Open and scalable trajectory-based exoskeleton control system architecture

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1. Introduction

Due to the growing amount of elderly people in populations of the developed countries, dysfunctions of the locomotion system are a common and serious problem. Young people are also affected to diseases such as spinal cord injury, cerebral palsy or multiple sclerosis. Lower limb exoskeletons are viewed as a potential tool for restoring at least partial movability of mentioned patients. In addition, exoskeletons can be used as a rehabilitation apparatus, partially or fully replacing the work of physiotherapists [1].

2. Objective of the study

The scope of the study was to develop a hardware and software platform for controlling a lower limb exoskeleton. The aim was to build a system, which would allow for controlling the machine in different configurations dictated by current research needs, such as independent control or human force-amplification. Even though the exoskeletons are a research area which is currently being widely studied around the world, there is still a low amount of publications regarding details of their control systems. Many control strategies can be taken to account such as: a classic-error based regulator [2], finite state machines or signal threshold systems, neuro-fuzzy systems [3], and systems which are based on a model of movement trajectories, which are either real [4] or analytically created [5]. It was decided that a trajectory-based architecture will best satisfy the needs of the project. Such trajectories were obtained during earlier research.

3. Results

Due to parallel development of the construction of the exoskeleton and the control system, the controller had to be open for addition of new features, the platform had to be scalable, and the logic had to be completely moved to the software domain. Therefore, it was decided that the controller should consist of an expandable set of slave modules, which are all managed by one master processing unit via a high frequency I2C protocol. The platform consists of the following modules: a processing unit - an ARM microcontroller working as the master unit; HMI - a human-machine interface, composed of a LCD screen and several input and output devices; expanders - each of them allows to control 4 additional stepper motors; sensors - any needed sensing devices can be added to the I2C bus. The proposed structure of the architecture is presented in Fig.1.

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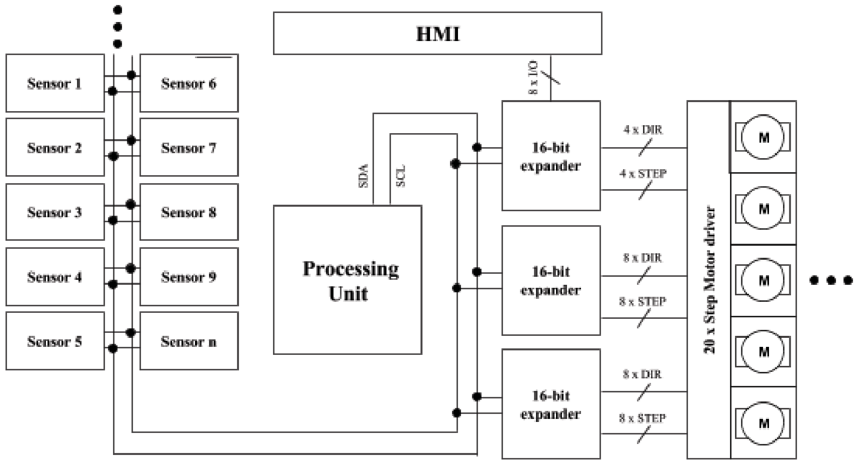

Fig. 1. System architecture

The exoskeleton's ability to follow a required path is the main functionality of the control unit, therefore it had to be reflected in the software architecture. The trajectory model is an array of 10 trajectories, each of them is again an array of 1000 control points, which describe the whole gait cycle. 10 trajectories correspond to the 10 driven joints. As previously mentioned, the control system is trajectory based. Experimentally obtained real gait trajectories were post-processed and standardised to a form, which can be directly fed to the controller's gait model. This step includes not only mapping of both trajectories, so that the number of samples would be identical, but more importantly it required to close the trajectory loop over one full gait cycle described in a phase domain instead of time. The transformation required some degree on manual approximation, as single human gait cycles are never identical, and therefore, the starting and ending positions normally are not exactly the same.

The main functional module of the software is the path-follower block, which is continuously tracking both the trajectory model and the real exoskeleton kinematic configuration. The path-follower is activated in every control point in which it calculates the difference between the current real state and the required model state for each joint independently. Speed of the gait can be adjusted by changing the time interval between control points. In order to reduce latency and jitter in the response of single drives, the dispatcher module slices the movement job of each joint into small increments and executes all moves for all joints sequentially in a fast loop, creating a quasi-concurrent effect of movement. It was proven that the latency achieved is not noticeable during normal-speed gait cycles and that the model-trajectory is being followed correctly.

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