Development of an intelligent therapy monitoring system for home-based measurement of physical activity, knee joint kinematics and muscle activity

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Abstract

Recording of physical activity, joint motion and spasticity of lower extremities are of clinical interest for the evaluation of therapy effectiveness for patients with neuromuscular disorders suffering from spastic paresis and gait abnormalities. Fluctuations of the patient's medical state, which occur during the course of a day, cannot be captured during scheduled examinations from the physician or physical therapist but might have huge impact on the patient's mobility, social interaction and quality of life. Therefore, we present an intelligent assistant system for the improvement and long-term monitoring of therapeutic interventions of such patients suffering from spastic paresis.

1 Introduction

Patients with neuromuscular disorders originating from stroke, multiple sclerosis, cerebral palsy or other central lesions often develop spastic paresis of their extremities, which has a huge impact on their quality of life [1]. Ashworth scale and modified Ashworth scale are preferred measures for muscular resistance to passive movement and description of spasticity in the clinical setting [2]. Since these assessments are limited to single time points in a controlled examination environment, they cannot describe the high variability of spasticity during the course of a patient's day [3].

Therefore, the aim of our work is the development of an intelligent assistant system for the improvement and long-term monitoring of therapeutic interventions of patients with neuromuscular disorders. The system NASFIT consists of a novel soft orthotic component and a sensor system for the assessment of therapy effectiveness and quality of life by monitoring physical activity, joint motion as well as spasm intensity and frequency over the course of at least seven consecutive days [4].

2 Methods

The NASFIT system consists of two motion sensor nodes, which are integrated into a soft orthosis. Both nodes contain three axial accelerometer, gyroscope and magnetometer sensors and are worn laterally at the patient's upper and lower leg. Muscle activity is recorded for the main agonist and antagonist muscles, i.e., M. rectus femoris and M. biceps femoris by means of a two channel bipolar electromyography (EMG) system. A Cortex-M4 microprocessor manages both sensor nodes and the EMG unit. It gathers and stores respective sensor data continuously on a micro SD flash memory card. Battery power supply, EMG unit, Cortex-M4 and data storage are contained in the same housing, which is worn on the patient's belt. The system application is shown in Figure 1. The patient does not need to interact with the monitoring system at all, except for changing the battery once during a recording period of seven days. However, the patient is asked to signal moments of interest, i.e., spontaneous muscle spasms by pushing a user button on the main unit.

The recorded data is processed by custom analysis software after the measurement is finished. Physical activity is categorized into the classes lying, sitting, standing, walking and corresponding transitions using a Support Vector Machine combined with a Hidden Markov Model. The knee joint angle is calculated by machine learning methods in combination with a kinematic model. The detection of muscle spasms will be based on the recognition of EMG characteristics and activity patterns [5].

During development of the monitoring system knee joint motion and EMG data have been recorded in a laboratory setting with healthy subjects and multiple sclerosis patients using available commercial sensor systems (XSens and Noraxon EMG) for training, testing and optimizing the evaluation algorithms (Figure 2). Subjects were asked to perform short and simple tasks in their natural manner simulating daily activi-

ties. Execution of those tasks was recorded using a video camera, which was defined as ground truth for physical activity categorization [4].
The NASFIT system is being tested and optimized for system stability and applicability in long-term measurements by healthy subjects. Ground truth for activity classification during this period is recorded and verified using activPAL sensors. Joint kinematics and muscle activity is evaluated in a laboratory setting using motion capturing systems (Vicon and XSens) and EMG (Noraxon).

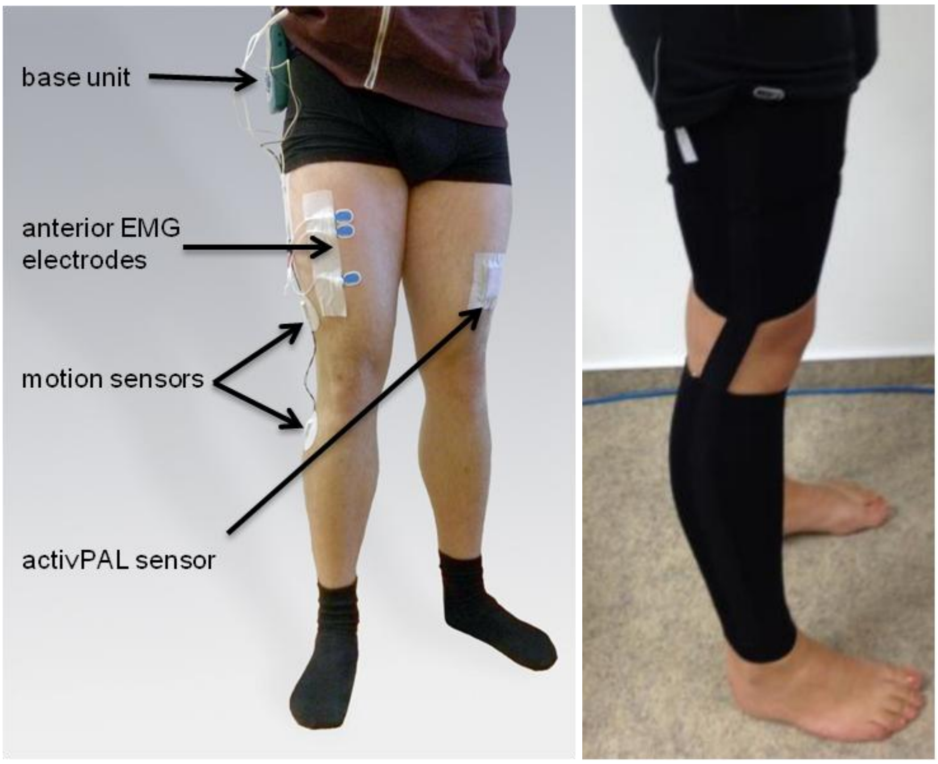

Figure 1: Monitoring system components without orthosis (left) and integrated into a soft orthosis (right).

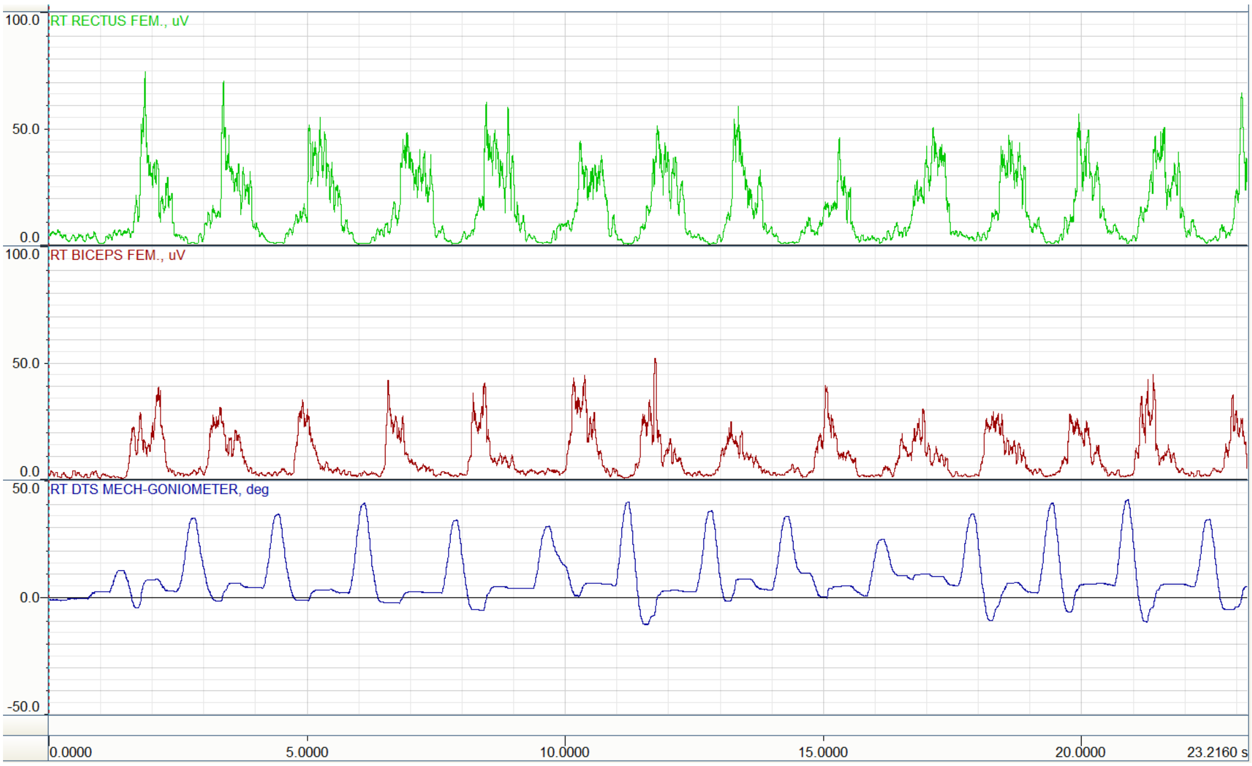

Figure 2: Low pass filtered and rectified EMG signals: M. rectus femoris EMG (green); M. biceps femoris EMG (red) and knee joint flexion angle (blue) from a multiple sclerosis patient during a 25 foot walk test.

3 Results

Preliminary results from the laboratory study show an accuracy of 94.6% and a precision of 93.7% for the classification of physical activities and corresponding transitions (Table 1). Calculation of the knee angle shows a mean squared error of 6.95° with machine learning methods and 5.05° using the kinematic model. Currently, there is no data for the detection and quantification of spontaneous muscle spasms because no such events occurred during our preliminary laboratory testing protocols with multiple sclerosis patients.

Table 1: Confusion matrix for physical activity classification.

		prediction			
		stand	walk	sit	lie
truth	stand	**23614**	415	265	0
	walk	995	**16790**	0	0
	sit	98	0	**98359**	975
	lie	0	0	591	**15308**

4 Discussion and Conclusion

The presented monitoring technique, altogether with a newly developed soft orthosis forms an intelligent assistant system for improving and monitoring the therapy of patients with neuromuscular disorders.
Despite the huge variability of commercially available monitoring systems which cover different ranges of functions and outcome measures [6], there is no system currently available which offers comparable functionality for long-term recording in the home environment.
Preliminary performance for the evaluation of physical activity and knee joint motion with the NASFIT system meet the requirements which were defined by physicians and health professionals as part of the project consortium. Since we decided not to deliberately induce muscle spasms in patients included in our laboratory setting, the detection and quantification of muscle spasms by analysing muscle activity and limb motion with our algorithms could not been evaluated so far. Therefore, a therapy monitoring study including patients with neuromuscular disorders and spastic paresis is under preparation. Ground truth for spasm detection in that study will be the patient's manual activation of the user button for signalling periods of interest.

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