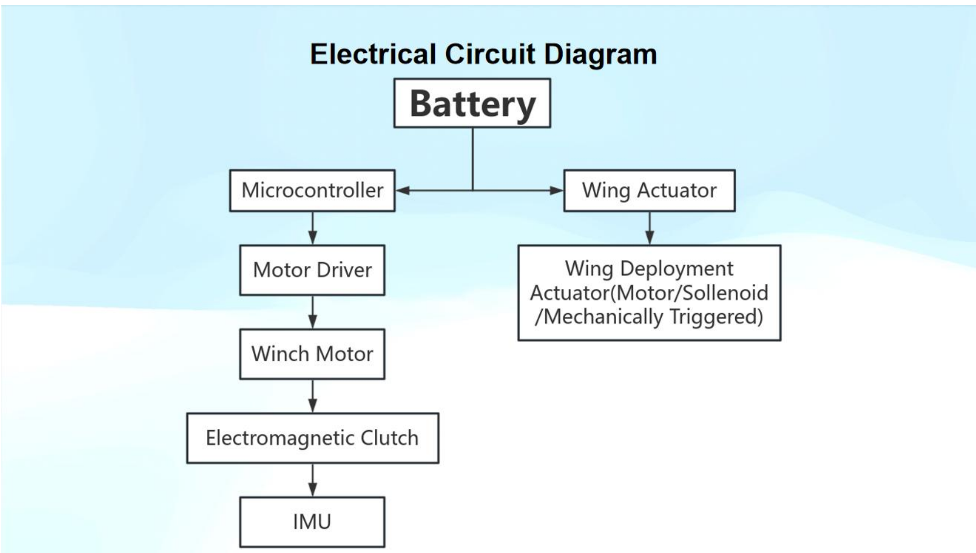
APPENDIX

− System Block Diagram



−Electrical Schematic



−Mechanical System Diagram