Paweł KIELAN, Marcin CIECIURA

Politechnika Śląska, Wydział Elektryczny, Katedra Mechatroniki

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System for examination of human movement system dysfunctions

***Abstract**. The paper presents the concept of an electronic system of multiple sensors measuring chosen parameters of human's motion. Set of such sensors continuously measure the position, speed, acceleration, vibrations and trembles of human's body parts and sends this data to the central computer, where it stored and processed. The structure and principle of operation of the limb motion sensor, which consists of an accelerometer, gyroscope, magnetometer and microcontroller, was described. The article also presents the construction of a measuring station for testing the developed limb motion single sensor. The measured signal was analyzed using a Fast Fourier Transform (FFT) method analyzing harmonics of periodic vibrations. The results of the research have proved that it is possible to detect vibrations of frequency and amplitude that are typical for patients with motion dysfunctions, e.g. with Parkinson's disease.*

***Streszczenie.** W artykule przedstawiono koncepcję elektronicznego układu wielu czujników mierzących wybrane parametry ruchu człowieka. Zestaw takich czujników nieprzerwanie mierzy pozycję, prędkość, przyspieszenie, wibracje i drżenia części ciała człowieka i przesyła te dane do komputera centralnego, gdzie są przechowywane i przetwarzane. Opisano budowę i zasadę działania kończynowego czujnika ruchu, który składa się akcelerometru, żyroskopu, magnetometru oraz mikrokontrolera. Jego niewielkie rozmiary i zasilanie bateryjne umożliwia przymocowanie go praktycznie w każdym punkcie ludzkiego ciała. W artykule przedstawiono również budowę stanowiska pomiarowego przeznaczonego do testowania opracowanego pojedynczego czujnika ruchu kończyny. Zmierzony sygnał analizowano za pomocą metody szybkiej transformaty Fouriera (FFT) analizującej harmoniczne drgań. Uzyskane wyniki badań wykazały, że możliwe jest wykrycie drgań częstotliwości i amplitudy typowych dla pacjentów z zaburzeniami ruchowymi, np. z chorobą Parkinsona.* (**System badania dysfunkcji układu ruchu człowieka**).

Keywords: kinematic chain of the human body, motion sensor, Fast Fourier Transform, dysfunction of the musculoskeletal system.
Słowa kluczowe: łańcuch kinematyczny ludzkiego ciała, czujnik ruchu, szybka transformata Fouriera, dysfunkcja układu mięśniowo-szkieletowego.

Introduction

Diseases with neurological background can cause dysfunction of the musculoskeletal system. Difficulties associated with everyday activities may be burdensome for people with this type of illness. The reasons that may cause tremors or uncontrolled movements are e.g. mechanical head injuries, epilepsy, diabetes, Parkinson's disease or multiple sclerosis. Some of these diseases are incurable or partially curable [1, 2, 3]. In order to better examine the symptoms of these diseases and conditions that cause them (e.g. pre-epileptic status), tests should be carried out that allow isolating syndromes that indicate the occurrence of uncontrolled tremor of the extremities, e.g. epilepsy attack.

The article presents the concept of an electronic system of multiple sensors measuring chosen parameters of human's motion. Set of such sensors [7] continuously measure the position, speed, acceleration, vibrations and trembles of human's body parts and sends this data to the central computer, where it stored and processed.

The concept of a measuring system that mapping the human movement

The motion mapping measuring system will consist of many autonomous limb motion sensors that wirelessly transmit data on the location of individual elements of the kinematic chain of a human being via the WiFi network. The concept of the measuring system mapping human movement is presented in Fig. 1.

The main task of the system will be the acquisition and archiving of data obtained from the limb motion sensors in order to examine the possibility of vibration occurring in particular limbs to identify diseases that cause tremor in the limbs.

The system for testing dysfunction of the human motion system is unique in relation to other methods of motor dysfunction testing, because it is intended for use by patients during everyday activities, without necessity of stay in a hospital. This type of system will be able to monitor the position of the limbs 24 hours a day, collect data on the frequency of tremors of individual parts of the human motion system and transfer the obtained data to the database controlled by a doctor. Thanks to the obtained data, it will be possible to diagnose under which conditions uncontrolled movements occur, in which time intervals there are subsequent phases (epilepsy) or what are the symptoms before the attacks.

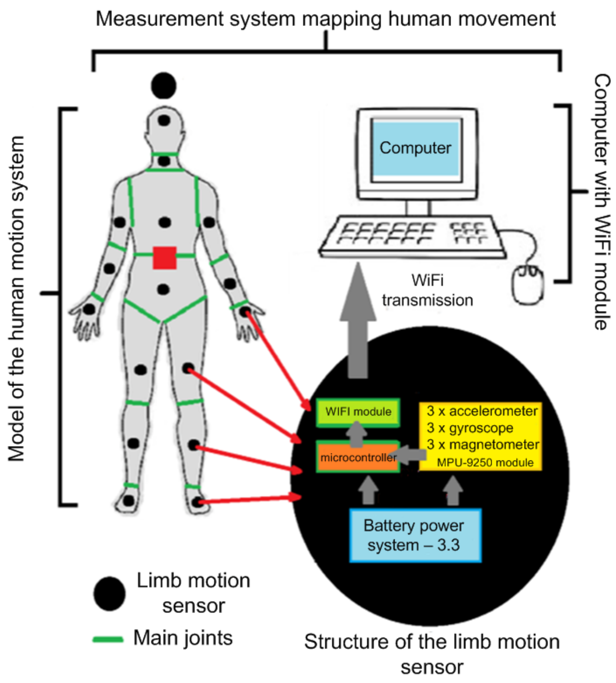

Fig.1. Concept of the measuring system mapping the human movement

Additional unique features of the system will be:

- Miniaturization of system components - limb motion sensors.
- Collecting and processing statistical data of all patients - centralized database system will allow to make wide

research on existing relations of various factors connected with particular diseases and with characteristic patients properties.

- Development of specific algorithms for the detection of amplitude and frequency of vibrations dedicated to the system, based on the analysis of measurement data - optimization of solutions. It is expected to use fuzzy logic methods together with evolutionary algorithms and neural networks, which are modern tools for building intelligent, expert systems that have the ability to generalize knowledge.
- Prediction of the selection of drugs for patients with Parkinson's disease - based on the results of the amplitude and frequency of vibration after taking the medicine prescribed by the doctor during daily activities.

Model of human kinematics with main joints marked is presented in Fig. 2. In this configuration of the 3D model of human kinematics, you can map the movements of the most important parts of the body responsible for the movement of the human body. One limb motion sensor is responsible for each of them. Limb motion sensors will be placed in the selected points of human kinematic chain as shown in figure. This allows examining the displacements between the joints at the critical points of the human body's motion system, so at such points where there are the most significant motor dependencies, e.g. thigh, knee, shank, foot chain or arm, elbow, forearm, hand.

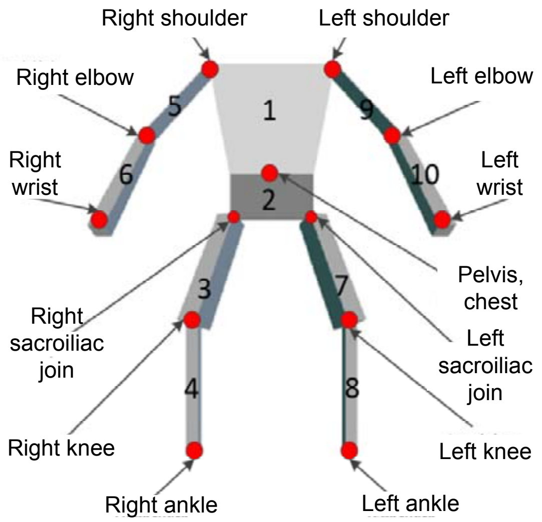

Fig.2. Model of human kinematics with main joints marked

The development of a monitoring system (during daily activity) of dysfunction of the human motion system, in which an integrated set of accelerometers is used, is now possible thanks to:

- Dynamic development of MEMS systems (Micro-Electro-Mechanical Systems) - a significant miniaturization of systems, low weight and energy efficiency. MEMS are systems that combine mechanical and electronic elements and are made on a miniature scale. They have a micrometre size, although with the advancement of technology smaller and smaller constructions are created, which are sometimes called NEMS (Nano-Electro-Mechanical Systems).
- Access to the Internet - the majority of the population in the European Union is within the reach of the Internet. It is assumed that access to the Internet is common in cities of the European Union. Elderly people also can use it.
- Popularity and universality of using computers, tablets and phones (smartphones), also by elderly people.
- Increasing computing power, of microprocessors (e.g. in smartphones). The computing power of commonly available devices enables registration, transmission, calculation and data visualization in real time. One of the parts of the developed system will be an application that should be installed on patient's device (computer, tablet or smartphone). The analysis of data received from the limb motion sensors will take place in external software, using a number of useful tools, filters, functions and algorithms (e.g. Fast Fourier Transform, FFT) for the analysis of harmonics of vibrations from limb motion sensors. It will allow obtaining information on vibrations of individual parts of the human kinematic system.

Construction of the limb motion single sensor

The limb motion sensor has been designed so that data from accelerometer, gyroscope and magnetometer can be collected for later analysis. The sensor has been designed to be compact and battery-powered, thanks this sensor to be attached at selected points in the human kinematic chain as shown in the Fig. 2. The structure of the limb motion sensor is based on 4 main modules connected together in one system.

- MPU9250 – multi-sensor module containing gyroscope, accelerometer and magnetometer.
- WIFI ESP-01 ESP8266 – wifi module enabling network communication using the TCP/IP protocol.
- ATMEGA16A microcontroller - an intermediary device in data transfer between the WIFI ESP01 8966 module and the MPU9250 module (communication interfaces I2C (TWI) and USART).
- Battery power supply system - stabilizer with 3.3V output voltage.

The block diagram of a limb motion sensor is presented in Fig. 3.

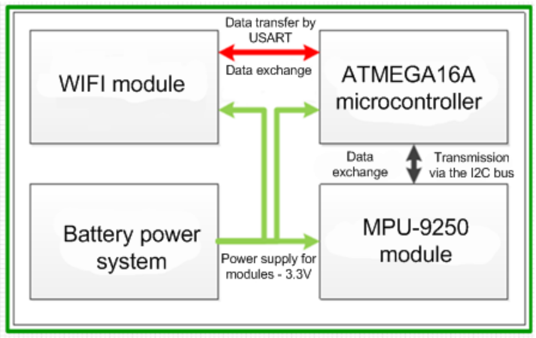

Fig.3. Block diagram of a limb motion sensor

The MPU9250 module is a combination of a 3-axis gyroscope, accelerometer and magnetometer on one modular plate. The first two sensors form an integrated set connected together in one MEMS system called MPU6500, while the magnetometer is a separate AK8963 system connected using the I2C bus with the MPU6500 sensor.

There are many implementations and ways to obtain reliable location and orientation data in space. For determining the position of objects in space is typically used inertial navigation system. The inertial navigation system can be divided into two main parts: AHRS (attitude and heading reference system) and IMU (inertial measurement unit). The IMU system uses three-axis acceleration and rotation sensors in determining the position of objects. The algorithm does not use a magnetometer as a reference axis indicator, so the azimuth determination is performed using the counting method. This makes it impossible to determine the direction in one of the axes and introduces an error resulting from the "drift" of the gyroscope. The AHRS system eliminates IMU system errors by using magnetometers to determine azimuth.

IMU and AHRS systems usually operate at the coordinates pitch ψ, yaw ϑ, roll φ which are the determination of the rotation of Euler's angles around the y, z, x axes, respectively. With such representation of the object can be determined rotation in three axes relative to the global coordinate system [5] [6] [8]. One of the biggest problems of this kind of orientation is the phenomenon of the so-called Gimbal Lock manifested in the loss of degree of freedom with a certain rotation of the object.

The Madgwick filter was used to implement the project. It is a filter based on the Kalman filter, which uses quaternary arithmetic to describe object orientations in three dimensions, which frees orientations from the adverse Gimbal Lock phenomenon. The filter implementation is available as Open Source and has been used in the project. To check the correctness of the Madgwick filter, the Mahony AHRS filter has also been implemented, which is also available as Open Saurce, and a complementary filter has been implemented based on the formulas. The determined angles (ψ, ϑ, φ) for the filters: Madgwick, Mahony, complementary are is presented in Fig. 4 - 6.

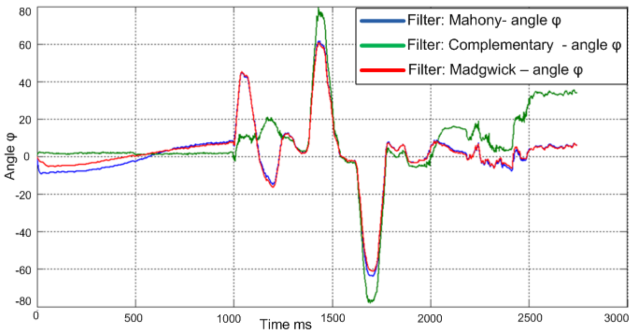

Fig.4. Determining the angles ϕ for filters: Madgwick, Mahony, Complementary

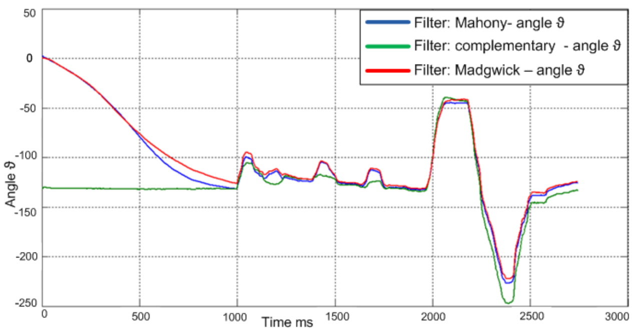

Fig.5. Determining the angles ϑ or filters: Madgwick, Mahony, Complementary

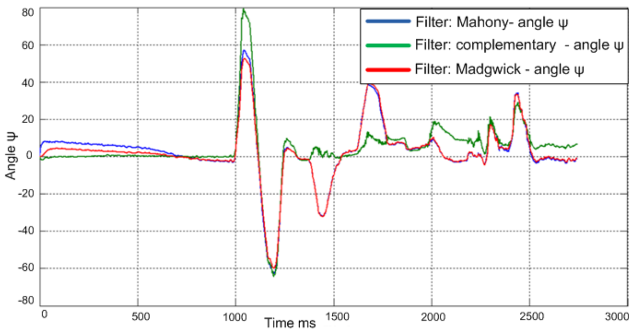

Fig.6. Determining the angles ψ for filters: Madgwick, Mahony, Complementary

As you can see Madgwick filters, Mahons orient the examined object in space in a similar way and the determined angles do not diverge significantly. The complementary filter deviates significantly from the previous filters. The reason for this may be incorrectly selected settings or a global reference system, which need not be the same. The complementary filter is also susceptible to quick changes of position in various planes, which causes errors in determining the actual angle. Therefore, it was decided not to use it during the implementation of the project.

Laboratory Experiment and results

To find out that the developed concept is feasible (recording of vibrations of a given amplitude and frequency, which occur among people affected by diseases causing shaking of the limbs), a measurement stand was built to study vibrations in the vertical plane. The construction of a measuring stand dedicated for testing the developed limb motion single sensor is presented in Fig. 7. The object of the study was a simple "shaker" made on the basis of a low-frequency subwoofer that allows generating shocks with controlled parameters. The shaker is powered by a generator generating waveforms with a given frequency and amplitude. The generator output is directly connected to the shaker input and enables supplying the shaker with voltage up to 4.40V. The oscilloscope performs the function of checking whether the voltage signal given to the shaker adopts the set parameters.

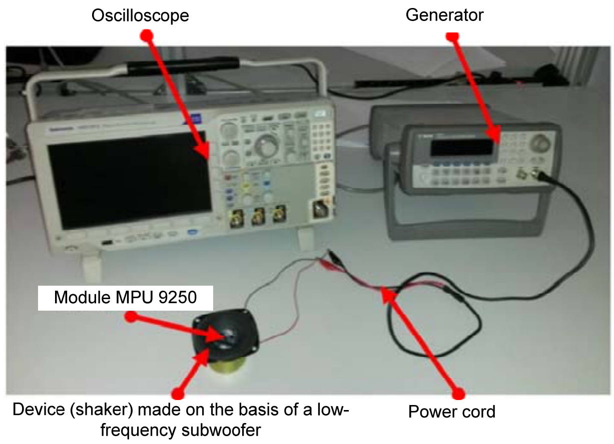

Fig.7. Construction of a measuring stand dedicated for testing the developed limb motion sensor

In order to generate vibrations from 1-8 Hz, it was decided to use a small subwoofer that provides low frequency mechanical waves. In the next step, a subwoofer was prepared for testing. The plastic membrane of the subwoofer was replaced with a rigid element, which was plastic glass, to which a tested limb motion single sensor was glued. The general diagram of the vibration detection system for a limb motion sensor is presented in Fig. 8.

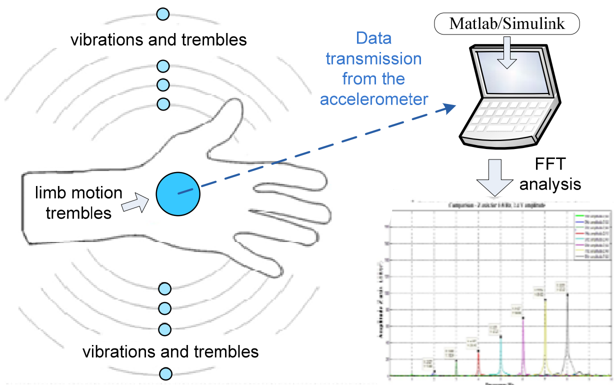

Fig.8. General diagram of the vibration detection system for a limb motion single sensor

The measuring system was a limb motion single sensor developed on the basis of the MEMS accelerometer and gyroscope sensor [5, 6] with a WiFi module as well as microcontroller. In addition, proprietary software for data archiving in the form of text files was developed. Generated files with saved measurements were used in software Matlab/Simulink for FFT calculations and visualization.

The measured signal was analyzed using a Fast Fourier Transform (FFT) method analyzing harmonics of periodic vibrations (Fig. 9). The results of the research have proved that it is possible to detect vibrations of frequency and amplitude that are typical for patients with motion dysfunctions, e.g. with Parkinson's disease.

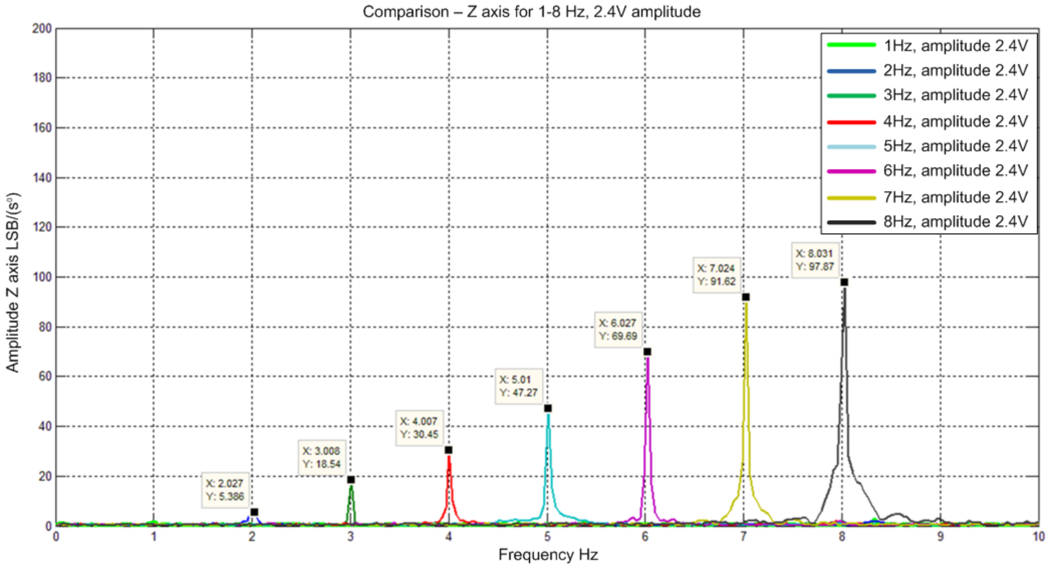

Fig.9. FFT analysis results for 1-8Hz frequency for 2.4V for limb motion single sensor based on MEMS sensor [4]

Conclusions

The obtained test results showed that the developed system based on MEMS accelerometer and gyroscope sensor provides detection of vibrations characteristic for a set of diseases in which there are tremors or uncontrolled movements of the limbs. Application of FFT analysis of signals registered by the MEMS sensor provided a convenient way to read individual harmonics the amplitude and frequency of vibrations.

The proposed solution may in the future be used to develop a warning system on the occurrence of symptoms of limb-shaking or as a medicines selection prediction system for patients with Parkinson's disease.

The system will significantly increase the effectiveness of treatment process by identification of correlation between the applied treatment and the level of symptoms severity. The self-learning algorithm will predict problems and warn the patient (and/or his doctor) when the symptoms will strengthen, suggesting an approaching epilepsy seizure. Doctors will be interested in the tool allowing making statistical research of dependencies between medical treatment, patient properties and symptoms.

***Authors**: dr inż. Paweł Kielan, Politechnika Śląska, Wydział Elektryczny, Katedra Mechatroniki, ul. Akademicka 10a, 44-100 Gliwice, E-mail: pawel.kielan@polsl.pl; mgr inż. Marcin Cieciura, E-mail: cieciura.marcin@gmail.com*

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