Wheeled-Legged Robot Proposal

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1 Introduction

1.1 Problem

The inspiration for this project stems from the challenges associated with conventional wheeled delivery robots, most of which are equipped with a four-wheel chassis. This configuration hampers their ability to traverse terrains with obstacles, bumps, and stairs—all commonplace in urban environments. A wheeled-legged balancing robot, conversely, can navigate these obstacles with ease, positioning it as a particularly attractive solution for delivery services in urban areas.

1.2 Solution

This project seeks to address this gap by focusing on the development of a wheel-legged robot that can adeptly maneuver through challenging urban terrains.

To ensure feasibility within our time frame, our initial focus will be on creating a dynamic, single robotic leg capable of demonstrating its potential as an electric suspension system capable of bearing weight and adapting to various terrains. This proof-of-concept will serve as a cornerstone for the future development of a complete robot, potentially revolutionizing urban delivery systems.

1.3 Visual Aid

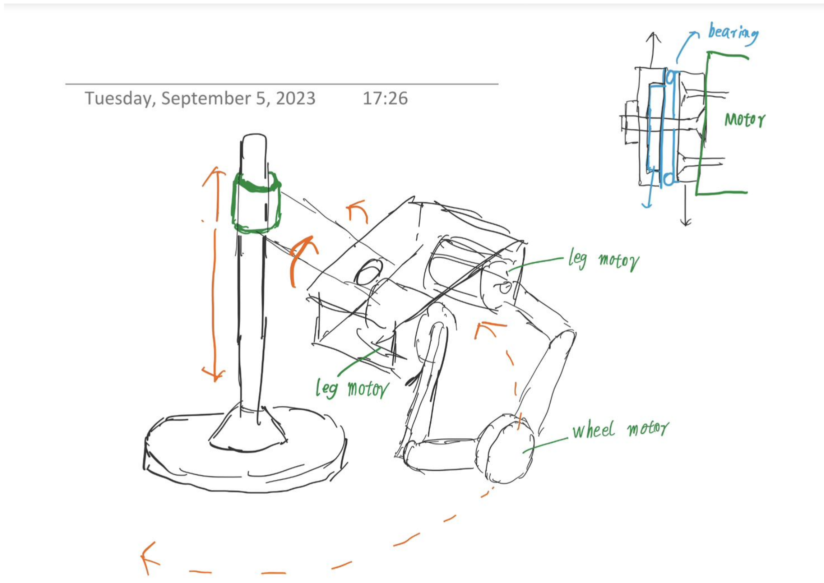


Figure 1: Visual Aid Hand Draft

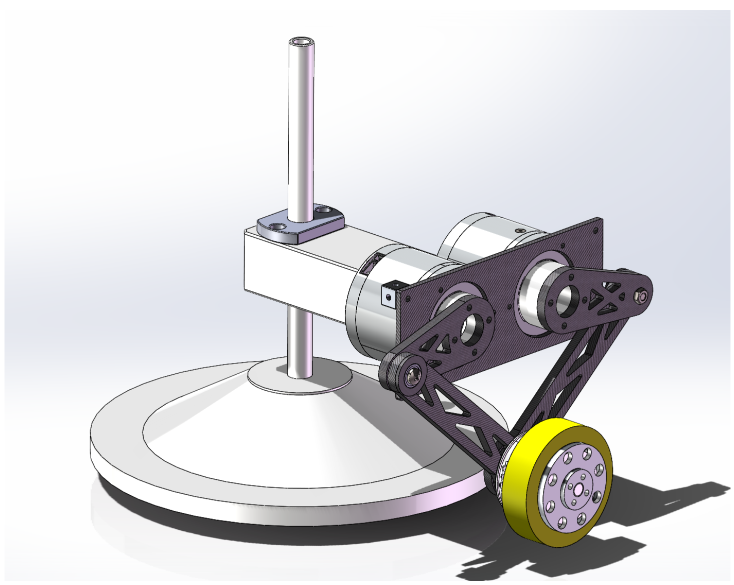


Figure 2: Visual Aid SolidWork before rendering

Figure 3: Visual Aid SolidWork after rendering

1.4 High-level Requirements List

1. The leg motors should provide a 4 Nm continuous torque to let the overall structure stand on the support of the legs and be able to apply about 1-2.5lb loads on the top of the platform.

2. The robot should respond to the remote control within 300ms and be able to execute pre-calculated trajectories in real time to demonstrate jumping and partial walking gaits.

3. The system's power management should ensure sustained and stable operation of all components for at least 15 minutes, with the ability to quickly shut down in 1s in emergencies, safeguarding both the robot and its environment.

2 Design

2.1 Block Diagrams

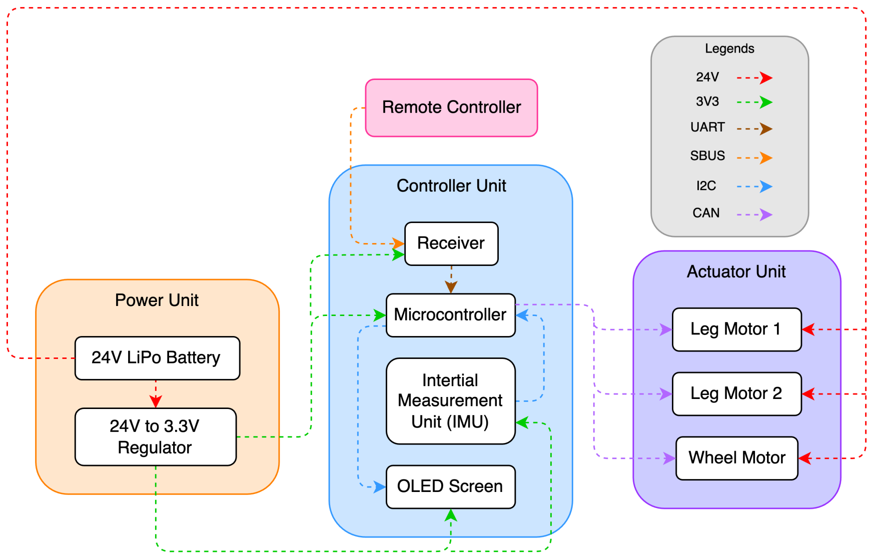


Figure 4: Block diagram of our design

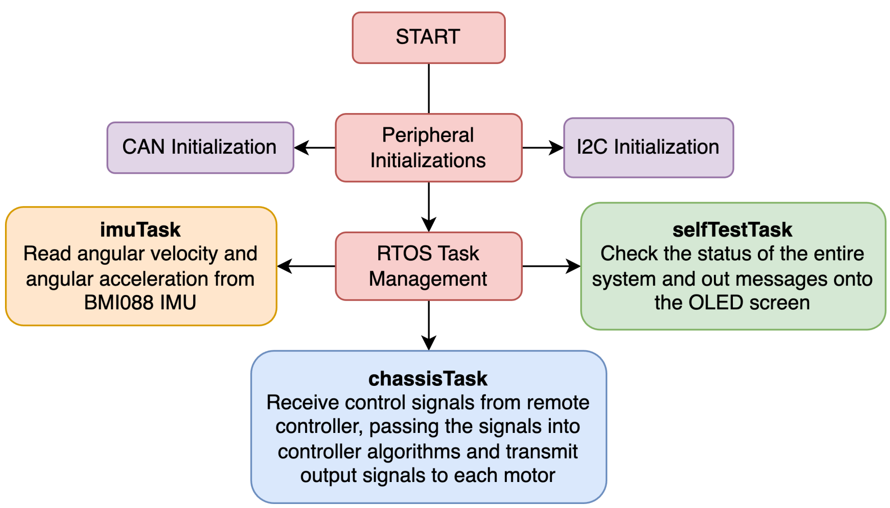
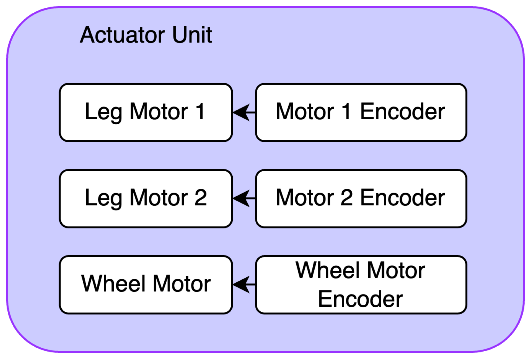


Figure 5: Software block diagram of our design

2.2 Subsystem Description

2.2.1 Hybrid Mobility Subsystem

1. **Actuated Legs**



Overview

Two actuator motors (DM-J4310-2EC) are utilized to power the legged system which will navigate uneven surfaces, obstacles, and stairs. The legs also function as an advanced electromagnetic suspension system, making rapid adjustments in damping and stiffness to maintain a stable and level platform.

Requirements:

(a) The motor should able to supply a continuous torque of at least 1nm with 60rpm.

(b) The motors must able to be powered by 20 - 27V.

(c) The motors must maintain a communication rate of 1kHz $\pm$ 10HZ with the STM32 through the CAN bus.

2. **Wheeled Drive**

Overview

A direct drive BLDC motor (M3508) propels the wheels, facilitating efficient travel on flat terrains.

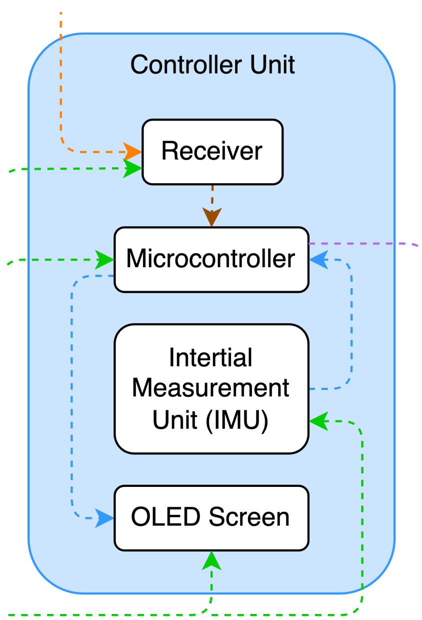
Requirements:

(a) The M3508 motor should maintain a communication rate of 1kHz $\pm$ 10HZ with the STM32 to ensure smooth and controlled movements.

(b) The motor need to have a continuous torque of at least 0.1nm and at least 2000rpm to move the entire robot under a load of around 2kg.

2.2.2 Central Control subsystem

1. **PCB and Microcontroller**



Overview

At the core is an STM32F103 microcontroller, processing inputs from the IMU via SPI signals and directing the motors through the CAN bus. The PCB encompasses the STM32F103 chip, BMI088 IMU, power supply components, and an Dbus remote control signal inverter.

Requirements:

(a) Should be capable of processing inputs efficiently and directing outputs to various peripherals.

(b) The system maintaining Can bus load under 80% between the IMU and the motors to ensure stable communication.

(c) STM32F103 should run at 72MHZ $\pm$ 5MHZ

(d) The design should consume $\leq$ 1W to ensure efficient power consumption.

(e) Must have protection mechanisms against power surges or short circuits.

(f) Capable of processing and interpreting signals from the IMU accurately.

(g) Should ensure minimal latency in signal processing for real-time applications.

(h) Must provide precise control signals to the motors via the CAN bus.

(i) Should support feedback mechanisms for closed-loop control.

(j) The system should be robust and reliable in various operating conditions.

2. **Attitude Sensing**

Overview

A 6-axis IMU consistently monitors the robot's orientation and movement, making real-time adjustments to secure stability and accurate navigation.

Requirements:

(a) **Sensors Included**:
- *Accelerometer*: Measures linear acceleration.
- *Gyroscope*: Measures angular velocity or rate of change of angular position.

(b) **Accuracy**:
- Low bias error and drift.
- Low noise levels.
- High resolution.

(c) **Range**: Suitable measurement range for the intended application.

(d) **Sampling Rate**: High enough to capture the dynamics of our system.

(e) **Calibration**:

- Ability to be calibrated to ensure accurate measurements.
- Temperature compensation to maintain accuracy across a range of operating temperatures.

(f) **Power Consumption**: Low power consumption for battery-operated devices.

(g) **Robustness**:

- Ability to withstand environmental factors such as temperature changes, humidity, and vibrations.
- Mechanical shock resistance.

(h) **Communication Interfaces**: Common interfaces like I2C, SPI, UART, or CAN for easy integration with other systems.

(i) **Temperature Stability**: Consistent performance across its specified temperature range.

(j) **Latency**: Minimal time delay between the occurrence of an event and the IMU reporting it.

2.2.3 Testing Platform Subsystem

Overview

The leg is attached to a harness as depicted in this sketch. This harness simplifies the model by limiting the robot's movement to a circular path, yet allowing for z-axis jumps.

Requirements:

1. The harness must be stable enough to stay **stationary** so that it can securely hold the robot when the robot is running or jumping.

2. It should ensure safety by preventing the robot from exceeding predefined motion boundaries. The height of the robot(full extension) should not exceed **50cm** and it should move inside a circle with a **40cm** radius.

2.2.4 Payload Compartment Subsystem (3D-printed)

Overview

A special section is designed to securely hold and transport items, shielding them from disturbances during the journey.

Requirements:

1. The compartment should be a **10cm x 15cm x 10cm** box with covering. Therefore, it is able to safely secure a variety of items, protecting them from shocks and vibrations during transit.

2. The platform should allow about 1-2.5lb loads on the top.

2.2.5 Remote Controller Subsystem

Overview

A 2.4 GHz RC remote controller using Dbus protocol will enable the user to control the robot. This portable device allows for real-time control over varying distances, with safety features like an emergency kill switch.

Requirements:

The remote control must maintain a reliable communication with delay $\leq$ 10ms.

2.2.6 Power System

Overview

Currently, a 6s (24V) Lithium Battery is under consideration to power the robot, with an DC-DC converter from 24V to 3.3V to power the micro controller.

Requirements:

1. The DC-DC should provide a stable output voltage of 3.3V $\pm$ 0.3V to ensure consistent performance of all connected systems.

2. It should feature mechanisms for quick power cut-off (response time $\leq$ 200ms) in case of any safety concerns, and the ability to switch between battery and wired power sources without affecting robot performance.

2.3 Tolerance Analysis

1. **Power Analysis:**

   Battery:

   We are using a Lithium Polymer battery to power our entire robot. Therefore, it is essential that the battery is powerful enough to support all electronics onboard, especially the three motors. The battery that we are using, DJI TB48S, has a rated power of 129.96 W and discharge rate of 10C, meaning that it can support a power consumption of 1299.6 W. The two DM-J4310-2EC motors each has a rated power of 60 W, and the M3508 motor has a rated power of 240 W. The total rated power of all motors are 360 W, so the the battery power is more than enough to support the entire system.

   DC-DC Module:

   The DC-DC module converts the 24V input down to a 3.3V output, to power the microcontroller which requires a voltage range of 2.0V-3.6V and a current of 50mA. This DC-DC module should operate with a output tolerance of $\pm 9\%$, ensuring stability and reliability in the system's power supply. Therefore, the DC-DC module can accept the voltage from 20V to 28V, and output 3.0-3.6V.

2. **IMU Analysis:**

   We want our IMU and motor(DM4310 and M3508) encoders to be updated frequently enough that we can have accurate enough data to update the torque of our leg motors. Ideally, the update rate of IMU is more than 200Hz and the maximum update rate of motor encoders is 1000Hz. For each data processing thread, the running time is from 50ms to 100ms. Therefore, for data processing of the microcontroller, IMU and encoders have sufficient update rate to supply the latest and accurate data to the microcontroller.

   Sensitivity tolerance requirement for the gyroscope:

   (a) RFS2000: $\pm 1\%$

   (b) Sensitivity Change over Temperature (TCS) for RFS2000: ± 0.03 %/K

   (c) Sensitivity Supply Voltage Drift (SVDD) for RFS2000: ≤ 0.4 %/V

(d) Nonlinearity for RFS1000, RFS2000: ± 0.05 %FS

(e) Zero-rate Offset for RFS2000: $\pm 1°/s$

(f) Zero-rate Offset Change over Temperature (TCO) for RFS2000: $\pm 0.015°/s$ per K

(g) Zero-rate Offset Supply Voltage Drift for RFS2000: $\leq 0.1°/s/V$

Data rate tolerance:

(a) $\pm 0.3\%$ for a data rate of 523Hz

(b) $\pm 1\%$ for a data rate of 230Hz

3 Ethics and Safety

3.1 Safety

Within in our project, there are several safety hazards:

Firstly, if the wheeled legged robot behaves unexpectedly or even losses control, it might cause harm to those around it. To avoid the unnecessary damages, we will implement two types(hardware and software) of emergency stops on our robots. For the hardware, we will install the wireless relay, which works like the emergency stop button, at the output of our battery to disable power to the motors and sensors. For the software, we will implement a safe thread and use a switch on our remote control to achieve a software emergency stop. If we turn on the switch, the safe thread will set the output of motors zero to stop all motors.

Another hazard is the usage of 24 Volt Lithium battery. Improper use of lithium batteries may cause them to expand, catch fire or even explode. In order to avoid accidents, will strictly adhere to the guidelines provided for the use of lithium batteries. We should check the appearance of the battery before using them, whether it is swollen or broken. We will use manufacturer-recommended charging methods, making sure that the load during use is less than the maximum discharge power of the battery, and constantly monitoring the battery temperature. In addition, during storage, the battery voltage will be adjusted to an appropriate storage voltage and keep them away from other flammable and explosive materials.

We will continue to update our safety manual if we become aware of or perceive any hidden safety hazards in the future.

3.2 Ethics

The structure of the wheel legs does not in itself present a ethical problem. However, when this structure is maliciously applied to some mobile robots, perhaps this will cause some ethical problems. Wheel-legged architectures can be built into automated mobile platforms that carry weapons or monitors. This would violate the **Three Laws of Robotics**[1] and **IEEE Code of Ethics**[2]. To avoid this situation, we will not be open-sourcing our core technical parts, such as PCB drawing, motion modeling, core code. At the same time, we will review our consumers(**avoiding malicious or illegal use**) and in the future will also apply our products in positive directions, such as urban logistics and transportation.

References

[1] Encyclopaedia, *Three Laws of Robotics*. Encyclopaedia Britannica, inc., 2023. [Online]. Available: https://www.britannica.com/topic/Three-Laws-of-Robotics

[2] IEEE. (2016) IEEE Code of Ethics. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html