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Preface

Human–robot integration, in particular human augmentation, outlines the future of robotics. Although autonomous robotic systems perform remarkably in structured environments (e.g., factories), integrated human–robotic systems are superior to any autonomous robotic systems in unstructured environments that demand significant adaptation. In our research work at Berkeley, we have separated the technology associated with human power augmentation into lower extremity exoskeletons and upper extremity exoskeletons. The reason for this was 2-fold. (i) We could envision a great many applications for either a stand-alone lower or upper extremity exoskeleton in the immediate future. (ii) More importantly for the division is that the exoskeletons are in their early stages, and further research still needs to be conducted to ensure that the upper extremity exoskeleton and lower extremity exoskeleton can function well independently before we can venture an attempt to integrate them. With this in mind, we proceeded with the designs of the lower and upper extremity exoskeleton separately, with little concern for the development of an integrated exoskeleton.

In the mid-1980s, we initiated several research projects on upper extremity exoskeleton systems, billed as ‘human extenders’. The main function of an upper extremity exoskeleton is human power augmentation for manipulation of heavy and bulky objects. These systems, which are also known as assist devices or human power extenders, can simulate forces on a worker’s arms and torso. These forces differ from and are usually much less than the forces needed to maneuver a load. When a person uses an upper extremity exoskeleton to move a load, the device bears the bulk of the weight by itself, while transferring a scaled-down value of the load’s actual weight to the user as a natural feedback. For example, for every 40 lb of weight from an object, a worker might support only 4 lb while the device supports the remaining 36 lb. In this fashion, the worker can still sense the load’s weight and judge his/her movements accordingly, but the force he/she feels is much smaller than what he/she would feel without the device. In another example, suppose the worker uses the device to maneuver a large, rigid and bulky

Figure 1. Electric upper extremity exoskeleton.

object, such as an exhaust pipe. The device will convey the force to the worker as if it was a light, single-point mass. This limits the cross-coupled and centrifugal forces that increase the difficulty of maneuvering a rigid body and can sometimes produce injurious forces on the wrist. In a third example, suppose a worker uses the device to handle a powered torque wrench. The device will decrease and filter the forces transferred from the wrench to the worker's arm so the worker feels the low-frequency components of the wrench's vibratory forces instead of the high-frequency components that produce fatigue.

Upper extremity exoskeletons (Fig. 1) were designed based primarily on compliance control schemes that relied on the measurement of the interaction force between the human and the machine. Various experimental systems, including a hydraulic loader designed for loading aircraft and an electric power extender built for two-handed operation, were designed to verify the theories. We also developed low-cost industrial upper extremity extenders (commonly referred to as intelligent assist devices (IADs)) that are now widely used in the US and Europe (Fig. 2). An IAD includes a computer-controlled electric actuator which is attached directly to a ceiling or an overhead crane and precisely moves a wire rope with a controllable speed. Attached to the wire rope is a sensory end-effector where the operator hand, the IAD and the load come in contact. In these IADs, the operator force on the device is sensed and amplified electronically by use of a computer to drive the actuator. The end-effector includes a load interface subsystem which is designed to interface with a variety of loads and holding devices, such as suction cups and hooks.

In October 2003, the first functional load-bearing and energetically autonomous exoskeleton, called the Berkeley lower extremity exoskeleton (BLEEX) (Fig. 3), was demonstrated, walking at an average speed of 2 mph (3.2 km/h) while carrying

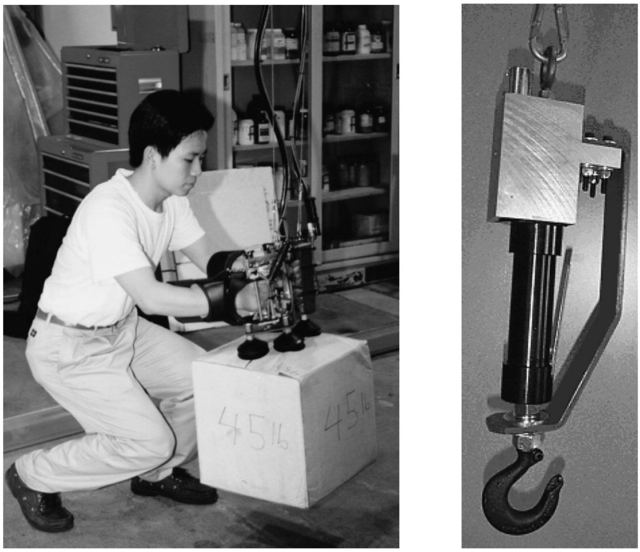

Figure 2. IAD: the simplest form of upper extremity enhancers for industrial applications.

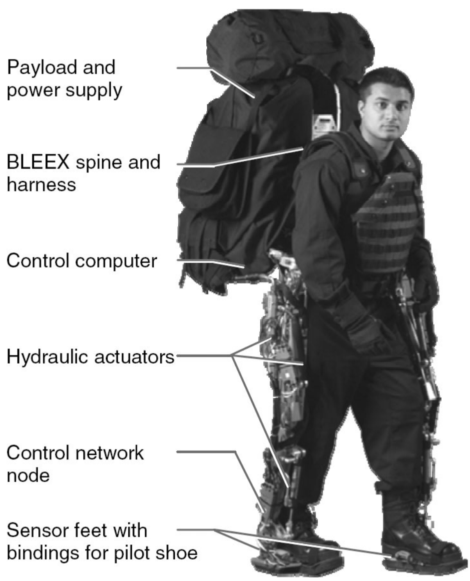

Figure 3. BLEEX and pilot.

75 lb of load. The project, funded in 2000 by the Defense Advanced Research Project Agency (DARPA), 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.

The primary objective of this project at UC Berkeley is to develop the fundamental technologies associated with the 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 pilot (i.e., its wearer) with the ability to carry significant loads on his/her back with minimal effort over any type of terrain. BLEEX allows the pilot 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. As the pilot 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. In this initial model, BLEEX offered a carrying capacity of 75 lb, with weight in excess of that allowance being supported by the pilot. 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.

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