PROJECT PROPOSAL: GROUNDED ROPE MANAGEMENT SYSTEM FOR BELAYING

Team 24

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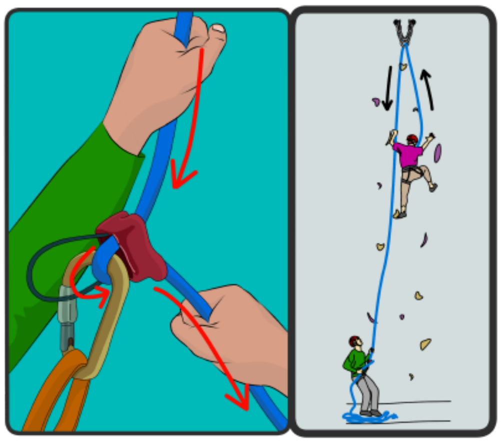
Introduction

Problem

When top-rope rock climbing, the climber is usually tied into a rope with a belayer on the ground for safety. While this does promote community and cooperativeness in the sport of rock climbing, this poses a problem for those who want to climb alone. While “bouldering”, (climbing shorter climbs at a safe enough height to fall directly onto crash mats), exists, it is a complete discipline of climbing. In fact, even within roped climbing, there exist several different variations, e.g. trad climbing, sport climbing, lead climbing.



Pictured above: Typical top-rope climbing setup. In this example the belayer is using an ATC instead of a grigri, but the same principles apply.

Solution

We will design a ground rope management system that replaces the belayer. Although there are auto-belays on the market, they are expensive (>$2000) and pre-installed at the top of the wall which makes them less practical for outdoor climbers or spontaneous usage. The rope management system will combine a grigri (rope management tool for belayers) and operate it with sensors and motors that read data about the tensions to adjust the rope feeding. It will be grounded and battery powered, with wireless control to be ideal for solo, outdoor usage.

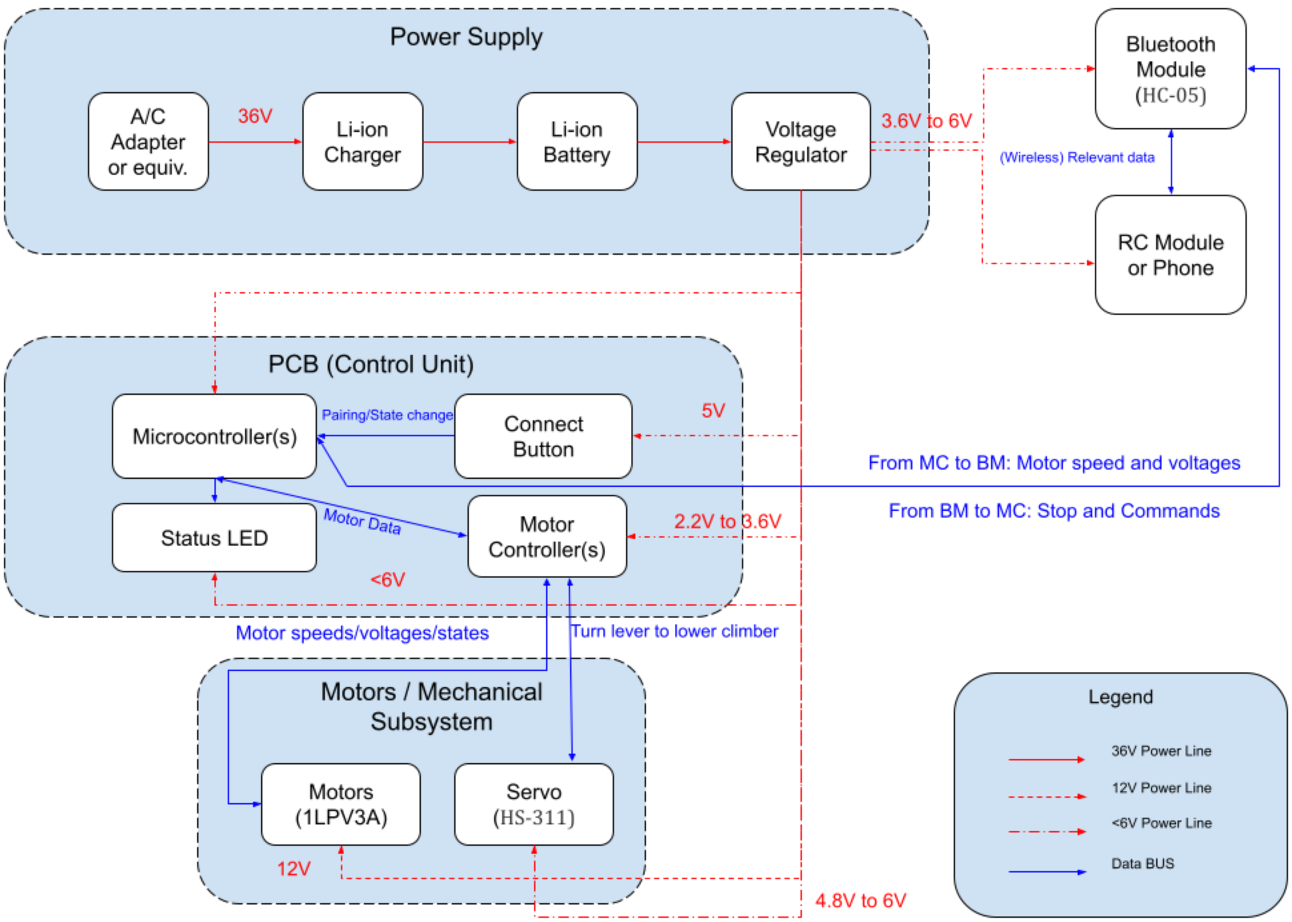
Visual Aid

High Level Requirements

- Rope system must be able to maintain an acceptable level of tension on the rope while the climber ascends without actively pulling the climber up the wall.
- The climber must be able to communicate with the rope system wirelessly (range of at least 50 feet) to give the following commands: stop, start, and lower.
- Rope system must be able to handle the climber's fall safely by catching the fall within ~4 feet.

Design

Block Diagram



Subsystems Requirements

Subsystem 1: Power Supply

The system will obtain power stored in the Li-ion battery, and the voltage regulator will adjust proper voltage for each subsystem. The battery will be rechargeable using an A/C power adapter, and be able to supply at least 36V.

Subsystem 2: Control Unit

The ESP32 microcontroller will handle the data from the motor controller and communicate with the bluetooth module, and the user can enter the information through the user interface for it to input data to the microcontroller. It contains the buttons of the state change and shows the status on the LEDs, and it operates between 2.2V to 3.6V.

Subsystem 3: Motors and Mechanics

Aforementioned, the motor controller will store the data regarding the tension by detecting the voltage change during the climbing and send it to the microcontroller for it to process the information. When tension is detected, the motor controller will send the data to the microcontroller that tells the remote host to adjust the rope. The motor we use is DC Dayton Gearmotor (model: 1LPV3A), which uses at most 12V at 2.1A, and it will be combined with a servo (model: HiTEC HS-311) for releasing the lever that will operate at approximately 4.8V to 6V and up to 0.8A.

Subsystem 4: Communication Unit

We will install a basic bluetooth module (model: HiLetgo HC-05) to communicate with the microcontroller, which should operate between 3.6V to 6V. The user can input data from the graphical user interface on the App to control the rope feeding through the motor controller. This should have the ability to start and stop the auto-belaying, as well as start and stop lowering the climber.

Tolerance Analysis

After speaking with Gregg Bennett at the Machine Shop and clarifying build ideas for the mechanical aspect of this project, we both agreed that the “left-hand” motor will likely be one of the most challenging aspects of this project. We are not overly concerned with the tension-sensing capability of the motor as we believe there are multiple ways to determine if an adequate tension has been reached (based on voltage, force sensors, etc).

However, we are concerned regarding the stopping force of this motor (or the mechanical mechanism needed to lessen the force the motor feels) during a fall. Although the rope is typically wrapped twice around a beam at the top of the climb (which in turn cuts the force the belayer experiences during a climber’s fall in half), this is still a significant amount of force for a motor to experience. There is also the issue with fall detection using this left-hand motor.

> We would like to detect falls in a weight range of 50 lbs to 200 lbs, therefore meaning that our left-hand motor must be able to sustain and detect forces between [~2500N, ~10500N]. This was calculated by taking masses of 20 kg and 90 kg, dropping from a height of 4 ft (~1.2m), and then finding half the average impact force (because of the looped system).
>
> Avg. impact fore * (0.05m traveled) = Change in kinetic energy.
> Change in kinetic energy = $0.5mv^2$, where we know $v = \sqrt{(2gh)}$.

We believe we can design a system that withstands these forces, especially using a high torque, low RPM motor. Furthermore, we will be able to detect tension changes, i.e. falls, depending on motor voltage spikes. A greater voltage indicates more work is needed to pull the rope, meaning the rope is taught.

Ethics and Safety

Rock climbing, especially rope climbing, is an inherently dangerous sport. Safety is of the utmost concern and several systems and techniques are used to mitigate risks. Using the correct equipment and taking extra precaution prevents injury and potential death.

When designing this rope-management system, we intend to follow climbing and mechanical industry standards, in addition to documenting the full process. Furthermore, when testing, we will take advantage of testing techniques currently used by professionals to completely eliminate excess risks. A belay-certified individual will always be operating a grigri behind the system in the event of failure, safely catching the climber. Therefore, the usage of our rope-management belay system will be no more dangerous than normal top-rope climbing is. To further eliminate risks, we will never climb above a height from which a freefall would cause injury. By strictly following these steps and rules we have defined for ourselves, we will confidently be able to climb and test with the system safely.

There are some ethical concerns regarding unintended usage of the system. However, we intend to be the only users of this system at all times, as we will be familiar with the controls and dangers. Under no circumstances will we allow any untrained or non-group members to use the belay system. When active, the system will be under supervision at all times to prevent any misuse and resulting damage. This is in accordance with IEEE Code of Ethics (section 7.8.I.1).

All group members have completed the lab safety training and understand that we must exercise caution when working in dangerous environments. When working in the machine shop, we will take adequate precautions to avoid injuries and accidents. This is in accordance with IEEE Code of Ethics (section 7.8.III.10). Using feedback from TAs, Professors, and the machine shop employees, we will work to alleviate concerns and pursue honest work (section 7.8.I.5).

Citations

UIAA Climbing safety standards: https://theuiaa.org/safety/safety-standards/

IEEE code of ethics: https://www.ieee.org/content/dam/ieee-org/ieee/web/org/about/corporate/ieee-code-of-ethics.pdf

Commercial auto-belay information: https://trublueclimbing.com/trublue-iq-auto-belay

Top-rope diagram: https://www.vdiffclimbing.com/basic-top-rope-belay/

Climber image: https://www.mensjournal.com/adventure/things-beginner-climber-should-know-before-first-outdoor-climb/

Grigri image: https://en.wikipedia.org/wiki/Grigri_%28climbing%29

Tension sensor image: https://www.hans-schmidt.com/en/produkt-details/tension-sensor-tsr/

Gear motor image: https://www.amazon.com/Dayton-3M326-Gearmotor-Nameplate-Enclosure/dp/B000TKETV2

Belaying example: https://www.youtube.com/watch?v=BAxY-BBSlGc

Grigri standards: https://standards.globalspec.com/std/1540615/EN%2015151-1