ECE 445

SENIOR DESIGN LABORATORY

RESEARCH PROPOSAL

Proposal for Project: Design, Build and Control of a Jumping Robot

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Team #445

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1 Introduction

Jumping robots represents a promising frontier in robotics with significant potential for applications in challenging environments. It is able to navigate rough terrains, overcome obstacles, access confined spaces, and operate in environments inaccessible to conventional wheeled or legged platforms [1]. This capability is particularly valuable for search and rescue operations, planetary exploration, and surveillance in complex settings.

However, the development of effective jumping robots faces several fundamental challenges, struggling to achieve controlled, efficient, and multi-level jumping capabilities. These limitations stem from difficulties in designing precise energy storage and release mechanisms, maintaining dynamic stability throughout the jumping cycle, and implementing adaptive landing strategies that preserve structural integrity.

To address the challenges of controlled and efficient jumping, we propose a bio-inspired jumping robot that draws inspiration from flea, one of nature's most exceptional jumpers, as shown in Figure 1. These tiny insects can jump to heights over 100 times their body length through a remarkable energy storage mechanism [2]. Similar to flea, Our robot uses a spring-based energy storage system to build up and release energy efficiently, generating powerful and controllable jumps. A motor-driven control system adjusts the force applied to change jump height. The lightweight structure mimics a flea's legs to improve force transfer while keeping the robot compact. By combining these elements, our design makes jumping more controlled and adaptable. We design three clear and comprehensive

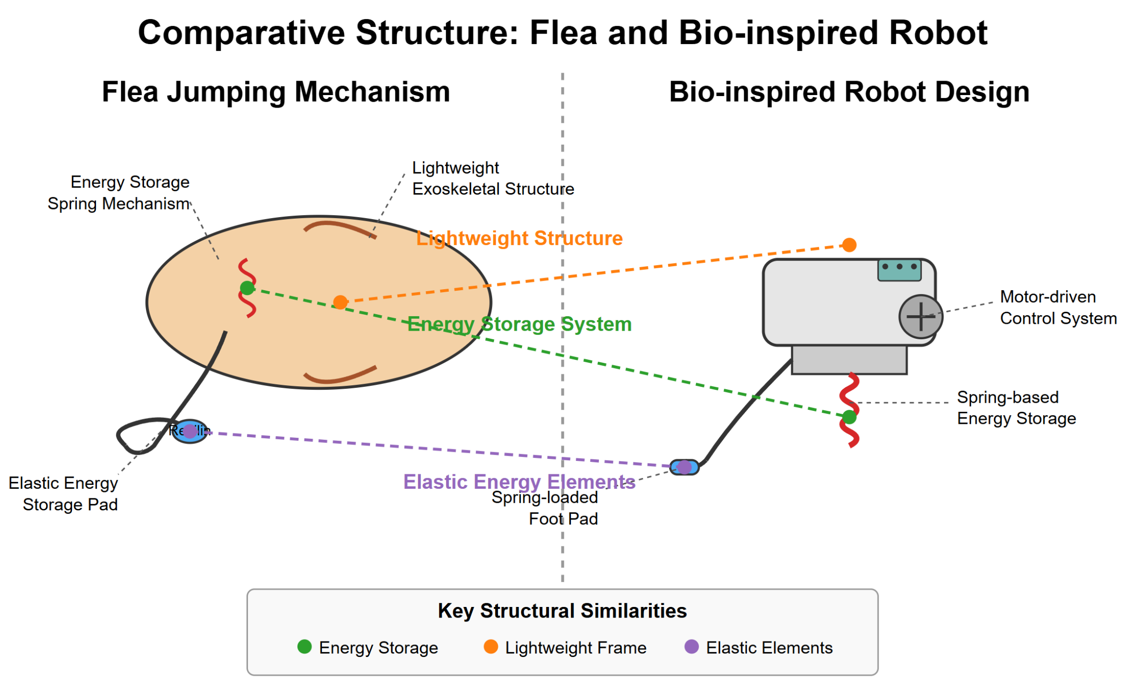

Figure 1: The comparison between biomechanics of flea and the design of our robots.

requirements for our jumping robots:

- **Multi-Level Jumping:** The robot must successfully perform three distinct jump heights with an error margin of ±30%, achieving at least two successful attempts for each height.
- **Instant Actuation:** The robot must initiate a jump within 10 seconds after receiving the command.
- **Durability:** The robot must complete 20 jumps without experiencing mechanical failure or a performance degradation of more than 10% in jump height.

2 Design

2.1 Block Diagram

Our block diagram is provided in Figure 2.1.

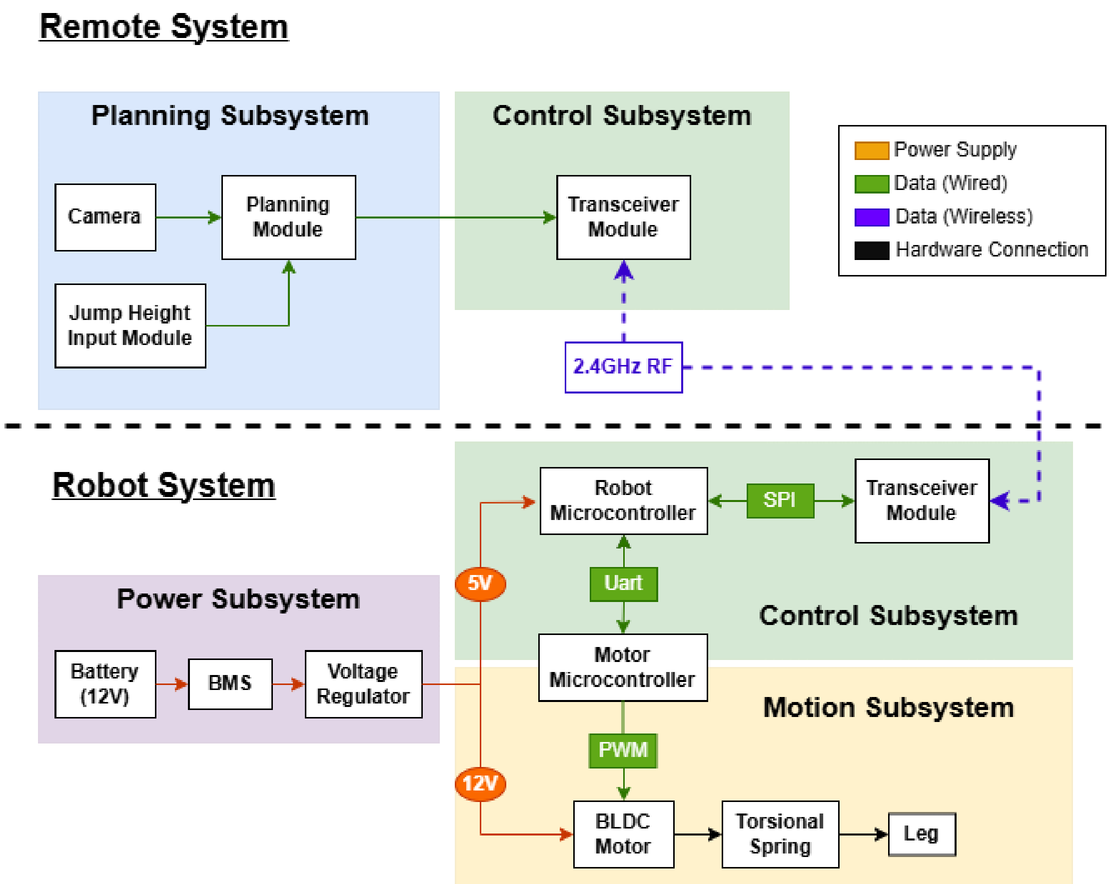

Figure 2: The block diagram of our jumping robot.

2.2 Subsystem Overview

Our robot includes four subsystems in total. The Planning Subsystem receives the jump goal and computes jumping parameters. It's connected to the remote end of the transceiver module in the control subsystem. The Control Subsystem manages the embedded control of the robot. It gets power supply from the power subsystem and controls the motor in the motion subsystem. The Power Subsystem provides 5V and 12V voltages for the microcontroller of the control module and the motor of the motion module, respectively. The Motion Subsystem gets power supply from the power subsystem and executes the jump based on control signals from the control subsystem.

2.3 Subsystem Requirements

The Planning Subsystem determines the robot's relative position using the camera, receives target information from external inputs (e.g., a keyboard), processes the data using a remote computer, and transmits the calculated jump parameters to the robot.

- Input module must accept user-defined jump heights in the range of 10 cm to 60 cm.
- The RF transmission range must be at least 2 meters with a signal strength above -75 dBm, and the data must be transmitted with a latency of no more than 500ms.

The Control Subsystem uses 5V voltage from the power submodule, receives jump parameters from the planning subsystem from the transceiver module, and communicates with the motor microcontroller to control the motor speed and torque.

- The Robot Microcontroller must operate at 3V ± 0.1V or 5V ± 0.1V.

The Power Subsystem consists of a battery, a Battery Management System (BMS), and a voltage regulator.

- The BLDC Motor must generate a peak torque of at least 1.5 Nm at 12V.
- Torsional Spring Stiffness: Must have a spring constant of 600 N/m ± 20%.

The Motion Subsystem consists of a BLDC motor, a torsional spring, and the robotic leg mechanism. The motor microcontroller receives control signals from the Robot Microcontroller and compresses the torsional spring. When the motor stops driving, the reaction force recovered by the torsion spring from the deformation will drive the mechanical leg to complete the take-off from the ground.

- Battery to Motor: Must supply 12V ± 0.5V with a continuous current.
- Battery to Microcontroller: Must supply 5V ± 0.5V with a continuous current

2.4 Tolerance Analysis

The key factor in achieving an 60 cm jump height is ensuring sufficient energy storage in the torsional spring. Risk factors include motor torque capacity, energy loss and spring non-linearily.

Specifically, k is the spring constant, θ is angular displacement, suppose $m = 0.18$ kg is the robot mass, and v is the required takeoff velocity:

$$v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 0.6} \approx 3.43 \text{ m/s}$$

Setting $E_s = E_k$:

$$k\theta^2 = mv^2 = 0.18 \times (3.43)^2 \approx 2.12 \text{ J}$$

For $k = 600$ N·m/rad:

$$\theta = \sqrt{\frac{2.12}{600}} \approx 0.0594 \text{ rad}$$

The required motor torque is:

$$\tau = k\theta = 600 \times 0.0594 \approx 35.64\ \text{N·m}$$

Therefore, a motor with sufficient torque or a gearbox can ensure feasibility.

3 Ethics and Safety

In this section, we primarily discuss the potential ethical and safety problems in our project, as well as the methods that we will use to avoid these problems. For ethics, our design follows the code of ethics for robotics engineers established by IEEE RAS [3], ensuring that robot design and operation consistently prioritize human safety and that the robot's sensing and data collection capabilities respect individual privacy rights. For safety, the mechanical design references EN ISO 12100:2010 [4], while the electrical system design follows IEC 61508 [5].

3.1 Ethics

As a simple robotics project, our project primarily consists of mechanical and electronic control components, without complex algorithms that closely connect with humans, thus posing minimal potential ethical problems. Our main consideration is in the concern about camera component. During the experimental process, we need to prevent this component from capturing inappropriate information involving personal privacy. To address this concern, we adhere to the principle of data collection minimization, collecting only the visual data necessary for task completion. Additionally, we plan to establish clear notices in the robot testing area during experiments to inform the public, thereby minimizing ethical issues potentially arising from robot testing.

3.2 Mechanical Safety

Our project primarily faces potential challenges in the aspect of safety. Regarding mechanical structure, there are three main safety challenges. First, high-velocity movement during jumping potentially causes harm to the surrounding environment and human. Second, unpredictable jumping may occur when the robot experiences loss of control or malfunction, with the energy contained within the spring mechanism exacerbating potential safety risks. Finally, repetitive jumping imposes high durability requirements on the robot structure.

In response to these three potential issues, corresponding solutions are designed. First, the robot is equipped with high-strength buffer casings, such as composite material buffer layers, which absorb impact energy during collisions and reduce potential harm. Second, an additional normally-closed physical safety locking mechanism is designed to automatically lock the spring release mechanism, preventing accidental energy release. This mechanism unlocks only upon receiving normal control signals, thereby adding double protection for spring energy control. The energy storage system is also divided into multiple independent springs rather than a single large spring, ensuring that single-point failures do not result in uncontrolled release of all stored energy. Finally, a modular design approach is adopted to ensure that components experiencing the most severe fatigue are easily identifiable and replaceable.

3.3 Electrical Safety

For electrical aspects, two primary safety challenges are considered. Regarding batteries, high energy density batteries potentially pose overheating or explosion risks, particularly when subjected to impacts during jumping and landing. Regarding electronic control, control system failures or software errors potentially lead to uncontrolled jumping.

In response to these two potential issues, we design corresponding solutions. For batteries, a specialized design incorporates shock-absorbing material linings and structural supports in the battery compartment to isolate batteries from the robot's primary impact forces. PWM-controlled active cooling fans will also be implemented in the battery compartment to ensure batteries maintain safe temperature ranges during high-intensity operations. To control the active cooling system, we will install sensors to monitor battery temperature, voltage, current, and charge-discharge status in real-time, automatically controlling fans or disconnecting power based on battery conditions. For the control system, watchdog timers are integrated to monitor control system response times. If the controller fails to reset the watchdog within a predetermined timeframe, the system automatically switches to a preset safe state, disabling the jumping function and safely releasing stored energy.

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