Bioinspired Exosuit

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Abstract

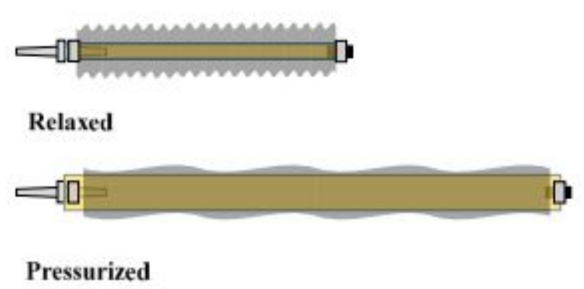
This project is focused on building on the work of the Humanoid Walking Robot and developing an application of the CRFC Valve to an assistive walking exosuit that lowers the metabolic cost of walking. Hydro Muscles are placed in the location of the gluteus maximus, gastrocnemius, and quadriceps femoris muscle groups and actuated to enhance the natural muscular movement.

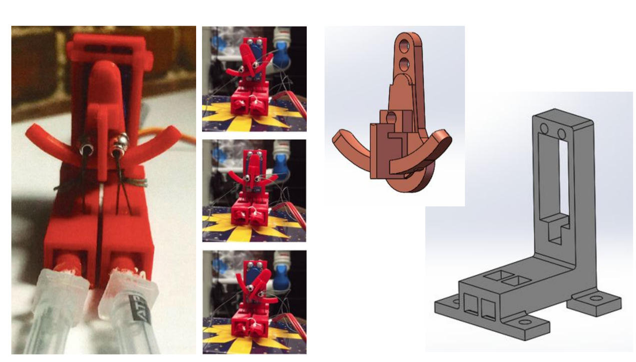
Objectives

- To develop a novel application of the Hydro Muscles and CRFC Valve.
- To design an exosuit that lowers the metabolic cost of walking by a statistically significant amount.
- Create an exosuit that can operate at three speeds and carry all electronic components while remaining under 15 lbs.

Background

The Hydro Muscle is a fluid elastic actuator that can be pressurized to expand and depressurized to contract. These muscles can be used to mimic the contraction of a biological muscle [1].





The CRFC (Compact Robotic Flow Control) Valve is an inexpensive, compact, and lightweight valve that allows for discrete and continuous fine flow control of both air and water.
The CRFC Valve is operated alongside the Hydro Muscle to create biologically realistic movement.

The gait cycle is a series of movements that occur during locomotion [2]. These movements can be broken down based on what muscles they use.

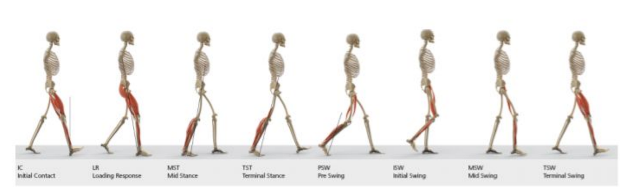
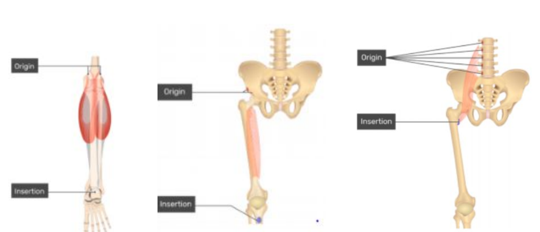


Figure 2.5: Complete gait cycle (Streifeneder, 2017).



The primary driving muscles are the gluteus maximus, gastrocnemius, and quadriceps femoris [3].

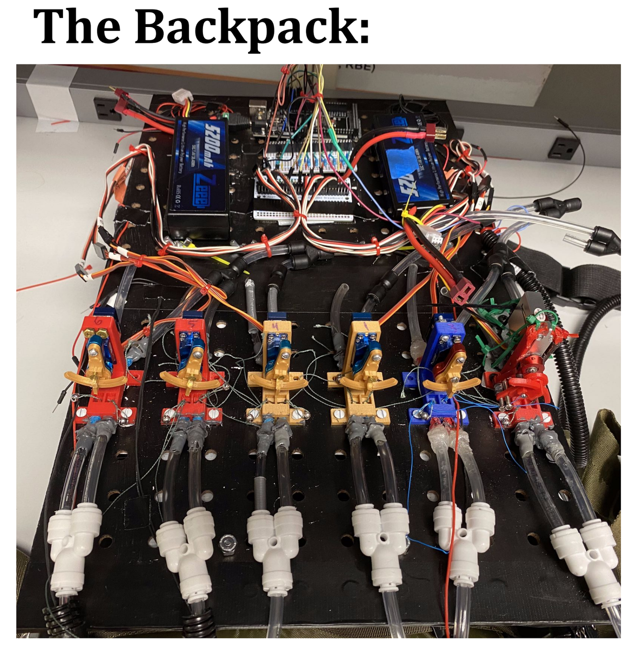
Methodology

The "Overalls":
The strap system used for the exosuit, which we refer to as the Overalls, allows for the Hydro Muscles to be attached to the user without hindering movement.

The overalls contain 5 main straps that each act as an attachment point for the Hydro Muscles; The hip strap, the thigh strap, the above the knee strap, the below the knee strap, and then the foot strap. The placement of these attachment points were inspired by the biological placements of the chosen muscle groups in the human body.

These straps are all interconnected along the sides to wrap around the shoulders all the way down to around the bottom of the foot. This prevents movement of the straps when being actuated, and allows the limbs to be actuated with the Hydro Muscles.

The Backpack:



The Backpack is made from a lightweight aluminum backpack frame often used for hiking, with a thin sheet of wood mounted to it.

On this backpack are 6 CRFC valves, two 7,4V lithium polymer batteries, an ELEGOO Mega 2560, and two perma-proto boards for the wiring of the sensors and the CRFC valves.

Sensors and Timing:
To determine the timing of when each of the Hydro Muscles should be actuated, a force sensitive resistor was placed under the foot by the heel between two protective 3D-printed plates. This sensor was used to determine the timing of one full gait cycle of the user.
There is then a calibration period at the start of operation that has the user take 10 steps, and the average time of the gait cycle of the user is found to modify the timing of the Hydro Muscle actuation.

Results and Analysis

To test the effectiveness of our exosuit, we used the PNOE Device, which measures the metabolic cost (energy expenditure) of the user.
A test was run on three individuals in which the users walked with and without the exosuit on at 1.4mph, 2.4mph, and 3.4mph for five minutes each speed. The metabolic cost was measured at each speed, with a rest period in-between to allow the user's heart rate to return to normal.

The Results:
The Bio-inspired Exosuit on average affected the metabolic cost for a 1.4mph, 2.4mph, and 3.4mph walking gait cycle by -0.67%, -22%, and +5.65% respectively. When wearing the exosuit, two out of the three users tested experienced a decrease in metabolic cost for all speeds, while one user experienced an increase in metabolic cost for all speeds. Our greatest reductions in metabolic cost for one user were -12.05%, -40.81%, and -33.3% respectively for the previously mentioned speeds. The consistent increase in metabolic cost from the one user could be contributed to some potential malfunctions during their particular testing, or simply being less familiar with the exosuit.
The final weight of our exosuit remained well within our goal, weighing only 7.6lbs.

Future Development

Some potential future developments of this project could include:
- Live updating of the walk cycle during use to accommodate any changes in the user's gait.
- An entirely untethered system.
- Assistance/augmentation in a wider range of movements: sprinting, walking up stairs, standing, etc.

Sources

[1] Sridar, S., et al. (2016). "Hydro Muscle - a novel soft fluidic actuator," 2016 IEEE International Conference on Robotics and Automation (ICRA), pp 4104-4021. Retrieved from http://users.wpi.edu
[2] Streifeneder (2017), The eight phases of human gait cycle. Retrieved from https://www.streifeneder.com
[3] Curran et. al. (2018). "Humanoid Walking Robot".

Acknowledgments

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