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# Prediction of movement for adaptive control of an upper limb exoskeleton

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## 1 Introduction

In the last twenty years, exoskeletons or wearable robots have made a huge development, having a strong impact on areas such as patient rehabilitation [1]. A more recent trend is the use of exoskeletons for the prevention of diseases or injuries - especially of a musculoskeletal nature - of workers in industry. In this field of application, it is important to create a cost-effective design to make exoskeletons affordable for smaller companies and thus make them accessible to a large number of users. In addition, the weighting of requirements known from medicine also differs for healthy users, and new demands arise.

One of the most important requirements for an exoskeleton for healthy users is to minimize – ideally eliminate – latencies between the movement of the user and the adequate reaction of the exoskeleton, to maximize user acceptance. These latencies are inherent to classical approaches to control exoskeletons using kinetic or kinematic data. New approaches like predictive filtering or the exploitation of physiological data – especially the electromechanical delay (EMD) [2] – could lead to a prediction of the user’s intended movement and thus contribute to the improvement of control.

Here, we show concepts to realize a movement prediction and an adaptive controller using multiple sensors in an own simple upper limb exoskeleton. All considerations are made with regard to biomechatronic knowledge and design [3].

## 2 Design of the control architecture

### 2.1 Basic concept

The basic concept of an adaptive controller for an upper limb exoskeleton with a prediction of movement – at least the intention – is given in Figure 1. This concept serves as a guide to realize different steps of implementation as well as for the establishment of different hierarchy levels in the final control. Plausibility tests can be performed between the layers, and fallback levels can be defined to increase safety for the user in case one or more layers fail or produce wrong data. In this concept, several known sensor systems are used partial redundantly for different purposes.

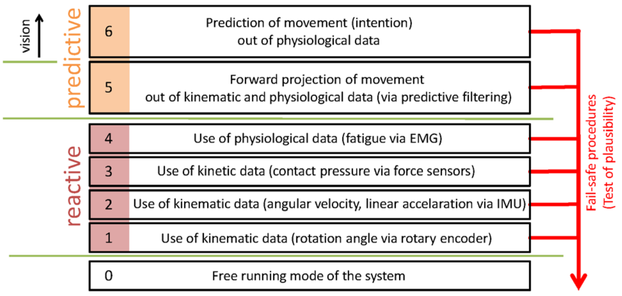

**Figure 1:** Concept of an adaptive control for an upper limb exoskeleton based on a reactive part of the control and leading to a predictive element.

For this control architecture, a lightweight exoskeleton is assumed (cp. Chapter 3). In case of emergency or complete loss of sensor data the system is supposed to be in a free running mode. This denotes that no actuator or support structure is restricting the movement of the user in a way that he cannot bring himself to safety under the weight of the exoskeleton with his own power.

### 2.2 Reactive control

Layer 1 to 3 of the control architecture (cp. Figure 1) utilize well-known sensor systems like rotary encoders, inertial measurement units (IMU) or force sensing resistors to gather kinematic and kinetic data. These can be used directly for position- or torque-controlled systems (cp. [4]) especially when latencies of the system are not a concern.

Each individual sensor system contains shortcomings, such as drift or cross sensitivity. Furthermore, because of a higher degree of freedom and the natural tilt of the helical axes it is difficult to describe a biological joint compared to an artificial joint. To compensate these redundant inputs are used.

The use of physiological data in layer 4 allows the first step of motor adaption of the system on a sensory level. Electromyographic information (EMG) can be used to make a statement about the user's fatigue and adapt the system to his current physiological disposition.

## 2.3 Predictive control

The primary goal of the predictive control (cp. Figure 1) is to minimize latencies between the reaction of the exoskeleton and the user's intended movement. Even small latency might give the user the feeling that the exoskeleton is working "against him" and will reduce user acceptance. One way to reduce latencies is to use predictive filtering of the present data to project the movement (intention). In combination with learning systems, and under the assumption of ballistic movements, this might work especially for distinctly repetitive tasks.

Prediction of the movement or at least intention to move can be determined from physiological data. Based on the EMD and other physiological characteristics distinguishable activation patterns can be found in EMG before the movement begins [5]. Time spans up to 100 ms and more seem realistic, which could be used to process the information, activate the actuators and perform the movement of the exoskeleton in time with the user's movement. Figure 2 shows exemplary data, in which the angular change in the elbow joint is predicted from EMG signals of *M. biceps brachii* and *M. triceps brachii*, using low cost MyoWare™ muscle sensors as well as an adaptive noise canceling filter. Prediction times of 20 ms were achieved with a coefficient of determination $R^2$ = 0.8698 to 0.8940, depending on the load applied.

## 2.4 Status controller

To maximize the flexibility and adaptivity of an exoskeleton, status controllers can differentiate between various use cases of the exoskeleton, depending on the state of movement as well as the estimation of muscular forces and load (cp. Figure 3). Related to the current static or dynamic situation, different sensory inputs, sensor fusion algorithms or control strategies can be used to optimize the functionality of the exoskeleton. The design of such status controller should be done in regard to the computing effort. Thus, the different use cases have to be described as well as possible.

## 3 Design of an upper limb exoskeleton

A specific exoskeleton to assist just elbow flexion and extension was developed to test the different concepts described. The development was carried out under the aspect of costs as well as flexibility as a test platform.

The exoskeleton consists of a modular support structure. A combination of c-cuffs with elastic hook-and-loop fasteners was used in the first iteration to allow easy assembly. Sensorized cuffs to measure contact forces are under development. The exoskeleton is driven by two antagonistic servo motors connected via Bowden cables to the artificial joint of the support structure. Two separate IMU connected via Bluetooth® Low Energy, a Hall sensor as well as two MyoWare™ muscle sensors attached to the skin above *M. biceps brachii* and *M. triceps brachii* serve as sensor inputs. Different microcontrollers taken from the Arduino® family as well as MATLAB® are used for data acquisition, processing and control of the actuators.

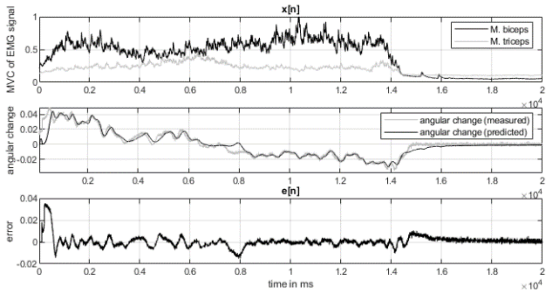

**Figure 2:** Detection of angular motion of the elbow joint using electromyography (EMG). Top – EMG signal of *M. biceps* and *M. triceps brachii*, normalized on the maximum voluntary contraction (MVC). Center – Angular change in the elbow joint measured via digital goniometer and predicted from of the EMG signal. Bottom – Error between measured and predicted value of the angle change

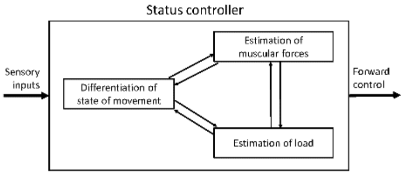

**Figure 3:** Concept of a status controller. Multiple and redundant sensory inputs are used to estimate muscular forces and load as well as to differentiate between various states of movement, to set parameters of a consecutive forward control

## 4 Conclusion and outlook

The use of multiple sensory inputs in combination with predictive filtering as well as a status controller is a promising way to increase adaptivity and flexibility of exoskeletons. Furthermore, new approaches exploiting the EMD could lead to a minimization of latencies between user and exoskeleton movement by motion prediction. In this paper, different concepts and preliminary results were shown, which need to be developed and tested continually in the future.

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