Introducing a Modular, Personalized Exoskeleton for Ankle and Knee Support of Individuals with a Spinal Cord Injury

Cory Meijneke, Shiqian Wang, Victor Sluiter and Herman van der Kooij

Abstract In the Symbitron Project, one of the main objectives is to develop a safe, bio-inspired, and personalized wearable exoskeleton that enables individuals with a spinal cord injury (SCI) to walk without additional assistance, by complementing their remaining motor function. The first target group of five subjects, have enough hip control to keep themselves upright, but need support around the ankle and/or knee joint. This paper gives an overview of the design features of the newly developed exoskeleton and shares some details about the design process.

1 Introduction

Many exoskeletons have been developed for Spinal Cord Injured (SCI) subjects [1–4]. These exoskeletons are mostly designed to support for full lower limb paralysis and require the use of crutches.

The exoskeletons to be developed in the Symbitron project aim to support SCI subjects with various levels of impairments. To achieve this, two groups of five subjects have been selected: (1) subjects who have impaired motor function at the ankle and/or knee, but sufficient function at the hip, and (2) subjects with fully impaired lower limbs. The first Symbitron Wearable Exoskeleton (WE1) is

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C. Meijneke (✉) · S. Wang · H. van der Kooij
Department of Biomechanical Engineering, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands
e-mail: c.meijneke@tudelft.nl

V. Sluiter
Biomechanical Engineering Laboratory, Institute for Biomedical Technology and Technical Medicine (MIRA), University of Twente, Drienerlolaan 5, 7500 AE Enschede, The Netherlands

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developed for the first group of subjects (group I), thus provides knee and ankle support. Because of the modular design of the joints, the ankle and knee modules can also be (re)used as a basis for the second exoskeleton (WE2) suited for group II subjects. Furthermore, the remaining motor function of the group I subjects varies as well, hence for some, the ankle module can give sufficient support, while for others, both the ankle and knee are needed.

Commercially available exoskeletons are developed for a large population and are fitted on different users using adjustment mechanisms and custom padding. The Symbitron exoskeletons are personalized i.e. the anatomical features of the subject are accommodated for in the design phase.

Special attention is given to the ease of doing on and off the device. Based on experiences with the Mindwalker [5] and Achilles [6] exoskeleton, it is key to reducing setup time and improving comfort during experiments.

The following sections discuss the mechanical and electrical design features and list some preliminary specifications of the exoskeleton.

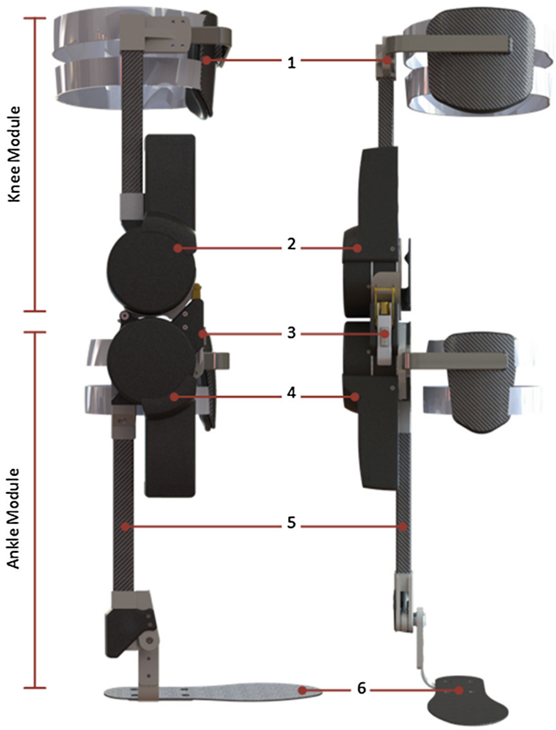

Fig. 1 Rendered 3D model of *side* and *front view* of WE1 where (1) denotes the personalized tube and strap to the wearer, (2) knee actuation unit, (3) quick connection mechanism between the ankle and knee modules, (4) ankle actuation unit, (5) personalized tube to the wearer with integrated linkage mechanism to the ankle, (6) personal footplates compatible with sensorized insoles [7]

2 Mechanical Design

An overview of the design features of WE1 is shown in Fig. 1. The design consists of a knee and ankle module, each with one actuated degree of freedom, respectively flexion/extension and plantar/dorsal flexion. Additionally, the ankle inversion/eversion is free, but has option to be locked. The two modules are connected by hooking them in to each other and locked using a toggling latch.

The size and shape of the exoskeleton segments and shells are adapted to body size, shape and anatomical axis (e.g. distance between ankle and knee joint center) of the subjects. Instead of introducing adjustment mechanisms, thus adding mass and complexity, some of the exoskeleton components are designed specifically to fit each subject in the test-groups.

An overview of the main features of the actuation unit are shown in Fig. 2. Most components inside the actuator are generic for each actuated joint. The included series elastic element and high resolution sensors enable accurate torque control. The gear ratio and mechanical attachments can be adapted to fit each joint.

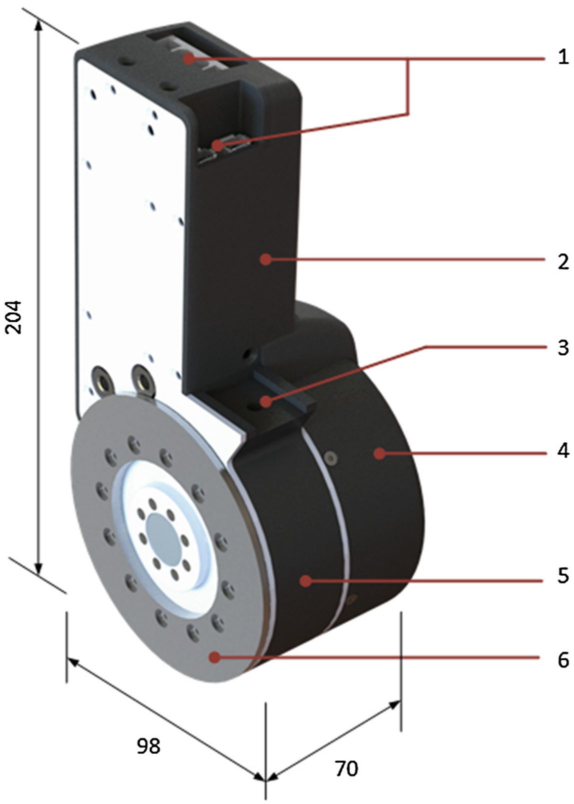

Fig. 2 Rendered 3D model of Symbitron Actuation Unit where (1) power and EtherCAT communication connectors, (2) Powerful control electronics with integrated IMU, (3) flexible connection to base components, (4) flat high performance electric motor, (5) compact harmonic drive, (6) output flange with integrated end-stops

Table 1 Preliminary specifications

Description	Value		Unit
	Knee	Ankle	
Peak output torque	70	100	Nm
Peak output speed	120	60	rpm
Average motor Power	750		W
Actuation unit mass	1.5		kg
WE1 mass per leg	5		kg
Torque resolution	0.012		Nm

3 Electronic Design

The modular design of each actuated joint puts special demands on the electronics. The actuation unit has custom-made EtherCAT slave electronics, which combines a motor controller, inertial measurement unit and various interfaces for additional sensors. The slave has three external connections, i.e., power supply and in/out EtherCAT communication ports. In this way, the actuation units form a distributed sensor and actuator network that allows flexible configurations and enables real-time control of the exoskeleton from a main computer at the trunk of the pilot.

4 Specifications

At time of writing of this article, manufacturing of the device is not finished and basic functional test have been one with a test joint. The specification in Table 1 are preliminary.

5 Conclusion

This paper showed and overview of a newly developed exoskeleton for knee and ankle support of SCI subjects. In an effort to get the best fit between the exoskeleton and subject in a simple and lightweight manner, multiple component sets tailored to fit all subjects in the test-group are made.

The modular design of the exoskeleton enables a flexible configuration and easy doing on and off the device. Thanks to the modular actuation unit, future extension of the exoskeleton to the hip and trunk is also made relatively simple.

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