The English Abstract of the PhD thesis - Artur Gmerek

Optimization of the design and control of an upper limb rehabilitation robot with the use of biofeedback

The aim of this doctoral dissertation was to confirm three rehabilitation robotics theses. The first thesis was linked with the optimization of an upper limb rehabilitation robot design. Two remaining theses were associated with the use of bioelectric signals to control robots. Especially the EMG signals were talking into considerations.

Research led to the creation of two upper limb rehabilitation robots and a spatial goniometer. Experiments linked with the robots required the development of technology "from scratch", including the mechanical structure, as well as the electronics and software for low- and high-level robot control.

The main robot, which was called "Arm Rehabilitation Robot" consists of 7 active degrees of freedom. The robot consists of three main parts: the base, the 3-D linear gantry system and the orthosis, which is the most important part of the mechanical structure. An upper limb of a patient can be placed in the orthosis in order the robot to assist patient in various movements.

The experiments connected to the mechanical structure inter alia led to the conclusions, that the joints of the robot should be compliant and reversible. There were proposed a view constructions, which took into account those considerations.

The control system of the main robot is based on a number of cooperating programs, including, inter alia, a virtual reality module, admittance driver, as well as a biofeedback system which utilizes electromyographic signals. The admittance controller allow the first joint of robot to be driven in complain framework of operation and the biological loop allows a patient to control the robot, even if he or she is only able to slightly tighten his or her muscles.
The indirect aim of the project was to develop an automatic rehabilitation system. Electromyographic signals carry information that make this possible, as they determine the activity of motor units from which one can determine muscle strength, muscle fatigue and even estimate the position of the patient’s limb. New electrodes had to be developed in order to effectively utilize myopotentials to control a robot, as well as new methods of signal processing that were capable of estimating the patient’s key parameters. The problem with analyzing bioelectric signal is that the signals from different muscles superpose with each other, so one has to use some of sophisticated methods in order to map the EMG signal.
to the parameters like activation of motor units or force produce by the muscles. There were used methods based on signal classification, as well as methods based on parametric identification of linear models (in case of force and fatigue estimation).

Also an optimal vector of features describing the activity of the shoulder and arm muscles had to be extracted in order to meet these requirements. The highest accuracy was linked with LPC coefficients. Two parametric models describing muscle strength and fatigue were also developed.

The conducted experiments made it possible to prove the 3 theses and also to establish further fields of scientific exploration and to draw conclusions for future robotic rehabilitation designers. Among the described applications, guidelines concerning the design of robot control systems and sample CAD models of new rehabilitation robots could prove to be especially useful.

Fig. 2 The general view of created mechanisms