That which does not stabilize will only make us stronger: The Berkeley Exoskeleton

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INTRODUCTION

In October 2003, the first functional load-bearing and energetically autonomous exoskeleton, called the Berkeley Lower Extremity Exoskeleton (BLEEX) was demonstrated, walking at the average speed of two miles per hour while carrying 75 pounds of load. The project tackled four fundamental technologies: the exoskeleton architectural design, a control algorithm, a body LAN to host the control algorithm, and an on-board power unit to power the actuators, sensors and the computers. This article gives an overview of the BLEEX project.

BLEEX2, developed in 2005, weighs 30 pounds and is able to carry 200 pounds. The speed of this system is limited by the wearer's speed.

WHAT IS A LOWER EXTREMITY EXOSKELETON?

The primary objective of this project at U.C. Berkeley is to develop the fundamental technologies associated with design and control of energetically autonomous Lower Extremity Exoskeletons that augment human strength and endurance during locomotion. The first field-operational lower extremity exoskeleton at Berkeley (commonly referred to as BLEEX) is comprised of two powered anthropomorphic legs, a power unit, and a backpack-like frame on which a variety of heavy loads can be mounted. This system provides its wearer (i.e., its wearer) the ability to carry significant loads on his/her back with minimal effort over any type of terrain. BLEEX allows the wearer to comfortably squat, bend, swing from side to side, twist, and walk on ascending and descending slopes, while also offering the ability to step over and under obstructions while carrying equipment and supplies. Because the wearer can carry significant loads for extended periods of time without reducing his/her agility, physical effectiveness increases significantly with the aid of this class of lower extremity exoskeletons. In order to address issues of field robustness and reliability, BLEEX is designed such that, in the case of power loss (e.g., from fuel exhaustion), the exoskeleton legs can be easily removed and the remainder of the device can be carried like a standard backpack.

BLEEX was first unveiled in October 2003, at U.C. Berkeley's Human Engineering and Robotics Laboratory. In this initial model, BLEEX offered a carrying capacity of seventy five pounds, with weight in excess of that allowance being supported by the wearer.

BLEEX's unique design offers an ergonomic, highly maneuverable, mechanically robust, lightweight, and durable outfit to surpass typical human limitations. BLEEX has numerous applications; it can provide soldiers, disaster relief workers, wildfire fighters, and other emergency personnel the ability to carry major loads such as food, rescue equipment, first-aid supplies, communications gear, and weaponry without the strain typically associated with demanding labor. It is our vision that BLEEX will provide a versatile transport platform for mission-critical equipment.

CONTROL METHOD

The effectiveness of the lower extremity exoskeleton stems from the combined benefit of the human intellect provided by the user and the strength advantage offered by the exoskeleton. The human provides an intelligent control system for the exoskeleton, while the exoskeleton actuators provide most of the strength necessary for walking. The control algorithm ensures that the exoskeleton moves in concert with the wearer with minimal interaction force between the two. The control scheme needs no direct measurements from the user or the human-machine interface (e.g. the force sensors between the two); instead, the controller estimates, based on measurements from the exoskeleton only, how to move so that the wearer feels very little force. The basic principle for the control of BLEEX rests on the notion that the exoskeleton needs to shadow the wearer's voluntary and involuntary movements quickly, and without delay. This means that the exoskeleton requires a high level of sensitivity in response to all forces and torques on the exoskeleton, in particular the forces imposed from the wearer.

One class of systems that has large sensitivity is marginally stable systems. We therefore designed a marginally stable closed loop controller system that uses the sensor information on the exoskeleton only. This is done by using the inverse of the dynamics of the exoskeleton as a positive feedback controller so the loop gain for the exoskeleton approaches unity (slightly less than 1). Obviously, to get this method working properly, one needs to understand the dynamics of the exoskeleton quite well, as the controller is heavily model based. Our experiments with BLEEX have shown that at this time, this control scheme—which does not stabilize BLEEX— forces it to follow human wide bandwidth maneuvers while carrying heavy loads although it requires a great deal of dynamic modeling. We have come to believe that that which does not stabilize, will only make us stronger.

BLEEX2 was developed recetnly to create a lighter and faster system capable of carrying larger payloads. BLEEX2 weighs 30 pounds and is able to carry 200 pounds. It is electrically powered and allows its wearer to walk and even run with minimal effort over any type of terrain.

REFERENCES

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ACKNOWLEDGEMENTS

This work is partially funded by DARPA grant DAAD19-01-1-0509.