Enhanced Mobility Mechanical Assistance System: Reducing Overexertion Injuries in the Manual Workforce

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Introduction

As civilization carries on growing to support its increasing population, the need for manual work only increases. Nevertheless, along with that work, comes the risk of strain and injuries on the human body: Every year in the United States, 255,000 manual work labourers (NCS, 2022) suffer from an injury resulting from overexertion.

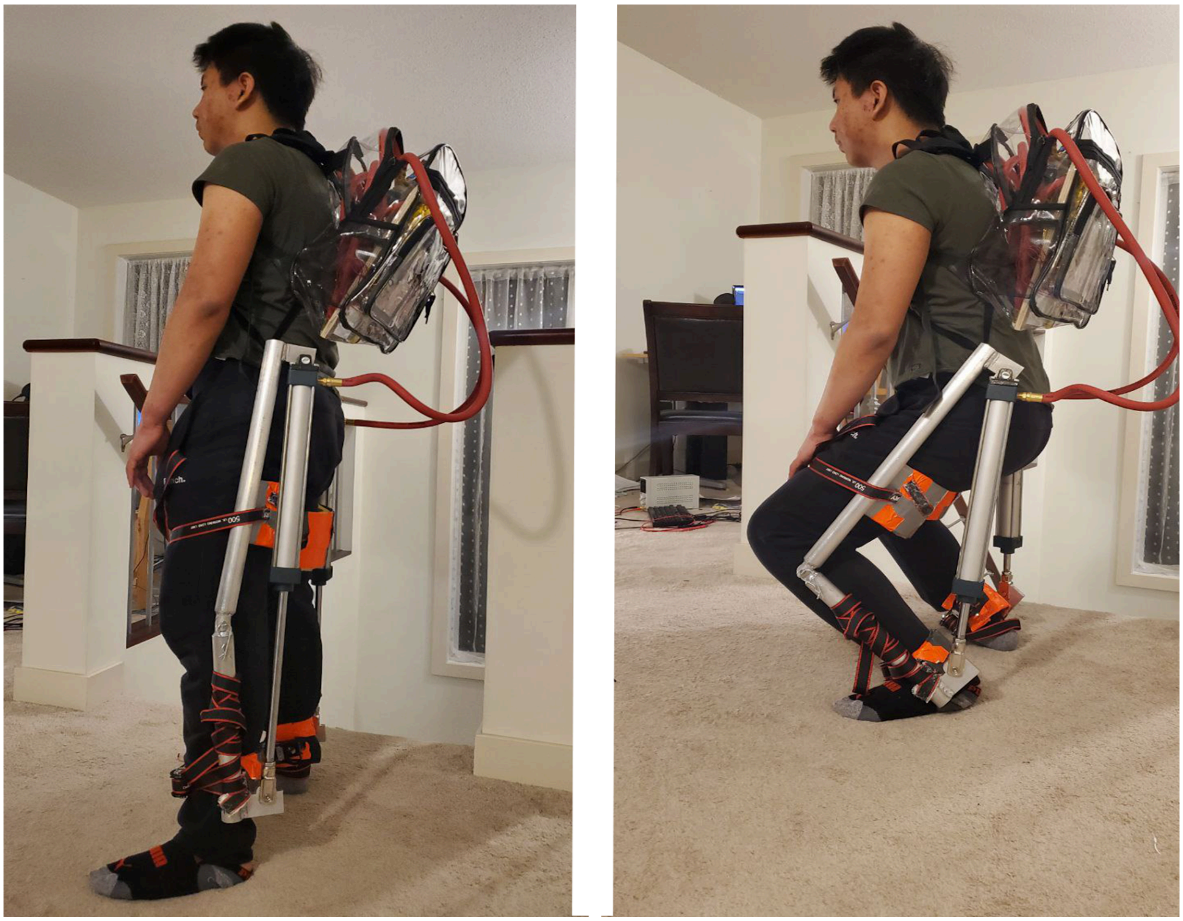
The concerning number of injuries generally stems from pushing, lifting, and carrying objects with improper technique. Using the incredible technological advancements humans have made, however, we have received the ability to eliminate this problem by enhancing the user's leg strength and mobility. Through the increase in strength, the user can once again return to focusing on their form knowing that they have the power to do so.

To solve the problem affecting millions of people worldwide, we came up with an active lower-body exoskeleton that uses pneumatic power to extend and retract the leg with a superhuman amount of force.

The design criteria, though they were vague, were minimal weight, maximum power output and maximum run time. The vagueness was due to the uncertain nature of this project.

Procedure

To supply additional power to the user to reduce overexertion injuries, we developed a rough idea for an exoskeleton that ultimately required four different systems: Frame & design, Air delivery, Battery, and Control. From then on we began prototyping each section.



The exoskeleton shown in both fully extended form and fully squatting form.

How it works:

<u>Battery system</u>

The main design criteria were high energy density to minimize weight. To achieve that, we leveraged the latest lithium-ion technology. By placing the batteries (18650 cells) in a 7 series 3 parallel design, we achieved a 250 Wh battery weighing 1kg. We then use a 24V step-down converter for the air compressor and microcomputer.

Air Delivery System

The air delivery system actively pumps air into the pneumatic cylinders. To control the flow of air, we developed a design that had an air compressor pump air into an air tank that would branch off into the two legs. On the legs, there would be two types of solenoid valves that control the flow using signals they receive from the computer to either let the air go through or not. The first layer of solenoid valves works off Pulse Width Modulation to control airflow out the tank (More details on P.W.M in the controls section) while the second layer uses P.W.M. to exhaust air when necessary.

Control: (Software: https://github.com/HOPE028/EMMAS)

The microcomputer's role is to analyze the user's input and send signals to the solenoid valves. To do so, the microcomputer sends 0 and 1 bits in the form of voltage to control the valve's state. The valve's state is what decides if air goes through or not. Building on top of that, we used the P.W.M framework for precise power control. To utilize it, we send signal changes at a high frequency to regulate the flow rate. All inputs are received from buttons and switches. Through the inputs, the user can change what mode the exoskeleton is in which affects how the exoskeleton behaves.

Design & Frame

During the motion of squatting, the distance between the hip and ankle reduces. By being able to manipulate the distance between these two leg parts, we can mimic the leg's movement. The pneumatic cylinder allows us to do exactly that through the manipulation of its own length by pumping air into its chambers when the ends are attached to the ankle and hip. When the pneumatic cylinder is compressing, however, it has the ability to buckle the knee. In response, we created a frame for the pneumatic cylinder to be attached to. The frame ensures that the force from the pneumatic cylinder is limited to one degree of freedom and that the frame and pneumatic cylinder do not slide.

When choosing the frame material, we prioritized reducing weight without compromising structural integrity. That is why we ultimately chose aluminum 6061-T6.

Results

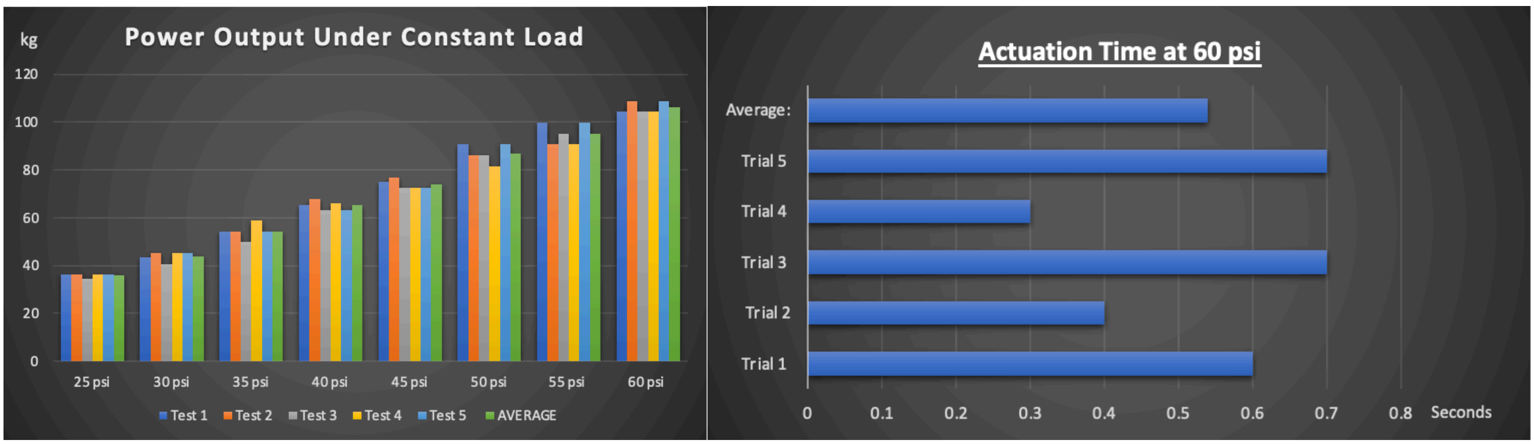
After we designed and constructed our prototype, we performed some experiments to verify our hypothesis of the ability to augment the user's lifting power.

We tested constant load performance by attaching one end of the pneumatic cylinder to a scale and the other end to a solid base. Through 40 different trials at 5 different pressures inside the air-delivery system, we received performance data:

The tests showed that when the system was running at 60 psi (pressure inside the air delivery system), the pneumatic cylinders could provide over 980N of force, more than enough force to lift most users without the user's leg needing to do any work at all. This would result in a substantial reduction of strain on the user's body and give the user increased lifting capabilities.

We tested actuation time by setting the air delivery system at 60 psi and measuring the time between the user turning on the power and the time it took for the system to start providing power. The results were the following:

At 60 psi, the system would take on average 0.54 seconds. That is fast enough so that the user could carry on with their regular work pace while being aided by the power of the exoskeleton.



Left: The measured force (at Earth's surface gravity) of the pneumatic cylinder under constant load at different pressures.

Right: The time it took for the pneumatic cylinder to react after the user had activated it.

Conclusions

The exoskeleton enhances the user's ability in ways we could not have dreamed of. It provides incredible power at an explosive pace. Providing up to 2940 newtons of force (at 150 psi inside the air delivery system theoretically) in less than 0.54 seconds, the user can achieve tasks never thought to be possible by humans. For testing equipment purposes, however, we were never able to reach that pressure inside the chambers due to safety concerns and air leakages stemming from prototyping. Instead, we tested with lower pressures that a user would more realistically use in real-life environments. The results were still very impressive.

References

Research:

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