XoSoft - Iterative Design of a Modular Soft Lower Limb Exoskeleton

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Abstract. XoSoft is a modular soft lower-limb exoskeleton to assist people with mobility impairments. Being a modular system, it comprises of ankle, knee and hip elements, which can be used in different configurations. XoSoft follows a user centered design strategy achieved by involving primary, secondary and tertiary end users as participatory stakeholders in the design and development process. This paper presents the evolution of the different prototypes developed during the project, as well as the testing stages. From the Alpha prototype, built from available technologies, to the Gamma prototype, which includes advanced textiles technologies, smart materials for sensing and actuation, biomimetic control and connected health monitoring and feedback system.

1 Introduction

The proportion of the world's elderly population is expected to reach 2 billions by 2050 [1]. Many elderly experience varying degrees of mobility impairment, due to decline in voluntary muscle strength. For this reason, remaining active and mobile during ageing is crucial to overall health and cognitive function [2]. Consequently, assistive devices play a pivotal role in their lives and impact on their ability to live independently and perform basic tasks of daily living. However, many assistive aids, such as powered wheel chairs, do not encourage or support activation of legs.

Mobility assistance is also required by patients, such as stroke sufferers or patients with incomplete Spinal Cord Injuries (SCI). Globally circa 16 million people per year experience a stroke for the first time, of which 5 million experience varying degrees of mobility difficulty, which significantly impacts their ability to perform tasks of daily living. SCI lesions are mostly caused by accidents, of which about the 51% are incomplete, i.e. the person is partially disabled [3]. Patients with an incomplete SCI do not suffer complete loss of sensory-motor function in the lower limbs but they may still require assistance to walk.

XoSoft is an EU project that is currently developing a soft lower-limb exoskeleton to assist people with mobility restrictions due a partial loss of sensory or motor function. Typically, the existing exoskeletons have a rigid structure

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that is heavy weight and bulky [4]. Following current trends [5,6], XoSoft has a flexible and adaptable structure [7]. The proposed system is not intended to substitute complete loss of function like already existing exoskeletons, but rather assist the user in a tailored manner. In order to reach this goal, the prototypes are based on smart soft robotics, biomimetic controlled actuation and connected health data feedback and interface.

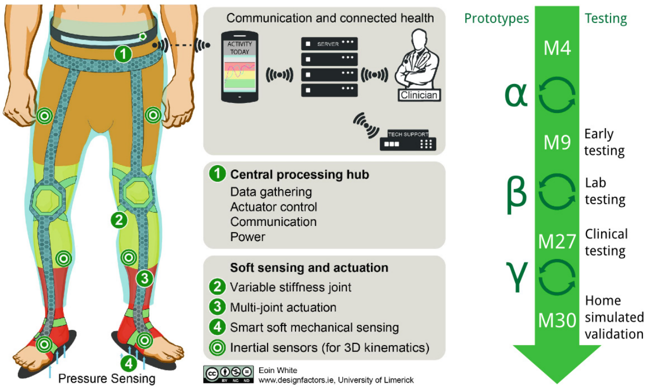

Fig. 1. XoSoft concept, evolution of the prototypes and testing stages during the project, following the UCD approach.

2 System Development

2.1 User Centered Design

A core feature of XoSoft is that it follows a User Centered Design (UCD) approach [8] as shown in Fig. 1. UCD employs design ethnography and participatory stakeholder involvement as key drivers for the technology development to ensure user needs are at the forefront XoSoft's development [9]. As a starting point for the technical developments, an Alpha prototype was built using off the shelf components. This prototype consisted in a series of independent modules divided in two categories: hard and soft. All the modules were developed with the main purpose of understanding the requirements of the following prototypes, simulating or replicating the desired functionalities using alternative available technologies. The Alpha prototype lied the foundation for the development of three versions of XoSoft, which are identifiable based on the module and subsystem developed, as described in the following subsections.

2.2 Beta 1 Prototype

The Beta 1 prototype was the first full prototype using novel technologies and actuation principles. Regarding the actuation, different technologies were evaluated: (i) variable stiffness based on Textile Jamming (TJ) [10]; and (ii) quasi-passive actuation based on elastic bands and clutches. The quasi-passive actuation was implemented using commercial electromagnetic clutches transmitting the motion to the elastic bands through a bowden cable. The selection of the actuation arrangement was based on the optimization method described in [11], including actuation for the hip and knee flexion only in a single mode configuration. This prototype included a first version of the textile based knee brace using soft capacitive sensors [12] for the measurement of the joint angle and a sensorized insole with embedded FSR sensors for the identification of the walking gait. The garment was built using commercial textiles with inelastic reinforcement bands to transmit and distribute the assistive forces.

2.3 Beta 2 Prototype

The main technological upgrade of the Beta 2 prototype was the substitution of the commercial electromagnetic clutches by novel custom made soft clutches based on similar pneumatic principles of TJ, but functioning as a linear clutch. They were integrated in series with the elastic bands providing assistance to the hip (flexion and extension), knee (flexion and extension) and ankle (dorsi and plantar flexion). The modular design of this prototype allowed to reconfigure the system to accomodate different patient profiles, allowing a maximum of 8 simultaneous actuators (clutches). This prototype was also equipped with IMU sensors for the measurement of the joint angles, besides the insole FSR sensors and soft capacitive sensors already integrated in the Beta 1 prototype.

2.4 Gamma Prototype

The final prototype developed in the project is the Gamma prototype and it includes all the features of the previous prototypes. Most of the components have been improved with respect to the Beta 2 prototype, including a completely new design of the garment, which improves significantly the wearability. The actuation has been limited to 6 simultaneous actuators in order to reduce the weight and energy requirements. The control is able to work with both the capacitive soft sensors integrated in the garment and the IMU sensors. Finally, the monitoring and feedback system, and the offline activity and task recognition are being integrated into the system.

3 Testing and Validation

3.1 Laboratory Testing

The testing protocol defined at the early stages of the project was executed during the testing of the Beta 1, Beta 2 and Gamma prototypes in a laboratory environment. The purpose of this feasibility study was to understand the impact of the exoskeleton on different biomechanical aspects (such as gait improvement) and overall system performance and ergonomic aspects. The Beta 1 prototype was tested with one post-stroke patient, the Beta 2 with four subjects with different conditions, and the Gamma will be tested with at least four subjects.

3.2 Clinical Testing

The Beta 2 prototype is being tested in a clinical environment with elderly people. The main purpose of this testing is to gather information about the use of the system in a rehabilitation environment and to collect feedback from primary users. The number of participants is estimated to be between 10 and 15.

3.3 Home-Simulated Testing

Finally, the Gamma prototype will be tested in a home simulated environment to understand the performance of the system in daily live activities. Between 10 and 15 incomplete SCI and stroke patients will participate in the trials.

4 Results and Conclusions

This paper describes the different prototype stages of the XoSoft project. Each prototype presents a different evolution of the technologies developed during the project. Each prototype is tested in laboratory conditions, including a validation of the final prototypes in clinical and home simulated environments. Preliminary results of the Beta 1 laboratory testing with a post-stroke patient [13] show that the proposed system provides a positive assistance to the users in terms of gait performance during straight walking. Further studies are being conducted in order to quantify the effects with different subjects in several tasks and conditions.

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