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Symbitron: Symbiotic Man-Machine Interactions in Wearable Exoskeletons to Enhance Mobility for Paraplegics

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Abstract. The main goal of the Symbitron project was to develop a safe, bio-inspired, personalized wearable exoskeleton that enables SCI patients to walk without additional assistance, by complementing their remaining motor function. Here we give an overview of major achievements of the projects.

1 Major Achievements

The highlights of the Symbitron project are summarized below. For pictures and movies we refer to the website: https://www.symbitron.eu

1.1 Symbitron Framework

The different components of the Symbitron framework will be discussed below:

1.1.1 EtherCAT

As was already decided in the first year of the project, the real-time control of the Wearable Exoskeleton will be done using EtherCAT. In this way we can easily

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combine several modules (EtherCAT slaves), which is according to our goal of developing a modular system. Furthermore, it contributes to the requirement of a minimal wire solution for the wearable exoskeleton.

The main etherCAT slaves (stack) are placed in the backpack of the exoskeleton together with the pc that runs the different models for the control of the EtherCAT slaves.

Some off-the-shelf EtherCAT slaves could be used (e.g. for the motor control), but also during the course of the project, some EtherCAT slaves have been developed/built for specific hardware components of the wearable exoskeleton.

1.1.2 EtherLab and Symbitron Wiki

To control the EtherCAT slaves in real-time, EtherLab in first instance has been selected as the EtherCAT master, because it is open-source and easily communicates with the hardware and the Matlab Simulink control models.

The installation of EtherLab was not described extensively anywhere, therefore a master student and some Symbitron members went through all the installation steps and have documented the required steps and especially the problems they encountered. The resulting installation manual has been put on the Symbitron wiki (www.symbitron.eu/wiki) to easily share it with the other Symbitron members, but also to share it with other people who want to use EtherLab. The Symbitron wiki is therefore open for everyone, but editing is only possible after creating an account with permission of the website manager. The Symbitron wiki shows up in the first hits on Google when searching for “EtherLab” and is the first hit when looking for “Etherlab installation”.

1.1.3 Simulink Libraries and GIT Repository

To control the different slaves, Matlab Simulink models are being used. For each EtherCAT module a Simulink library block has been created. These blocks can be directly inserted in a Matlab Simulink model and by putting the correct slave number in the blocks the data from the blocks can be read out or data can be sent to the slaves.

To be able to (1) share the different Simulink models among the consortium, (2) to be able to use them on different pc’s (development pc and control pc) and (3) to have version control, a Symbitron GIT repository is being used. This GIT repository is being stored on Bitbucket. Bitbucket not only provides the hosting of the repository, but also allows for issue tracking for every project. The Symbitron repository is only open for Symbitron members or on request.

1.2 Symbitron Measurement Week

Ten symbitron test pilots came over from Rome to Enschede (UTwente), which required a high level of organization. During the whole week, three different measurement setups have been used:

1. The LOPES is installed at the lab of the Biomechanical Engineering group at UTwente. For the LOPES experiments an 8 channel Delsys EMG system was used for EMG measurements. Data from the LOPES (angles, velocities, interaction forces, etc.) and the EMG system were synchronized and stored on a measurement pc.

2. The Achilles experiments were performed on the instrumented treadmill that is installed in the lab of the Biomechanical Engineering group at UTwente. The instrumented treadmill is equipped with handrails and a safety harness is used to ensure the safety for the patients. The Achilles (the motors to provide the torque around the ankle) has its own control pc that works via EtherCAT and EtherLab. This pc is also used to read out the data from three IMU's that were placed on the trunk and the upper and lower leg. An 8 channel Porti EMG system (TMSi, the Netherlands) was used for EMG measurements and data was captured and stored on a separate laptop. Motion capture data was collected by using the Visualeyez system with four cameras, four wired markers on the knee and ankle joints and several marker clusters on different body segments. The marker data was also collected on a different measurement pc.
   The last measurement pc was used to control the Pusher device that was used to provide the perturbations at trunk level to the subjects and to measure the force data from the force plates of the instrumented treadmill. From this pc also a synchronization signal (random signal) was sent to the Visualeyez pc, the EMG pc and the Achilles pc.
3. The spasticity measurement setup consisted of a bed, which could be adjusted in height, where the subjects could lay down and the legs could be freely moved by the experimenter in different angles and at different speeds. 3D-printed handles with incorporated force sensors were used to move the legs. These handles were made of thermoplastics, which allowed for a custom fit for all subjects. Besides force data, also EMG data was collected via an 8 channel Delsys EMG system and Xsens IMU's were used to collect data of the leg movements.

1.3 The Symbitron Modular Exoskeleton Hardware and Software

Mechanical engineers from TuDelft and electrical engineers from the UTwente with support from Ossur made a considerable effort to design and realise the WE1 and WE2 prototype. We developed a lightweight (1.5 kg) powerful universal joint that is connected with a personalised structure. The exoskeleton can be used in different configurations, like ankle only, ankle and knee, and ankle-knee-hip. All configurations can be used for one leg or both legs. The Software automatically recognizes the hardware configuration.

1.4 Successful Clinical Training and Evaluation with SCI Test Pilots

The extensive clinical training and evaluation with the SCI test pilots showed that symbitron hardware and software could be personalised to the size of the different test pilots and to specific capacities and characteristics of our test pilots. With the biological inspired controllers all incomplete SCI subject could walk, and they improved their walking speed and/or balance during training with the Symbitron devices. A combination of a biological inspired ankle controller and trajectory control at the knee and hips enabled two complete SCI subject to walk again. Psychometric test showed that Symbitron technology was well received by test pilots, and they remained all motivated to use our devices.

2 Final Results and Their Potential Impact and Use

After more than 4 years of research we have developed a modular exoskeleton that can be modified to the size of different subjects wearing the device and their capacities. The unique modular design allows different configurations: only ankle support, ankle-knee support, or ankle-knee-hip support. It is also possible to support only one or both legs, which might be interesting when used by stroke survivors. This mechanical modularity makes it possible to adapt to hardware to the specific needs of its user. Also the electronics and software is modular. Using Ethercat the software automatically recognizes the hardware connected to it. Also the software was build in such a way that within a few seconds it can be adopted to the configuration it is connected to, by simple toggle on or off some software modules.

In the Symbitron project we included incomplete SCI subjects that needed only support at the ankle, or at the ankle and knee and complete SCI subjects that needed full support of both legs. Clinical tests showed that hardware and software could be adjusted to the specific characteristics of these subjects, which provided a proof of the feasibility of the unique Symbitron approach. The control of the devices was biologically inspired and rendered muscle and reflex dynamics on the exoskeletons legs. In Symbitron we were the first to implement this successfully in wearable exoskeletons, and we were also the first to apply this biologically inspired neuro-muscular controllers to multiple joints on a wearable robot. The clinical tests with SCI subjects proofed the feasibility of this approach, and showed that in contrast to conventional approaches it allows for gait patterns that are variable (in term of speed and step length).

Although the clinical results are still preliminary, the chosen approach is promising, in particular for incomplete SCI subjects or similar patient groups who have some remaining function left. We showed that during training with the Symbitron devices incomplete SCI subjects improved walking speed and/or balance. In some cases also a rehabilitation effect was seen, i.e. they improved their function during training with the Symbitron devices even when they did not use the device. Psychometric test also showed that the test pilots were very motivated and satisfied using the devices.

In conclusion, the Symbitron approach exploiting modularity of hardware and software and biological inspired control, has potential in supporting incomplete SCI subjects but also stroke survivors during rehabilitation and as an assistive device.

The Symbitron hardware and software will be re-used in a national Dutch Wearable Robotics research program that will start August 2018, and which involves 5 universities and more than 20 companies and end-user organisations. The Symbitron technology will also be used and further developed in the Symbitron$^+$ team that will compete in the Cybathlon 2020 competition in Zurich.