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Wearable sensor-based motion analysis and recovery trend quantification in hemiparetic patient in free-living

Abstract: Wearable sensors offer potential for ubiquitous monitoring application and the digitalisation of healthcare. In particular, in stroke rehabilitation, wearable sensors are increasingly used to derive clinical relevant insights. Especially, for longitudinal, remote monitoring applications in free-living, wearable computing could lead to new health knowledge. Patients, clinicians and insurers could benefit from knowledge gained by data extraction and analysis from wearable sensors using machine learning. In this thesis we investigated methods for unsupervised motion data extraction and analysis in free-living to predict clinical scores, and evaluated recovery trends to derive insights in stroke rehabilitation. We showed how ubiquitous wearable computing, could be used for continuous, objective movement quantification, to devise clinical relevant health recommendations in free-living.

INTRODUCTION

Wearable computing has become an ubiquitous technology in recent years, thus enabling digitalisation of personalised healthcare to improve health and well-being. In particular, digitalisation is beneficial for patients, clinicians and insurers to derive clinical relevant information, devise therapy strategies and provide health recommendations. Moreover, patient-monitoring and recovery trend estimation in free-living becomes feasible. However, objective quantification and evaluation of patient-behaviour is challenging, especially for hemiparetic patients, e.g. after stroke, suffering individual functional limitations.

In this research we used wearable sensors, i.e. inertial measurement units (IMU) to monitor and describe patient behaviour, estimate clinical scores, compare body sides, and quantify recovery trends without specific tests or restricting patients daily life. So far, existing approaches presented, e.g. by Patel et al, van Meulen et al., to evaluate stroke patients' functional ability were limited to short measurement durations ranging from minutes to hours, and required patients to perform specific functional tasks. Stroke rehabilitation, however, is a gradual process over weeks, months, and even years, thus continuous, objective measurement methods and evaluation strategies are needed.

We focused on longitudinal measurements and monitoring of patients during activities of daily living using IMUs to investigate patients' recovery after stroke without specific test. In particular, comparing affected and less-affected body sides could reveal insights, enabling clinicians to devise targeted therapy recommendations and intervention planning. Our research and methods could influence future stroke rehabilitation research, rendering large scales studies in free-living feasible.

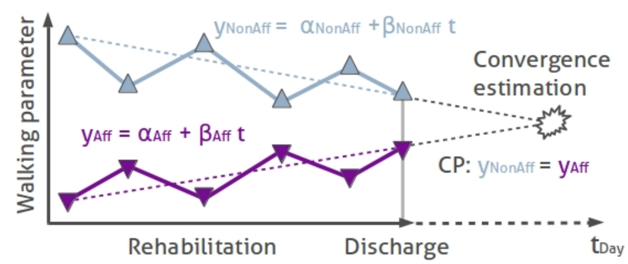

Fig. 1: Longitudinal convergence point estimation for recovery trend evaluation in hemiparetic patients using walking parameters.

In particular, we provide the following contributions:

1. We showed how clinical scores can be estimated without specific tests using unsupervised methods, thus demonstrated how our research could be applied in remote monitoring applications in free-living.
2. We analysed upper and lower body parts of affected and less-affected body sides, to gain insights in patients movement behaviour.
3. We demonstrated how ubiquitous wearable sensors could be used for stroke recovery evaluation and proposed convergence points and posture cubics as quantification metric.

METHODS AND EVALUATION

We designed and implemented an empirical observation study during November 2013 and May 2014 in the neurological day-care centre, rehabilitation clinic Rheinfelden, Switzerland. We recorded 102 full-day motion data, using six body-worn IMUs from eleven hemiparetic patients during their rehabilitation. We evaluated approaches for unsupervised activity primitive extraction from motion data and estimated clinical scores using machine learning [1].

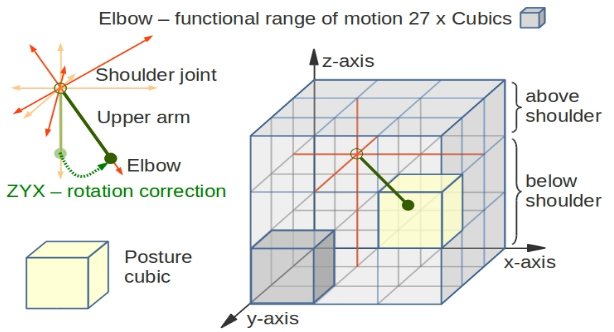

Fig. 2: Functional range of motion analysis off upper arms relative to the shoulder joint using orientation estimation and posture cubics.

We implemented a regression-based comparison of affected and less-affected body sides during walking, and analysed the functional range of motion using orientation estimation algorithms [2,3]. We developed and evaluated intuitive quantification metrics, including convergence points and posture cubics [2,3]. Figures 1 and 2 illustrate our metrics.

RESULTS

We demonstrated that wearable sensors are suitable to analyse motion data of hemiparetic patients in free-living. We showed that the Extended Barthel Index reflecting patients ability for independent living, could be estimated with an average relative error of 12.5% using subsequent support vector regression [1].

We further showed that walking parameters derived from thigh-worn IMUs were suitable for walking segment detection across patients with high inter-patient walking differences. Moreover, we derived average specificity above 94%, demonstrating that non-walking activities were excluded. However, our convergence point analysis revealed that patient-individual habits and therapy schedules, influenced walking behaviour, rendering trend evaluation challenging [2].

The functional range of motion analysis using our intuitive 3D posture cubic metric, showed that upper arm postures differ in affected and less-affected body sides, particularly between free-living and therapy. During free-living, postures below the shoulder were often estimated in both body sides. In contrast, during clinician guided therapy, postures including over shoulder movements were reached frequently, indicating patients' movement potential [3].

DISCUSSION

Wearable computing could enable digital healthcare. Our research, including wearable sensors and subsequent motion data analysis derived from hemiparetic patients revealed valuable insights in the stroke rehabilitation process and how a recovery trend could be quantified. The observation study in the day-care centre enabled data analysis and investigation of different approaches, useful to devise further research. In particular, the observation study, where no interventions were intended, and patients could follow their individual therapy programmes, real-life conditions patients will face after clinical rehabilitation were created. Hence, we believe our methods could be applied in free-living. For example, unsupervised activity primitive extraction could be used continuously to assess clinical scores daily at home [1]. Such continuous quantification renders personalised recovery trend evaluation over long measurement periods likely, hence predicting further recovery progress might be feasible. Walking segment extraction and walking parameter analysis could lead to better understanding of patients' mobility behaviour. Moreover, evaluating physical activity, to promote an active lifestyle by providing exercise recommendations and quantified feedback is an option [2]. Thus, health and well-being might improve. Beside patients and clinicians, health insurers could benefit from the patient digitalisation and the continuous behaviour information extraction based on wearable computing.

Although wearable sensors and computing render the digitalisation of healthcare applications feasible, how such applications generalise among hemiparetic patients or across different cognitive impairments, e.g. Parkinson's disease, requires further research.

CONCLUSION AND FURTHER WORK

We analysed stroke patients' movement data using wearable IMUs over several months and investigated recovery during free-living and therapies. We showed insights in patient behaviour, and confirmed published related work. However, recovery trend modelling and outcome predictions remain challenging. New simulation methodologies and synthetic sensor data analysis to complement real-life measurements, are currently evaluated. Simulation offer potential for novel analysis approaches and evaluation of machine learning algorithms without the need of laborious data recording. Functional limitations could be investigated, and no burden for patients and clinicians exist.

We are interested in collaborations with clinical partners, and researchers working in healthcare and rehabilitation related to neurological diseases, e.g. stroke and Parkinson's disease. Collaboration could include the development and evaluation of wearable computing systems integrated in ubiquitous accessory or clothes. Further approaches for personalised healthcare recommendations and feedback system are intended. Currently, we explore 3D-printing technologies and sensor-based human-computer-interaction using assistive robots. The project offers interesting challenges for students interested in systems engineering and the digitalisation of healthcare.

REFERENCES

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