Recognition of Low Amplitude Body Vibrations via Inertial Sensors for Wearable Computing

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Abstract. Pathological shaking of the body or extremities is widely known and might occur at chronic diseases e.g. Parkinson. The rhythmical shaking, also known as tremor, can be such intense that extremities are flapping. Under certain circumstances, healthy people also show a shivering and shaking of their body. For example, humans start to shiver whenever it is too cold or if feelings such as stress or fear become dominant. Some wearable devices that are in direct contact to the body, such as smartwatches or smartglasses, provide a sensing functionality of acceleration force that is sufficient to detect the tremor of the wearer. The tremor varies in frequency and intensity and can be identified, by applying detection algorithms and signal filtering. Former works figured that all endotherms show muscle vibrations. These vibrations occur in the condition of sleeping as well as when being awake, or in unconsciousness. Furthermore, the vibrations are also present when subjects are physically active, emotionally stressed, or absolutely relaxed. The vibration itself varies in structure, amplitude, and frequency. This paper shows that these muscle vibrations are measureable by acceleration sensors attached to the user, and provides an outlook to new applications in the future. It also proves that custom mobile devices are able to detect body and muscle vibration and should motivate designers to develop new applications and treatment opportunities.

Keywords: Activity monitoring · Inactivity · Acceleration · Sensor · Recognition · Wrist · Watch · Smart · Sleep

1 Introduction

Muscle activity is important for a variety of processes that take place in human organism. For instance, shivering is an unconscious movement of muscles to increase the core temperature for compensating heat loss. Other examples for body-controlled muscle contractions and vibrations would be the support of blood and liquid exchange in the vessels and cells. This influence of vibrations and oscillations was addressed by former work [1]. The effect of autonomous muscle activity is mainly visible at patients

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with disorders of the muscle function, e.g., Parkinson disease or cerebral palsy patients. Current technology in signal processing and sensor technics is able to detect pathological muscle activity that is not even visible to the human eye. Moreover, it is possible to measure that every muscle is vibrating, even if the person is calm or sleeping [2]. This paper proposes new approaches for detecting microvibrations in a mobile context for providing services in Wearable Computing, which are not only applicable for patients but also for healthy people. Therefore, new interaction concepts are presented as well as new measurement methods and hardware requirements are being discussed. Future work is then outlined as a motivation for researchers to explore the influences and dependencies of microvibrations on healthcare and other areas of application.

2 Related Work

In 1944, Rohracher [2] explored very low amplitude muscular vibrations in endotherm organisms. He was the first scientist to refer to these small amplitude oscillations as microvibrations. Rohracher used piezo-electric pick-ups to detect the muscular activity. With these also known as phonograph needle sensors, he detected vibrations that where present even in complete relaxation or sleep. Rohracher's research has shown that all endotherms generate these so-called microvibrations. Moreover, the vibrations could also be measured even one hour after the dead of the organism. Rohracher also measured variations in frequency and amplitude for different conditions, such as temperature variations. He pointed out that low temperature leads to an increasing frequency of vibrations. Marko [3] made microvibrations visible by magnifying them 400 times with a microscope. Pacela [4] evaluated five sensor technologies for the measurement of human body surface vibrations. Pacela used besides a non-contacting capacitance sensor a seismic (velocity) sensor, linear-variable-differential transformer sensors and a miniature accelerometer. A second kind of body vibration is the so-called tremor. Many works in the field of vibration measurement mostly refer to this as a pathologic body movement. However, Rohracher [2] has recommended differentiating between microvibrations and macroscopic tremors. He has pointed out that in case of healthy subjects, tremor only occurs in certain stimulus situations, such as excitement and coldness, whereas microvibrations occur constantly. Furthermore, he has pointed out that macroscopic tremor, that occurrs on patients with Parkinson's disease, disappears while sleeping or being in anesthesia.

Microvibrations in Current Research

Currently there are very few papers working on this topic. Recently, Bieber et al. [5] identified sensor requirements for measuring biometric data with accelerometers. They identified that accelerometers build in custom off-the-shelf hardware are able to measure data, such as heart rate. In this research a smartwatch was placed on the chest of a lying or sitting user and captured data for short periods of time (15–30 s). The resulting accelerometer data contained suitable heart rate information. The attempt of measuring the pulse frequency in absolute rest showed frequencies in the Fourier spectrum that where located clearly over pulse or breathing thresholds. These frequencies where identified as small vibrations that occurred even in total relaxation. The authors expect commercial smart devices (mobile devices with inertial sensors) to be capable to measure microvibrations.

Characteristics of microvibrations presented by Rohracher [2]:

- Frequency between 7 Hz and 11 Hz
- Amplitude in total relaxation between 1 to 5 micro meter
- During muscle contraction the amplitude increases to ten times the rest value
- During psychological tension and bodily strain, the amplitude increases
- During fever or hyperthyreoses the frequency increases up to 14 Hz
- While sleeping the amplitude decreases about half of its value in wakefulness
- Medication can lower the amplitude
- Even up to 60 min after death, microvibrations are still measureable
- Can be measured at any body-part
- Only present in endotherm organisms
- Constantly measureable

3 Example Implementation

This section proposes three ways of detecting microvibrations using gyroscopes or accelerometers. Therefore, three different positions had been chosen: (1) head placement, (2) arm placement, and (3) leg placement. To perform the measurements, the Invensense IMU-3000 gyroscope, which is built into the SensorTag from Texas Instruments [7], and the Kionix KXTi9 accelerometer of the TI MetaWatch Strata were used [8]. The gyroscope collects data with a resolution of 7-bit and a sampling rate of 100 Hz. The accelerometer was set to a 13-bit resolution with a sampling rate of 32 Hz. Both sensor boards are light and relatively small. After dismantling the MetaWatch board off its wristband, both devices could be placed at different body positions as illustrated in Fig. 1. For measurement at the head, the devices were simply attached to a pair of glasses. To perform the measurement at arm and leg, both devices were simply laid down, thus not being affected by static fixations (Fig. 2).

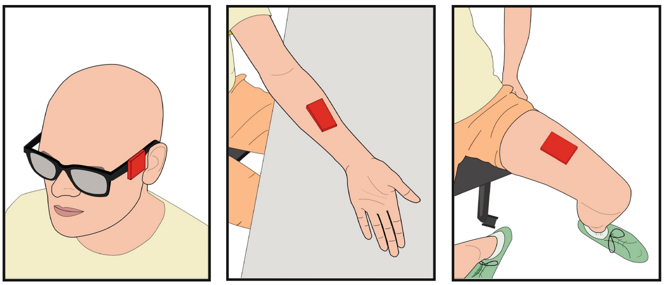

Fig. 1. Sensor positions for vibration measurement. The placement is directly on the muscle and without adjustment (except the head placement). Placement positions were: (1) head placement, (2) arm placement, (3) leg placement.

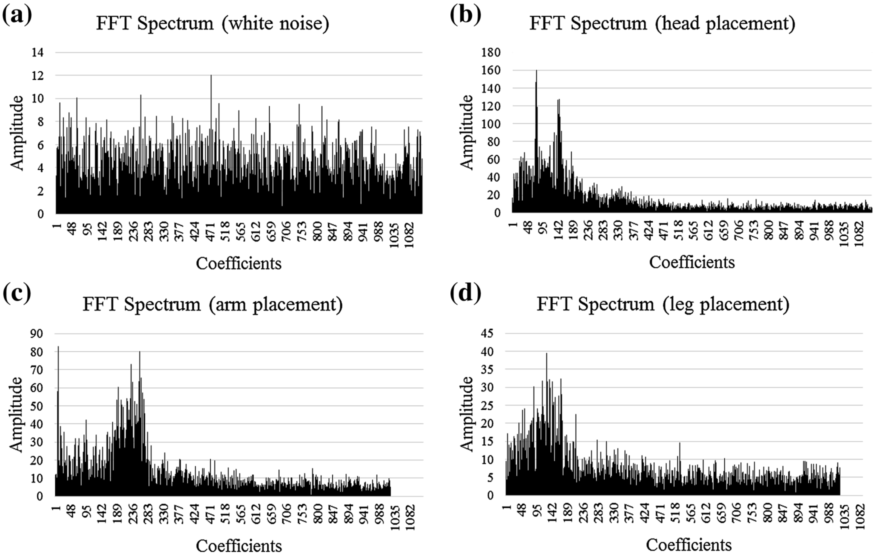

Fig. 2. Frequency spectrum of the gyroscope sensor data. Subfigure (**a**) shows a white noise. In this measurement setup the sensor was lying on a table. Subfigure (**b**) shows the frequency spectrum for a head placement. Subfigure (**c**) shows the frequency spectrum for an arm placement. Subfigure (**d**) shows the frequency for a leg placement.

To collect the sensor data, the devices were connected via Bluetooth to an Android smartphone. For this purpose a rudimentary app was implemented, which simply reads out sensor data and saves it into a CSV file. After that, the analysis of the raw data could be comfortably done. When the app was recording, the subjects were instructed to sit down, while being as calm as possible. To obtain the signal information and to calculate the frequency of each signal, a Fast Fourier Transformation (FFT) was performed on each sensor axis with 2048 samples. The signals provide different frequencies roughly between 4–11 Hz. The direct position of the body parts did not play a significant role. Nevertheless, the frequencies of the head are slightly lower than those of the other parts. After more tests, it could be shown that the head data was very similar, even by varying the recording setting, e.g., by lying down on the ground or by bracing the head onto the arm on a table.

4 New Applications

This section discusses new ways on how to integrate the recognition and assessment of microvibrations into new applications. The aim of these approaches is to measure microvibrations with off-the-shelf hardware such as smartwatches, to provide services to the user, which is derived off the vibration information.

On-Body-Detection
Wearable technologies are frequently used in medical applications. For instance, actigraphy or sleep recognition systems enable a measuring of human activity in activity-counts. These systems determine a sleep state, whenever the activity count falls below a pre-defined threshold. As a result of this, actigraphy systems often detect sleep whenever the hardware is doffed. To overcome this shortcoming, microvibrations can be utilized to detect whether the hardware is worn or doffed. Similar effects occur on fall detection systems and lead to unnecessary false detections.

Sleep Detection
Low microvibration signal amplitudes - in relaxation - could be used as a feature for sleep detection. The technology is suitable to improve the capability of detecting short periods of nightly awakenings. Moreover, most of the current actigraphy systems suffer of underestimating nightly awakening [6]. Recent research proves the feasibility of detecting the rapid eye movements (REM) sleep state via microvibrations [9]. Using our proposed system to improve the algorithmic detection of sleep could significantly gain better results in sleep recognition.

Weight Abatement
Fitness applications or other technologies try to motivate the user to lose weight. Physical activity is a major aspect in a successful therapy for patients for adiposity. Microvibrations are also a kind of muscle activity, and deliver valuable information on energy consumption. The progress in current technologies suggests that the inclusion of relevant features of the muscle microvibration could improve, or support a therapy for obese or overweight people.

Individual Medication
Microvibrations are depending on many parameters. However, current data gives rise to the expectation that monitoring these vibrations would possibly provide essential information on individual patients' drug dosage.

Anomaly Detection
Based on the knowledge of microvibrations, varying amplitudes in the state of unconsciousness possibly concludes to a better prediction of an anomaly for epilepsy patients or patients with narcolepsy. Therefore, wearable devices could be used to detect vibration amplitudes in a daily context for recognition of anomalies in sleep-like situations.

5 Conclusions and Future Work

Currently, microvibrations are known in the field of medical diseases, but not in the field of human physical activity recognition. It might be expected that new analyzing features and algorithms combine the area of unconsciously movements and deliberately movement to create new application fields and new scientific findings. The advantages of measuring microvibrations with wearable technologies lie in the wide area of application fields (e.g. sleep detection, anomaly detection etc.). Most of the results presented in previous research where achieved by using stationary devices (e.g., [2, 4, 9]), and therefore is not applicable to most real world scenarios. The aim of this paper was to prove that microvibrations are measureable with mobile inertial sensors. Preliminary measurements, presented here, with mobile CE (Customer Electronics) devices, namely MetaWatch Strata and TI SensorTag, showed promising results for detecting microvibrations. These results are consistent and are matching with the findings of Pacela [4] in terms of sensor accuracy and technology as well as measured frequency. However, for future wearable application scenarios, the quality of recognition for microvibrations has to be further evaluated. Therefore, the results of previous research on non-inertial sensors (e.g. conducted by Rohracher [2]) have to be validated with a reconstructed study with off-the-shelf wearable devices. This way, a comparison and evaluation of both detection techniques would be possible. In addition, the connection between microvibration and sleep (or even diseases such as diabetes) are worthy to be investigated. This could possibly lead to more insight on nightly hyperglycemia. Another field of interest that requires further research is the detection of stress or tension.

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