Section 3

Devices

Chapter 9: Real time gait planning for a lower limb exoskeleton robot
Chapter 10: Soft wearable assistive robotics: exosuits and supernumerary limbs
Chapter 11: Walking assistive apparatus for gait training patients and promotion exercise of the elderly

In this section, a variety of different types of exoskeletons are described, with details of the designs, how they were built, and tested with users. The exoskeletons have been created for different types of markets such as spinal cord injuried persons, medical rehabilitation devices, user assistance exoskeletons, military, industrial, and recreation systems. A good description of commercial devices can be found at www.exoskeletonreport.com and www.wearablerobotics.com.

In this section, three chapters are included describing exoskeletons used in the medical markets. The medical, exoskeleton market is the most mature as researchers have focused on this area. In Chapter 9, a medical exoskeleton to aid persons with spinal cord injury is described. The chapter focuses on generating a stable gait to ensure balance. The user's legs are powered at the hip and knee, and crutches are added for maintaining balance. The gait which includes both two legs and two crutches is analyzed as a quadruped gait. When one leg or crutch is not touching the ground in the swing phase, a tripod structure is formulated to ensure balance. Experimental results show a user able to walk with the system. There are many spinal cord injury exoskeletons and readers are encouraged to review Chapter 1 as well and study systems by Ekso Bionics, ReWalk, Indego, Rex Bionics, and Fourier Intelligence.

In Chapter 10, soft wearable robotic systems are described as well as the chronology of robot development from typical, stiff actuation to compliant actuation allowing for human–robot interaction. The compliant actuators allowed worldwide researchers to focus on rehabilitation robotics where systems can assist as needed and guide and improve human function such as reaching and walking. Recently, soft robotic solutions were employed to design systems that can compliantly interact with the human to improve safety and ergonomics and reduce weight. Typically, rigid structures strapped or placed in-parallel with the human limb structure can be uncomfortable, heavy, and limit sideways motion. The authors believe that soft robotics is a natural progression in the research line from stiff actuation, to series and parallel elastic actuators, to compliant exosuits to improve safe human–robot interaction. Examples are described in the chapter: a soft-robotic arm exoskeleton is described in detail along with the Bowden-type actuators. A soft-glove system is used to aid picking up objects and a unique supernumerary finger is added to a user's arm to aid in grasping objects improving dexterity and aiding in activities of daily living of stroke survivors.

In Chapter 11, lower limb devices are described to aid in gait training and assist users with reduced leg muscle strength. One exoskeleton uses a leg mechanism with a foot plate that helps to lift the foot at the correct time. A second exoskeleton uses pneumatic muscles to assist the whole body. The system assists the legs and arms to enhance walking by swinging the arms and legs in a synchronized rhythm. Last, a lightweight ankle device, RE-Gait was designed to assist push-off. This device has been commercialized in 2016.

As the field is growing rapidly, we foresee new devices also emerging in the industrial area. Commercialized devices are already assisting the lower back when bending over and reaching in various pick-and-place tasks. Passive exoskeletons allow the user to hold heavy grinders and other objects by transferring the load to the ground. Typical devices use some type of gravity balancing mechanism.