Design, build and control of a jumping robot

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Team 36

Introduction

Why a Jumping Robot?

Obstacle? Just Jump.

Small ground robots often stop at obstacles taller than their chassis—bricks, cables, post-disaster rubble.

Our palm-sized spring-powered jumper jumps more than 30 cm in a single bound.

Where Jump Wins：

Rough terrain: hops over debris, steps, and uneven ground

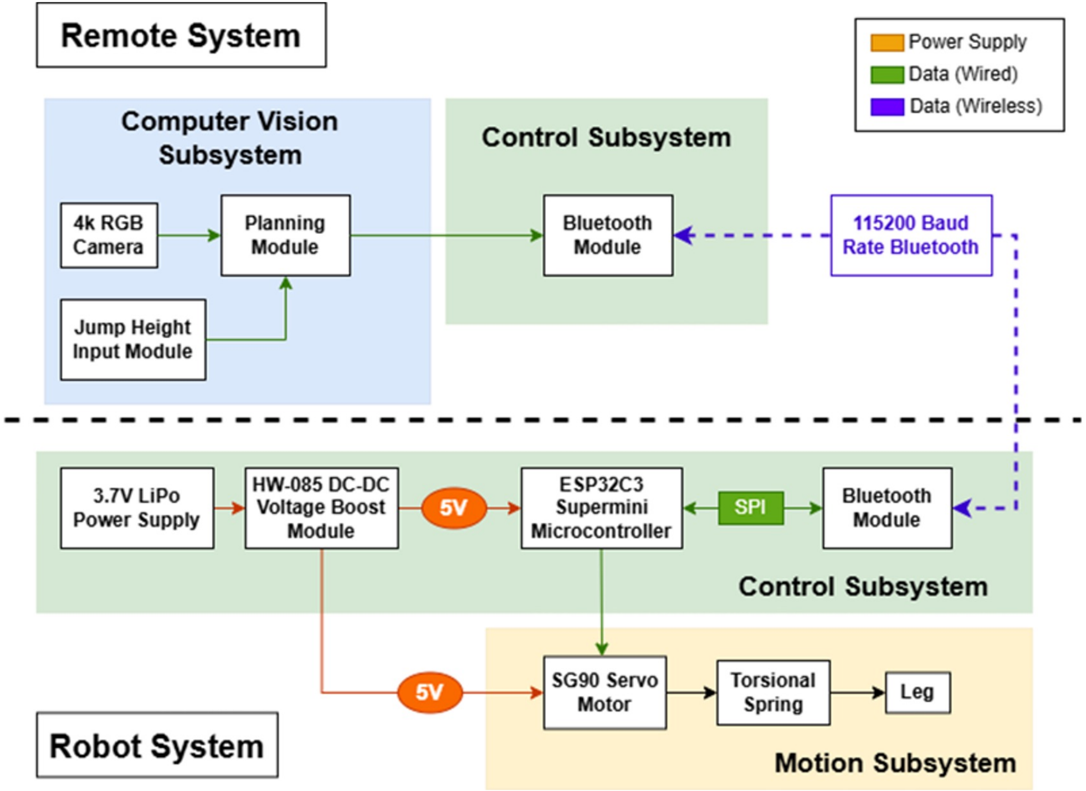
Confined spaces: threads through pipes, collapsed rubble, narrow corridors

Vertical barriers: clears low walls, rocks, and sudden drops

System Overview: Perception → Control → Jump Actuator

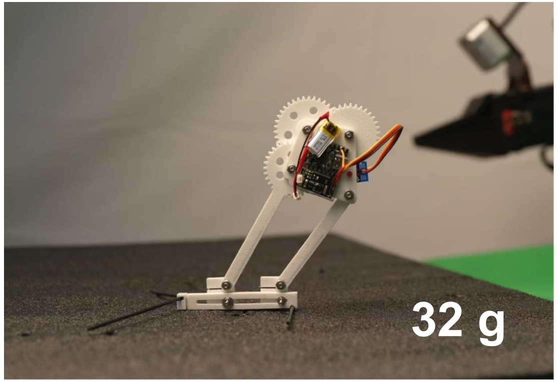
Three Subsystems

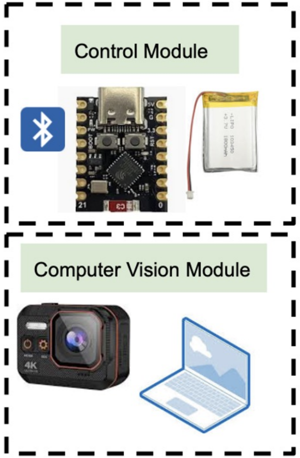
- Computer Vision
- Control
- Motion

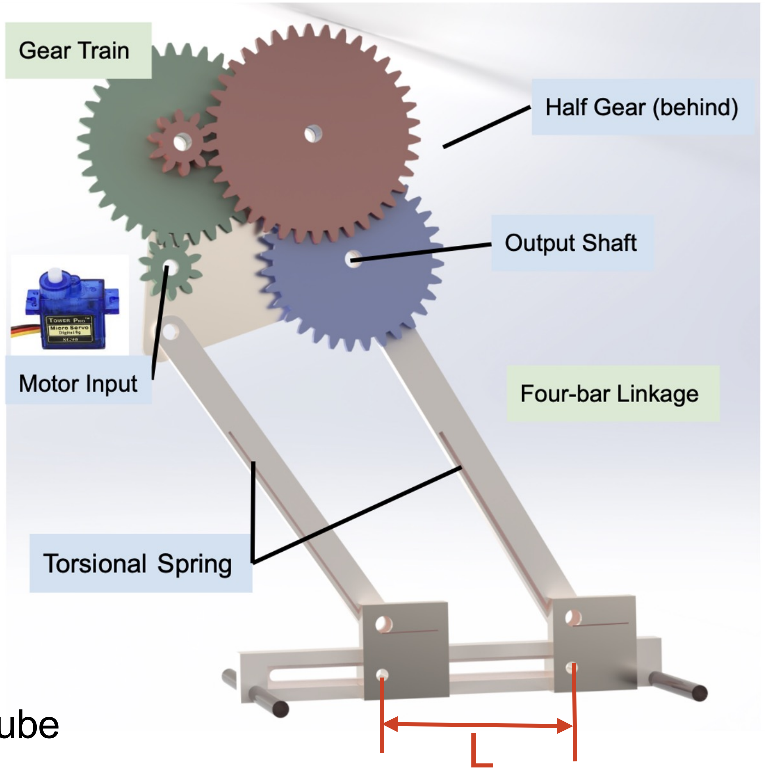


Block Diagram

Physical Design







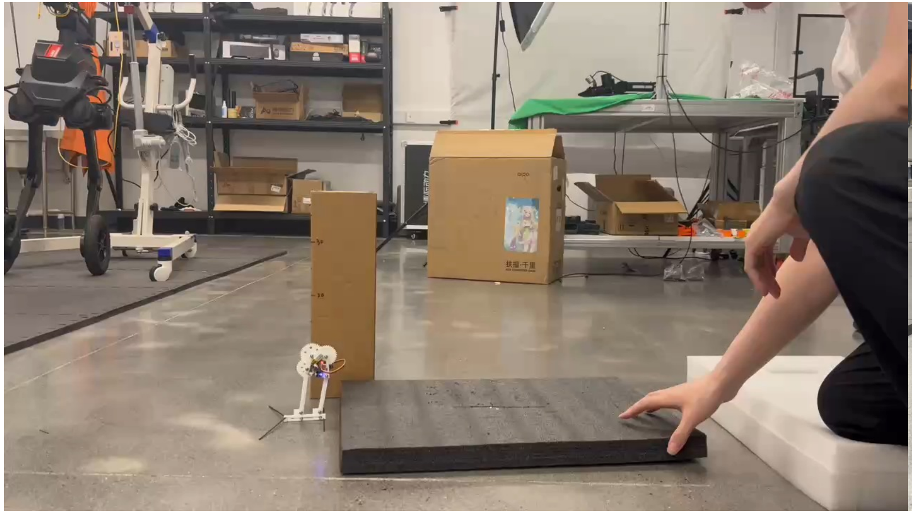
High Level Requirements:

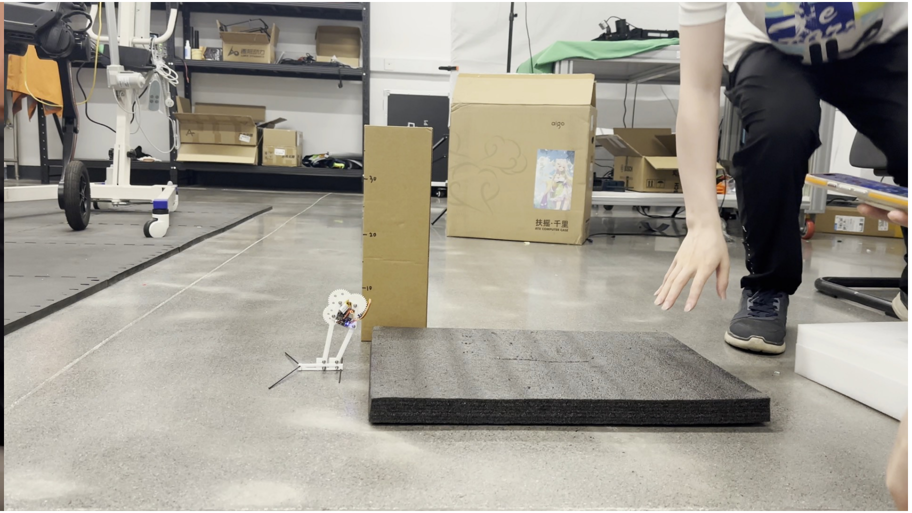
- **Compact footprint:** fits within a 15 × 15 × 15 cm cube
- **Dual jump modes:** two heights, highest > 10 cm
- **Smart perception:** simultaneous multi-target ranging & auto-adjusting link lengths
- **Wireless control:** jump command triggered via Bluetooth

Demonstration

Demo

1. Dual Jump Modes: 10 cm vs. 40 cm



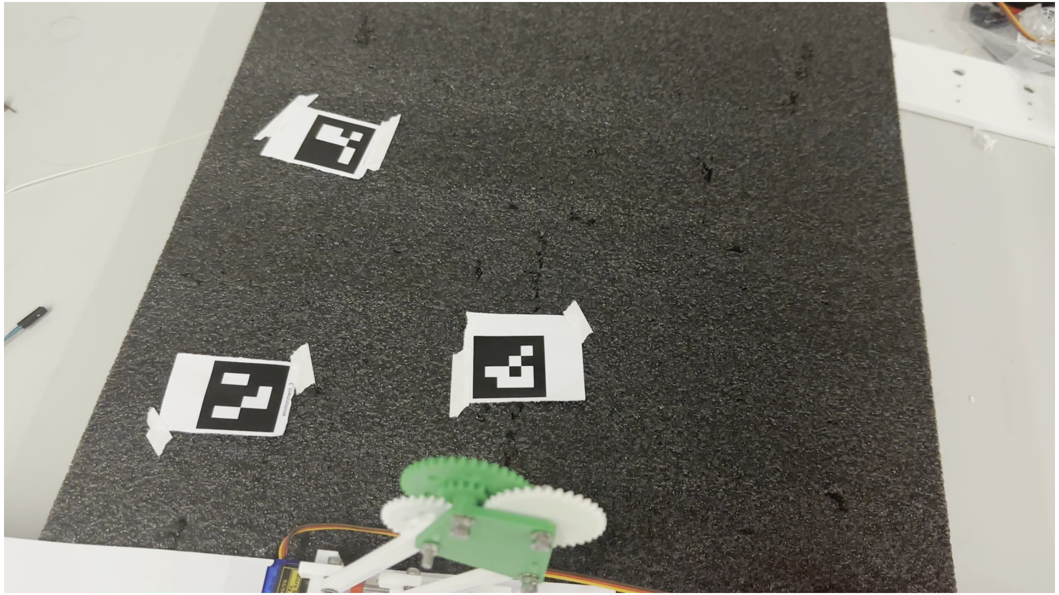


L= 33 mm

L= 23 mm

Demo

2. Targets Detection & Automatic Adjustment of Link Length



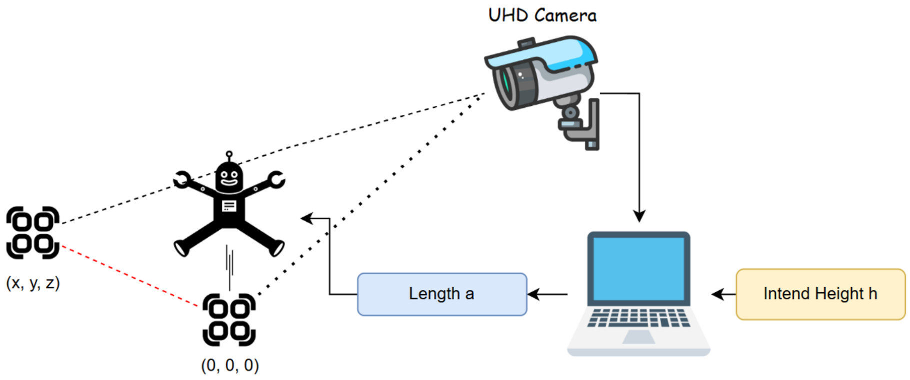
Subsystem Details

Subsystem 1
Computer Vision

Computer Vision

Three Unit

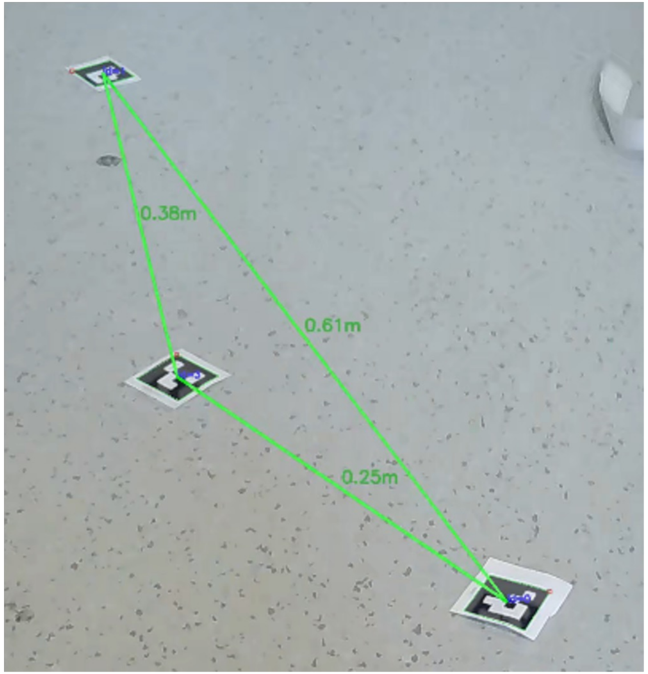
- Computing Unit
- Camera Unit
- Aruco Markers



Computer Vision

Program Parts:

- Aruco Marker Detection
- 3D Distance Estimation
- Ground Arm Adjustment Calculation
- Bluetooth Signal Communication



Computer Vision

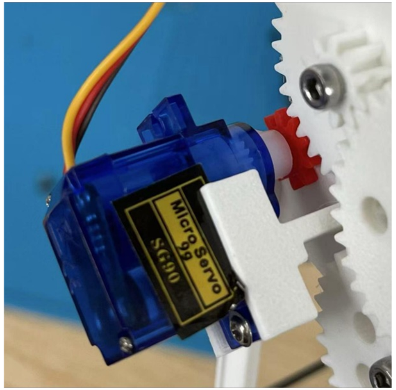
Requirement	Verification Results
The UHD camera must capture frames at 30 Hz with a resolution of 3840×2160 to ensure sufficient visual detail.	A. The system successfully connected the camera. B. The system is able to collect consecutive frames using OpenCV at 30 fps, 3840x2160 resolution each frame.
Camera intrinsic parameters must be precisely calibrated for accurate 3D reconstruction.	A. The system successfully uses OpenCV calibration functions to compute reprojection error. B. The reprojection error is under 3.
ArUco markers (3cm×3cm) must be detected up to a distance of 3 meters with a false positive rate less than 0.1%.	A. The false positive rate is 0.057%.
Vision processing must maintain latency below 100 ms per frame.	A. The end-to-end latency is 87ms.
The system must successfully calculate the length a with a error in 10%.	A. We prove it by comparing the landing or highest location of the robot with the input height or distance successfuly for three times.

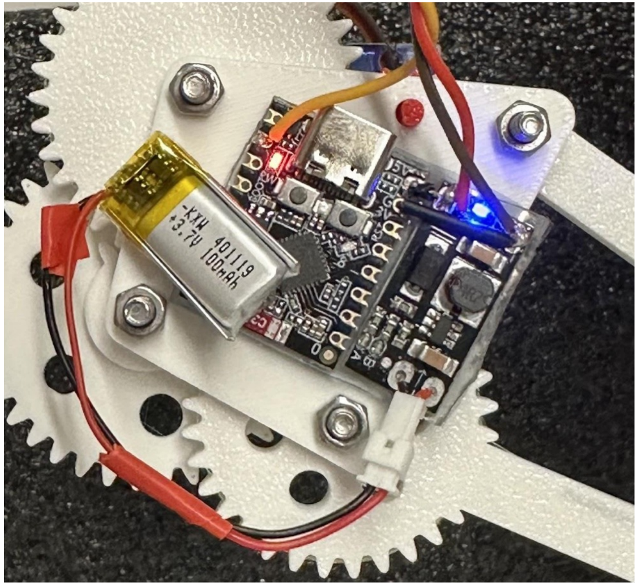
Subsystem 2
Embedded Control

Embedded Control

Hardware Design

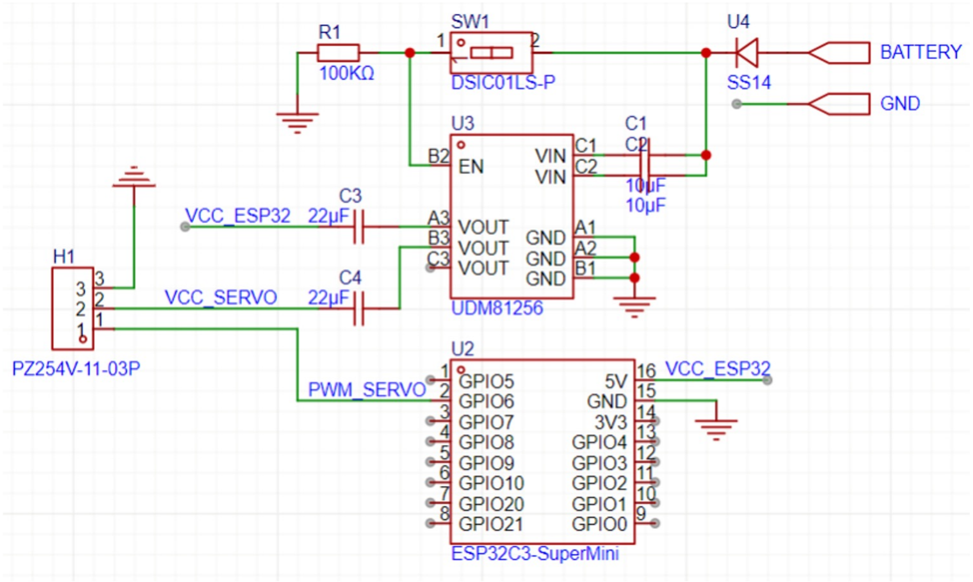
- **Microcontroller**:
  ESP32-C3
- **Power Supply:**
  3.7V LiPo 401119-100 Battery
- **Power Management**:
  HW-085 3.7V-5V DC-DC Regulator
- **Motor:**
  9G SG90 Servo

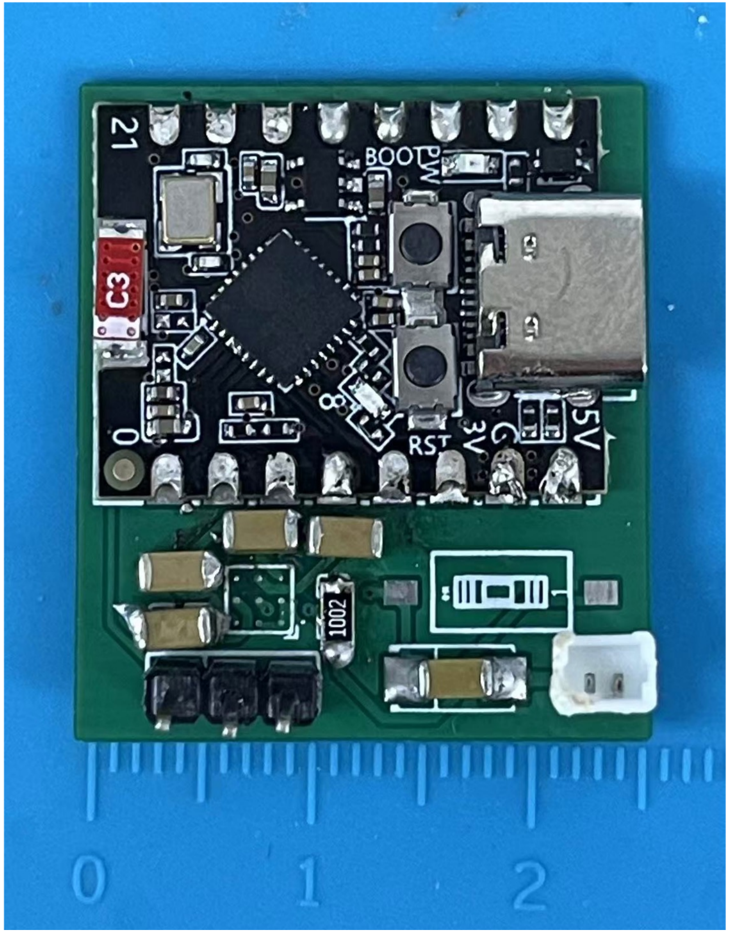




Embedded Control

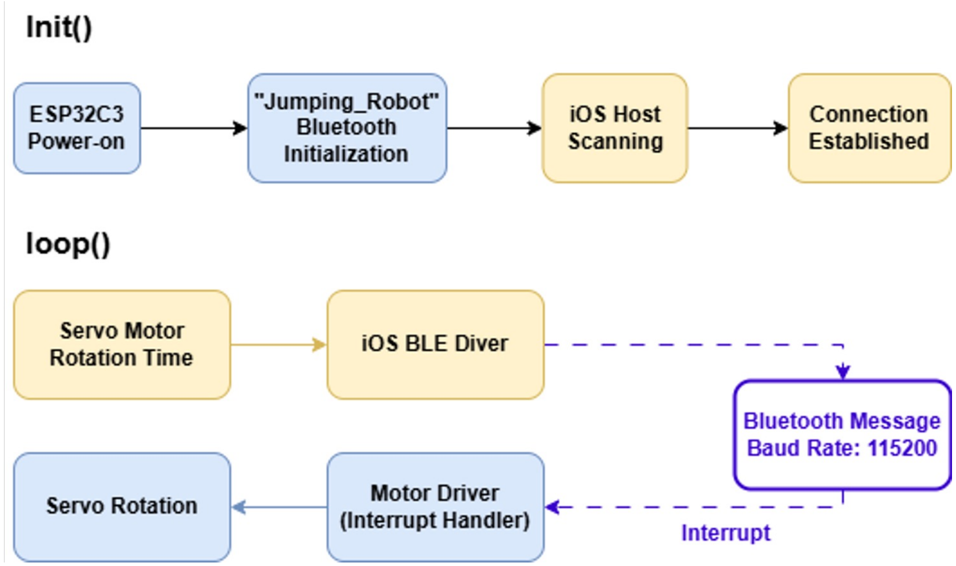
PCB

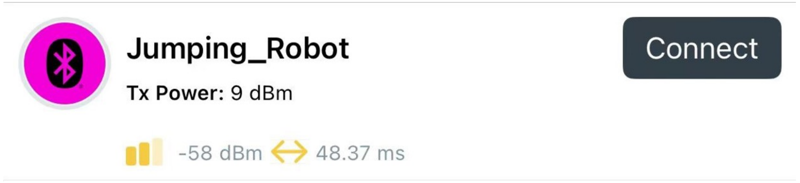


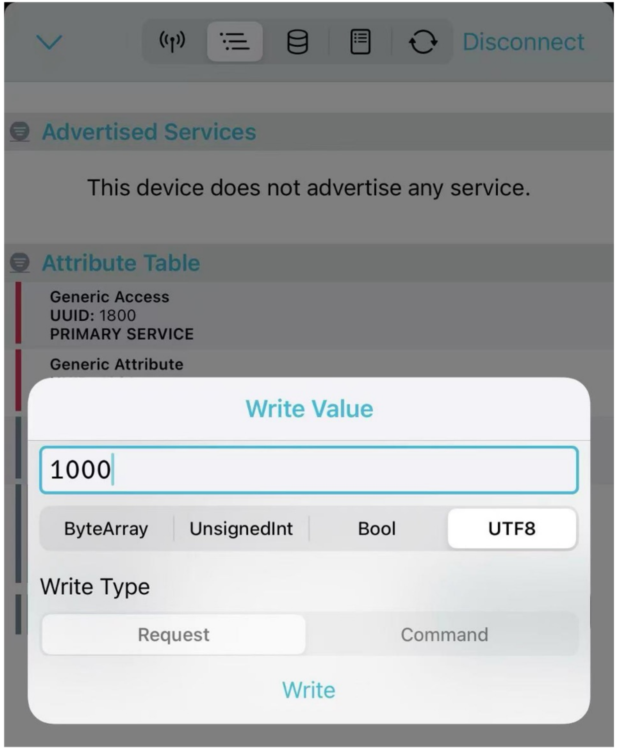


Embedded Control

Control Logic



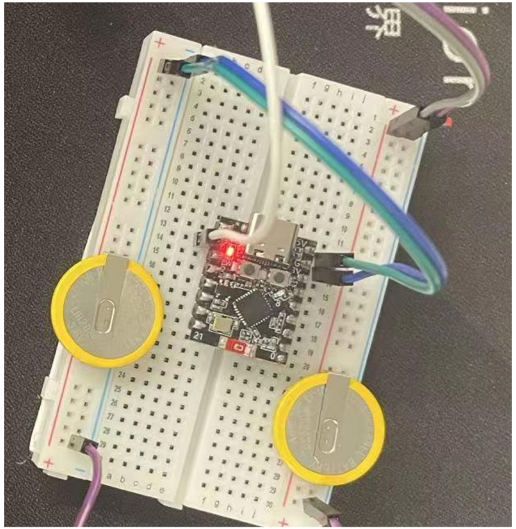


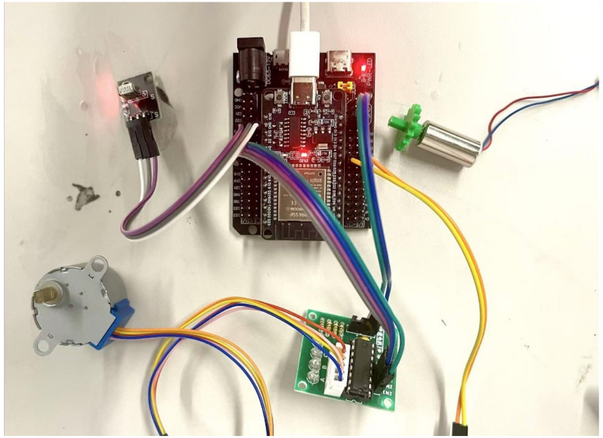


Embedded Control

Iteration

Component	*Motor*	*Power*	*Controller*
Initial	Stepper (Too Heavy)	PC Supply (Wired)	ESP32 (Oversized)
Intermediate	Coreless (Weak Torque)	Coin Cells (Low Power)	—
Final Choice	**Servo (SG90)**	**3.7V Li-Po+Boost**	**ESP32-C3**



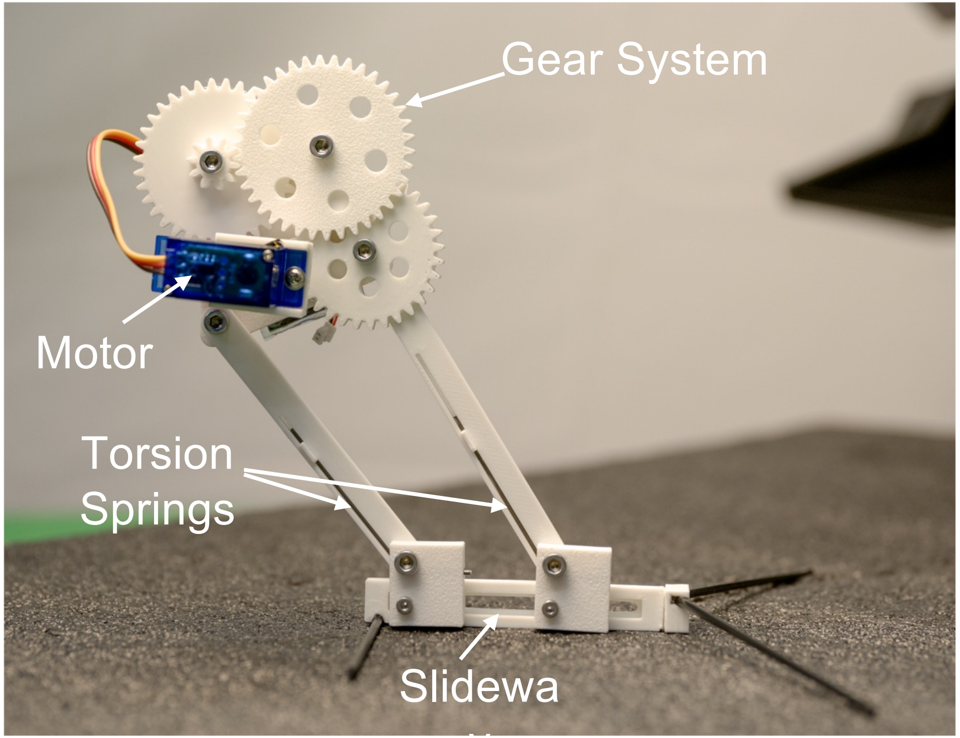


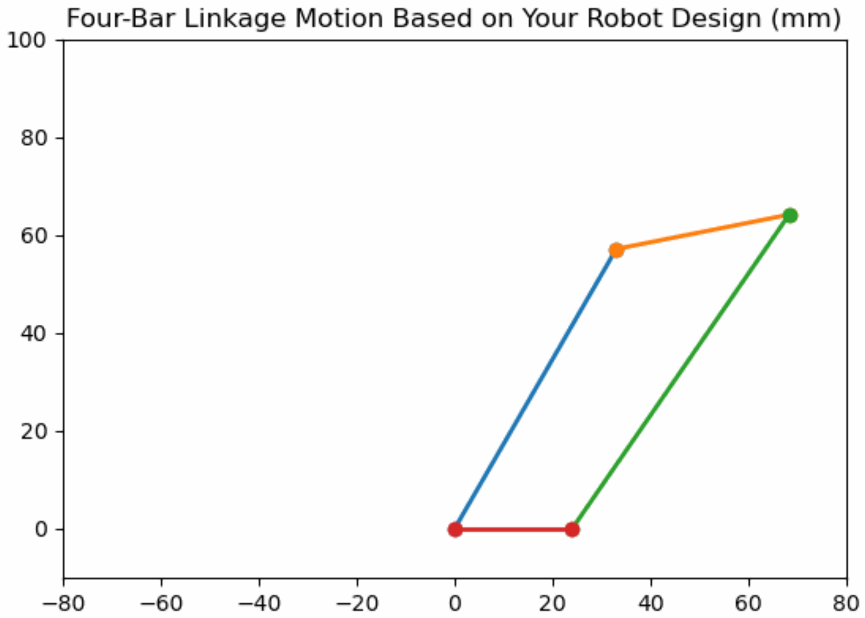
Embedded Control

Requirement	Verification
The embedded system must reliably generate PWM signals to control SG90, with direction and duration specified via bluetooth commands.	A. The system successfully generated 50 Hz PWM signals with pulse widths ranging from 1.0 ms to 2.0 ms using microcontroller's internal timer. B. The servo is enabled to rotate continuously in both clockwise and counterclockwise directions for arbitrary durations as specified by the input commands. C. Rotation duration matched command inputs within ±500 ms tolerance over 5 trials. **Result: Requirement met.**
The system must establish and maintain BLE connection with the host device for at least 30 seconds under normal operating conditions.	A. BLE module initialized successfully within 3s after power-up. "Jumping_Robot" shoud be observable from the host side. B. Connection with smartphone was sustained continuously for over 3 minutes in a static environment. **Result: Requirement met.**
The servo motor must provide sufficient torque to preload the torsional spring used in the leg actuation.	A. The SG90 servo was mounted with mechanical linkage connected to the spring preload mechanism. B. When commanded to rotate, the servo was able to compress the torsional spring from rest to its full preload position. **Result: Requirement met.**

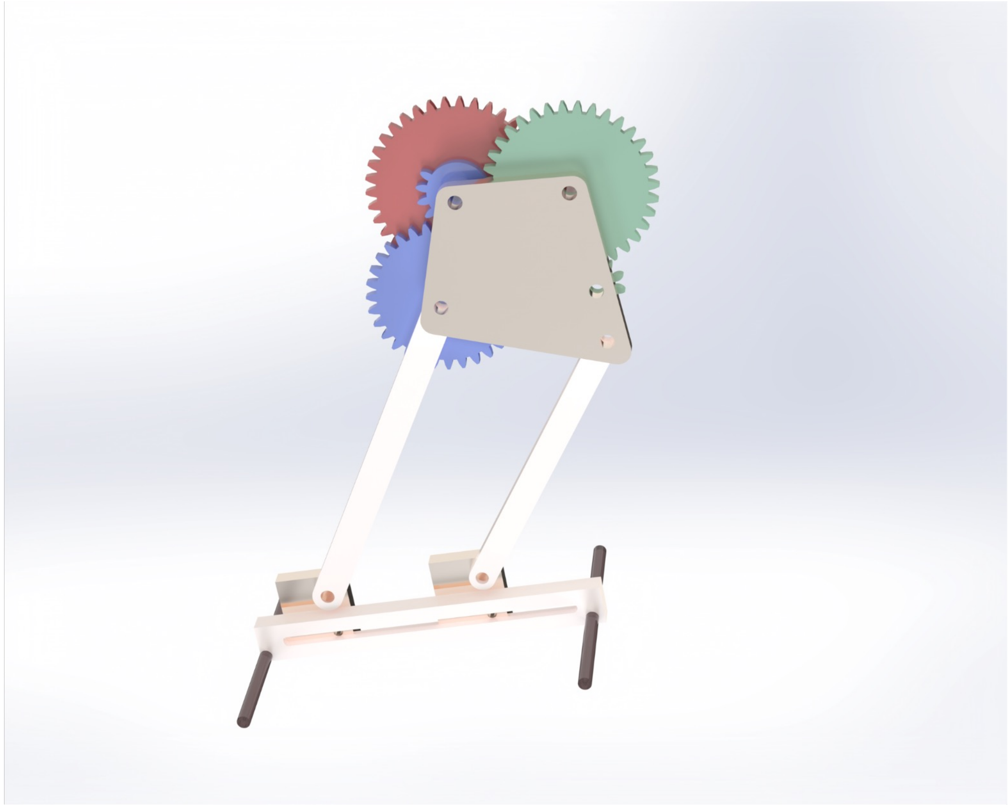
Subsystem 3
Mechanical Design

Mechanical Design





Half Gear Release System



Gear System

Requirement	**Verification**
The gear train must provide sufficient torque amplification for the motor to preload the torsional spring. The designed gear ratio is 28.88:1.	A. The gear train was assembled with a total reduction ratio of 28.88:1 to amplify motor torque. B. Under test, the motor was able to rotate the spring from 30° to 120°, confirming sufficient torque transfer. C. No additional gearing or motor stall was observed, indicating the current configuration is adequate for spring loading. **Result: Requirement met.**

Torsion Spring

$$E = mgh = 0.03 \cdot 9.8 \cdot 0.4 = 0.1176\,\mathrm{J}$$

$$E_{\text{spring}} = \frac{0.1176}{2} = 0.0588\,\mathrm{J}$$

$$E = \frac{1}{2}\tau\theta \quad \Rightarrow \quad \tau = \frac{2E}{\theta} = \frac{2 \cdot 0.0588}{\frac{\pi}{2}} = \frac{0.1176 \cdot 2}{\pi} \approx \frac{0.2352}{3.1416} \approx 0.0749\,\mathrm{N} \cdot \mathrm{m}$$

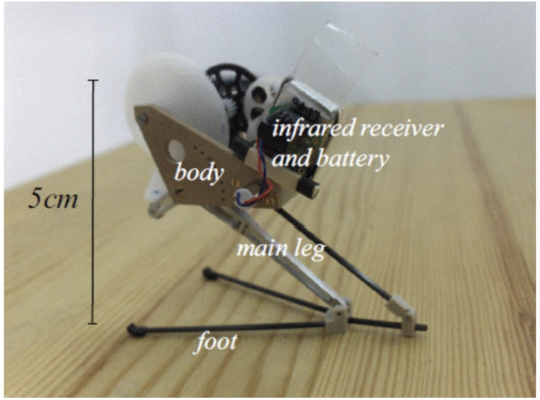
$$\boxed{\tau \approx 0.075\,\mathrm{N} \cdot \mathrm{m}}$$

Verification

Requirement	Verification
The torsional springs must output sufficient torque ($\geq 0.075\,\mathrm{N\,m}$) when twisted from 120° to 30° to actuate the linkage mechanism for jumping.	A. The torsional spring was mounted to a shaft with a known moment arm ($0.04\,\mathrm{m}$). B. The spring was rotated to 90°, and weights were added until equilibrium. C. Measured force was $6\,\mathrm{N}$, resulting in torque: $$T = F \cdot r = 6\,\mathrm{N} \cdot 0.04\,\mathrm{m} = 0.24\,\mathrm{N\,m}$$ D. The spring was then released and successfully actuated the four-bar linkage through its full stroke. **Result: Requirement met.**
The detachment mechanism must disengage automatically at full compression to release stored energy instantly.	A. A custom half-gear was used as a passive release mechanism. B. Through testing, the optimal tooth coverage was found to be $\frac{5}{16}$ of the full gear circumference. C. This profile keeps the gear engaged from 30° to 120°, and ensures disengagement occurs precisely at the maximum preload angle. D. Experimental trials showed consistent detachment at the desired angular position with no failure or delay. **Result: Requirement met.**

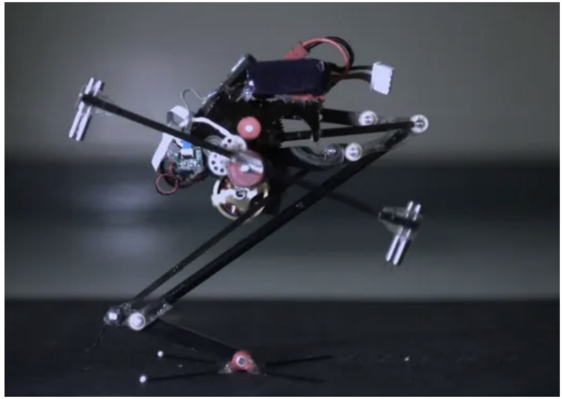
Related Designs in Literature

7g Jumping Robot



M. Kovac, M. Fuchs, A. Guignard, J. -C. Zufferey and D. Floreano, "A miniature 7g jumping robot," 2008 IEEE International Conference on Robotics and Automation, Pasadena, CA, USA, pp. 373-378, 2008. doi: 10.1109/ROBOT.2008.4543236.

Salto



D. W. Haldane, M. M. Plecnik, J. K. Yim, and R. S. Fearing, “Salto-1P: A monopedal robot for high jumping and agile movement,” *Sci. Robot.*, vol. 2, no. 5, pp. eaag2048, 2017. doi: 10.1126/scirobotics.aag2048