The Possibility of Using Spectral Analysis of Data Obtained from Mobile Device's Accelerometer for the Detection of Musculoskeletal System Pathologies

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***Abstract*—In this paper, we consider the feasibility of developing a remote monitoring system for patients with diseases of musculoskeletal system, based on data from the accelerometers mobile devices. In the course of research, we examined such diseases as coxarthrosis and scoliosis. Following algorithms were developed:**

- **Determining exact sector of data set, which contains information about movement (walking).**
- **Detecting presence of scoliosis in the subject.**
- **Processing data for comparison of frequency characteristics of different spectrums.**

I. Introduction

Accelerometers are used in the diagnosis of diseases of the musculoskeletal system, as one of the basic components of medical equipment. However, such systems are currently expensive and cumbersome.

At the same time, a plurality of various sensors such as accelerometers, gyroscopes, pressure sensors, etc. are included in a modern mobile phone. Most of these sensors are microelectromechanical systems (MEMS). In general, MEMS sensors are devices that transform various physical effects in electrical signal. Three-axis MEMS accelerometers provide data on device's acceleration in three dimensions.

Hypothesis: if we fix such gadget on a person's body, it is possible to measure the acceleration occurring during movement performed by this person. It is possible to analyze the state of the musculoskeletal system based on this data, and transmit information about patient's state to his physician via mobile device. This approach will allow creating a remote monitoring system for patients with diseases of the musculoskeletal system.

The goal of the research:

- develop algorithms, which allows for analyzing the state of subject's musculoskeletal system using data from mobile device's accelerometer.
- Create a system for remote monitoring of patients with musculoskeletal diseases, using only data obtained from mobile device's accelerometers, based on developed algorithms.

The remainder of this paper is structured as follows. Section II provides an overview of the known solutions. Proposed system and its uses are discussed in Section III. Section IV is devoted to the description of the algorithms and the experiments conducted to confirm the hypothesis. Section V presents the current results of the research. The paper is finalized with Conclusion in Section VI.

II. Overview of the Known Solutions

There are several known methods of investigating human gait, which can be divided into three categories:

- Based on machine vision technology.
- Using floor sensors.
- Using wearable sensors [1].

In the machine vision technology method, subject's gait is recorded on a camcorder from reasonable distance. Afterwards, algorithms for processing images and video sequences are used in order to extract the biometrics, Most of the algorithms for machine vision are based on building a human silhouette [2], [3], [4], [5]. Background is removed from the image, and then human silhouette is extracted and analyzed.

In the methods using floor sensors, a plurality of sensors are mounted on the surface [6], [7], [8], [9]. When a person walks on them, these sensors allow measuring some of characteristics associated with gait.

In contrast to two previous approaches, the method of using wearable sensors is the newest. This method lies in attaching the sensor that records movement to some part of the human's body: on the waist [10] in the pockets [11], in the footwear [12], etc.

Wearable sensors can be used for various purposes due to a large number of different obtainable data. Accelerometers, gyroscopes, pressure sensors, etc. can be used as wearables, with accelerometers being the most commonly used to study gait [11], [13], [14].

Usually, an accelerometer consists of weight that is fixed in an elastic suspension. Weight deviation from its original

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position in the presence of the apparent acceleration carries information about the magnitude of this acceleration [15].

Three-axis accelerometer allows you to obtain values of acceleration along three axes, which provides the definition of the acceleration of the mobile device with such built-in sensor in the three-dimensional space – Fig.1.

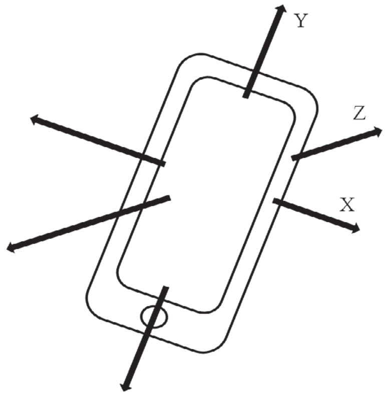


Fig. 1. Mobile device orientation in three-dimensional space. X, Y, Z – three axes, orthogonal to each other

Proposed system – is a system for remote monitoring of patients with musculoskeletal diseases, using only data obtained from mobile device's accelerometers. This system consists of following software and hardware parts.

- Mobile device with the software for patients installed.
- Server in medical facility with the installed application handler.

Therefore, it is planned to develop software for mobile devices, which will be used by patients, and for servers in medical facilities, which will be used by doctors.

The market presents a number of applications that are somehow related to human health. Some examples of such applications are:

- «Wireless Blood Pressure Monitor» by «Withings» [16].
- «Scout» by «Scanadu» [17].

These mobile applications only allow you to measure simple indicators such as blood pressure or heart rate, and require using additional instrumentation.

In the field of orthopedics, for the diagnosis of diseases of the musculoskeletal system it is common to use these methods:

- X-rays.
- CT scan.
- Magnetic resonance imaging.
- Devices that use accelerometers

In addition, in the thesis [18] there was a research conducted on informative parameters for determining the functional state of the human musculoskeletal system. This thesis also used accelerometers, but the diagnostic system in which they were used was a bulky construction, consisting of a large number of devices, which is why there were no possibility to make remote monitoring of patients with abnormalities of the musculoskeletal system. All of the devices that are currently used in orthopedics and traumatology are bulky, expensive, immobile structures that cannot be used without the presence of a patient in a medical facility.

Overall, it can be stated that there is no such application currently on the market, which can remotely monitor patients with diseases of the musculoskeletal system, and be simple to use.

III. THE PROPOSED SYSTEM

Using the idea presented in [18], we propose the following approach to the construction of a remote patient monitoring system. It is known that due to musculoskeletal system diseases, frequency in the spectrum can change, for example, the emergence of the peaks at higher frequencies.

Thus, an application that records accelerometer readings in the mobile device and processes them in a special way can be created - Fig. 2.

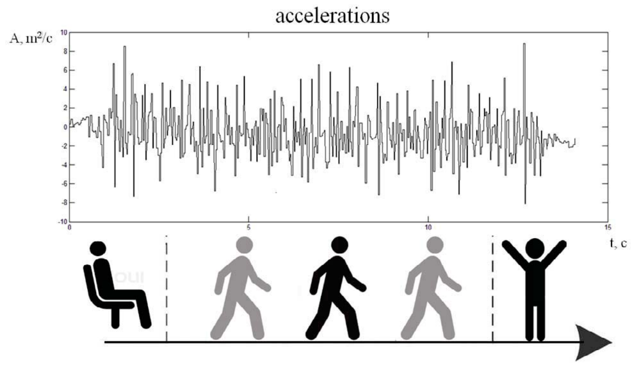


Fig. 2. Collecting data about persons gait via mobile device's accelerometer

When device is attached to the human body, this application takes readings of a person walking, processes the data and sends the relevant results to the attending physician - Fig. 3.

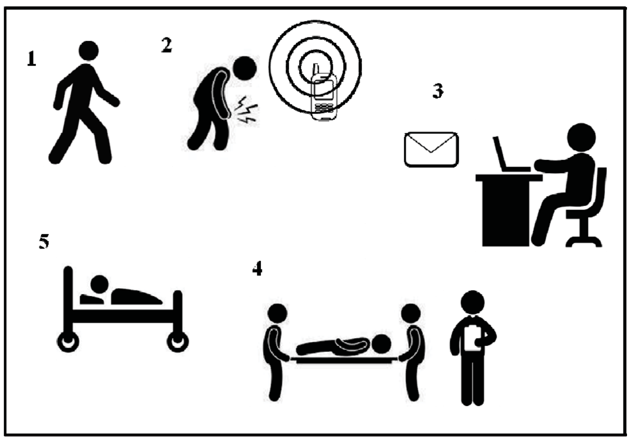


Fig. 3. A graphical representation of how to use the proposed system

It is expected that the mobile application will be used in two ways.

- Patients will use the application during their rehabilitation at home after surgery, and it will be used to monitor the status of the musculoskeletal system of patients in medical institutions after starting a course of medications and medical gymnastics.
- Persons, who are not currently on treatment, but simply want to check the state of theirs musculoskeletal system for preventive purposes.

The proposed system of remote monitoring of patients with musculoskeletal diseases consists of the following components.

- Mobile device with embedded accelerometer, which is mounted on patient's body.
- The application on the mobile device, which receives data from the accelerometer, processes it and sends the results to the application handler, located on a computer in a medical facility.
- The computer accessed by the attending physician. The computer is connected to the Internet and is located in a medical facility, or in any other place accessible to the physician.
- The application handler on the computer, that receives data from an application on a mobile device, processes the received data and provides information about the state of the patient to attending physician.

The application on the mobile phone, in addition to core functions, will also perform a testing of working condition of built-in accelerometer, in order to confirm that it can do the required tasks.

Thus, it is planned to develop software for mobile devices to be used by the patients, and for the servers in medical institutions.

It is expected that this system will be applied in the field of orthopedics and traumatology as an aid for remote monitoring of patients with diseases and injuries of the musculoskeletal system.

IV. Preliminary testing

A. Tests description

To verify the possibility of creating described system, a series of experiments has been conducted, which were as follows:

1) A mobile device is attached to the subject’s body on the right side of the waist vertically. In these experiments, a simple waist case pouch was used for this purpose. A test subject walks in a straight line with his normal pace for about 15 seconds. During this time, the data is recorded on three-axis accelerometer. Readings were taken at 100 Hz, i.e. every 10 ms.

2) The data received from mobile device accelerometers was processed using discrete Fourier transform.

3) The obtained spectrums were qualitatively analyzed.

In total, the experiment involved 34 test subjects. Among them: 14 subjects without diseases of the musculoskeletal system; 14 subjects with scoliosis, 2 subjects with dual coxarthrosis; 4 subjects with a mix of diseases of the musculoskeletal system. The characteristics of all the subjects are presented in Table I.

TABLE I. TEST SUBJECTS CHARACTERISTICS

Test subjects	Age	Gender	Disease
Test subject №1	20	F	–
Test subject №2	44	F	–
Test subject №3	44	M	–
Test subject №4	23	M	–
Test subject №5	21	M	Scoliosis
Test subject №6	20	M	–
Test subject №7	21	M	–
Test subject №8	35	F	–
Test subject №9	55	F	–
Test subject №10	32	M	–
Test subject №11	32	F	–
Test subject №12	22	M	–
Test subject №13	22	F	Scoliosis
Test subject №14	80	M	Coxarthrosis
Test subject №15	22	F	Scoliosis
Test subject №16	47	M	Various
Test subject №17	35	M	Coxarthrosis
Test subject №18	22	M	Various
Test subject №19	26	F	Scoliosis
Test subject №20	64	F	Various
Test subject №21	22	M	–
Test subject №22	22	F	Scoliosis
Test subject №23	22	F	–
Test subject №24	22	F	Scoliosis
Test subject №25	22	M	–
Test subject №26	22	M	Scoliosis
Test subject №27	21	M	Scoliosis
Test subject №28	20	M	Various
Test subject №29	22	M	Scoliosis
Test subject №30	22	M	Scoliosis
Test subject №31	72	F	Various
Test subject №32	22	M	Scoliosis
Test subject №33	22	F	Scoliosis
Test subject №34	67	F	Various

This research used a mobile phone HTC Desire 300 on the Android 4.1 platform with built-in three-axis accelerometer «BMA250» from the company «Bosch», a full description of the characteristics and properties of which are presented in [19].

It should be noted that despite the described properties of the accelerometer in [19], not all of them could be used due to the limitations of the operating system API on the mobile phone.

B. Developed algorithms

Based on conducted experiments and gathered statistical data, an algorithm of determining the state of the human musculoskeletal system has been developed, which is summarized in Algorithm 1.

Algorithm 1 Generalized algorithm for determining the status of the musculoskeletal system

0: Using data from mobile device accelerometer, a file with recorded acceleration occurring during human movement is created.
1: Created file is processed by cutting off unimportant data, leaving only the exact part containing human walk accelerations.
2: Windowed Fourier transform is performed to obtain a spectrum.
3: According to certain rules, a decision is made on the state of the musculoskeletal system.

At this stage, Algorithm 1 is not yet finalized and may be further modified or supplemented.

A more detailed description of certain steps of the algorithm is presented below. Algorithm 2 is devoted to identifying the exact sector of signal containing walking.

Algorithm 2 Determination of sector containing data relevant to walking movement from the original file.

0: The original file is broken up into smaller fragments.
1: Discrete Fourier transform is performed on each fragment of the file.
2: In each processed fragment, on each of 3 axes X, Y, Z, peak values of frequencies are checked, since during a walk these values should be approximately equal for any subject, as described in Section V.
3: If in a fragment all three checked values are equal within a tolerance, then a decision is made that the subject have started walking in this fragment.

Modern Android devices are provided with Google API, and one of its functions is to send data from the sensors to Google Play Services to determine the type of human activity: walking, running, biking, riding a car, etc. - Fig. 4. However, this solution is not suitable to accurately determine the beginning and end of the walk, because response time with the Google Play Services takes a long time.

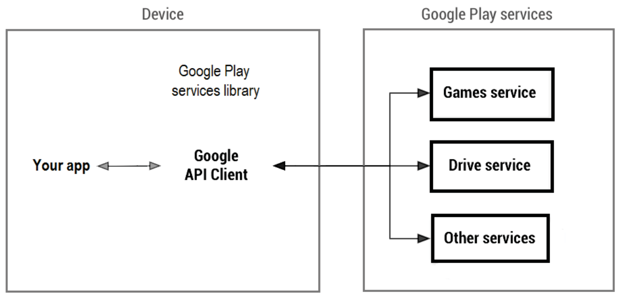


Fig. 4. Diagram on Google API operation

Algorithm 3 describes how the decision is made on the state of the human musculoskeletal system.

Algorithm 3 Determining the state of the musculoskeletal system

0: Based on already processed signal, peaks of values on axes X, Y, Z are found.
1: Frequency values on three peaks are compared between each other, and if they are not equal within a tolerance, a decision is made that the subject has scoliosis.
2: If they are equivalent within a tolerance, then values of the global peaks themselves are compared to each other. If the peak of the Y-axis exceeds the others, then a decision is made that the subject does not have diseases of the musculoskeletal system.

It should be noted that the Algorithm 3 is only able to identify such disease as scoliosis. Other diseases of the musculoskeletal system also have their own signs, as will be described in more detail in Section V. However, due to the small sample size of such test subjects, as demonstrated in Table I, the establishment of a formal algorithm is a matter of time.

As for the choice of windowing function for processing signals, so far it is a matter of a further research.

At the moment, a prototype of the proposed system had been developed, which receives data from a mobile device accelerometer, performs discrete Fourier transform and sends the processed data via e-mail. Experiments were conducted, confirming the feasibility of this approach.

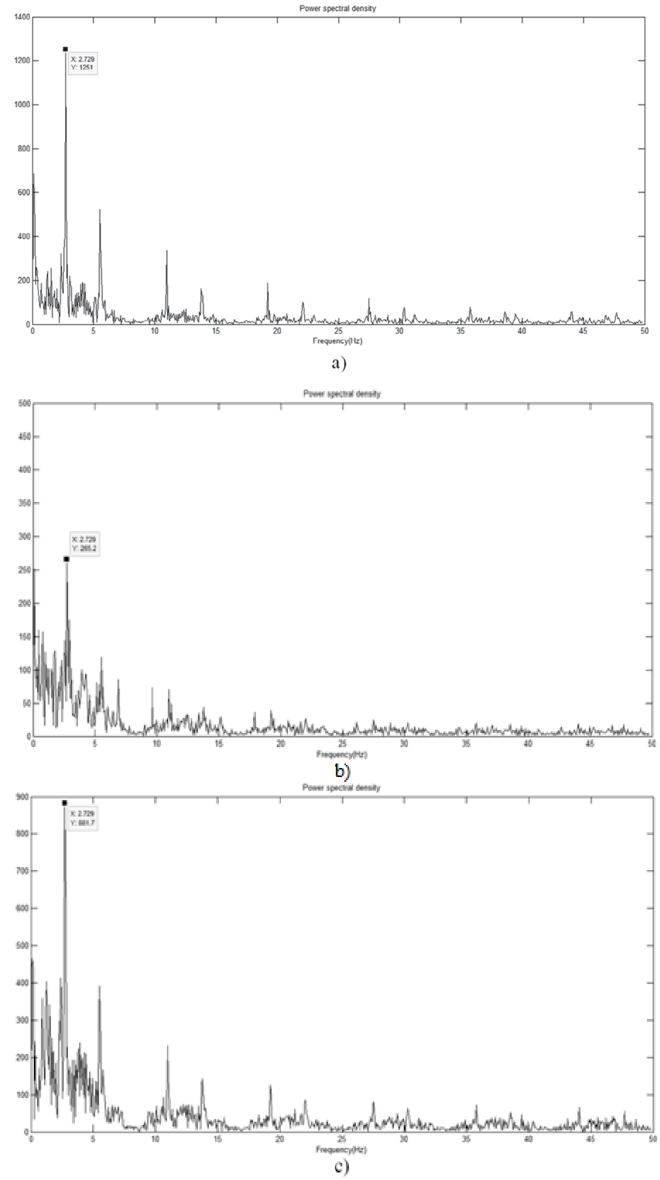
V. Results

A. Spectrums, belonging to people without any diseases of the musculoskeletal system

Tests results revealed the following reappearing features in the spectrums belonging to subjects without diseases of the musculoskeletal system - Fig. 5, Fig. 6.

1) The maximum fluctuation amplitude on all accelerometer axes are at the same frequencies for subjects without any diagnosed musculoskeletal diseases (14 cases).

2) For every subject without any musculoskeletal diseases (14 cases), the strongest fluctuations occur in the direction of up and down.



a)

b)

c)

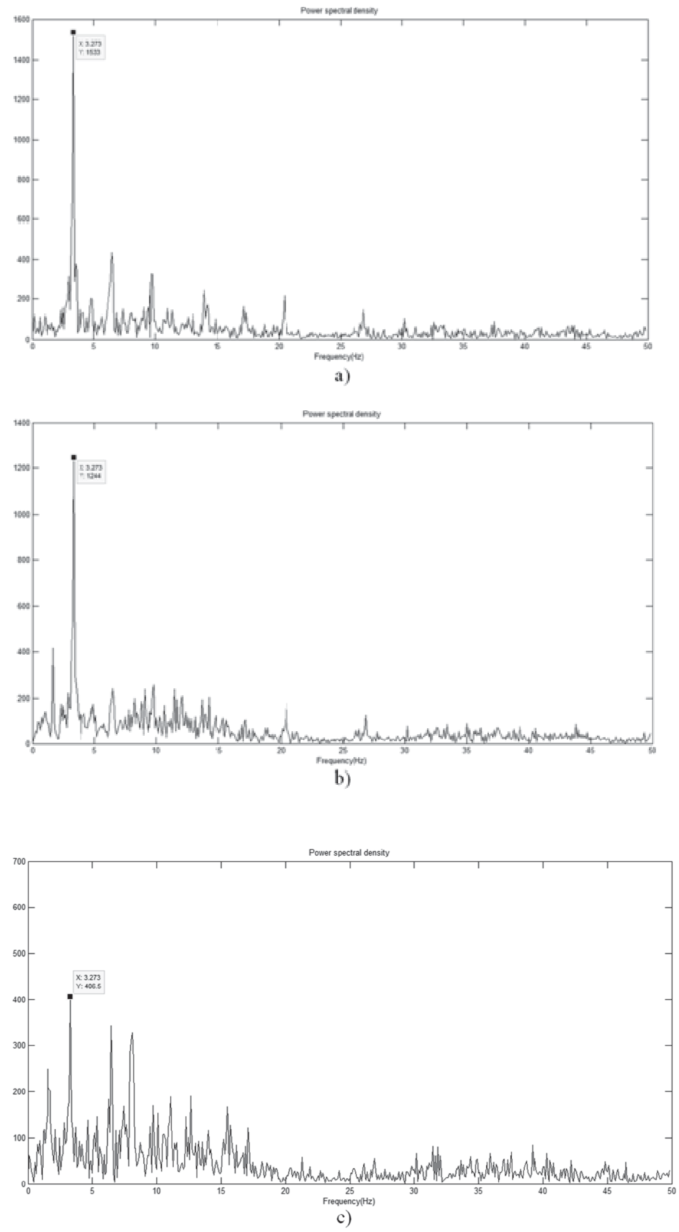
Fig. 5. A typical spectrum belonging to the test subject №25: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

B. Spectrums belonging to people with scoliosis

For subjects with scoliosis, following reappearing features in the spectrums were revealed – Fig. 7, Fig. 8.

1) The peak amplitude of the fluctuations of three axes are shifted in frequency

2) For all test subjects with scoliosis (14 cases), the strongest fluctuations occur in the direction of up and down or left and right.



a)

b)

c)

Fig. 6. A typical spectrum belonging the test subject №2: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

C. Spectrums belonging to people with dual coxarthrosis

For subjects with dual coxarthrosis, following reappearing features in the spectrums were revealed: Fig. 9, Fig. 10.

1) The maximum fluctuation amplitude on all accelerometer axes are at the same frequencies.

2) The strongest fluctuations occur in the direction of back and forth.

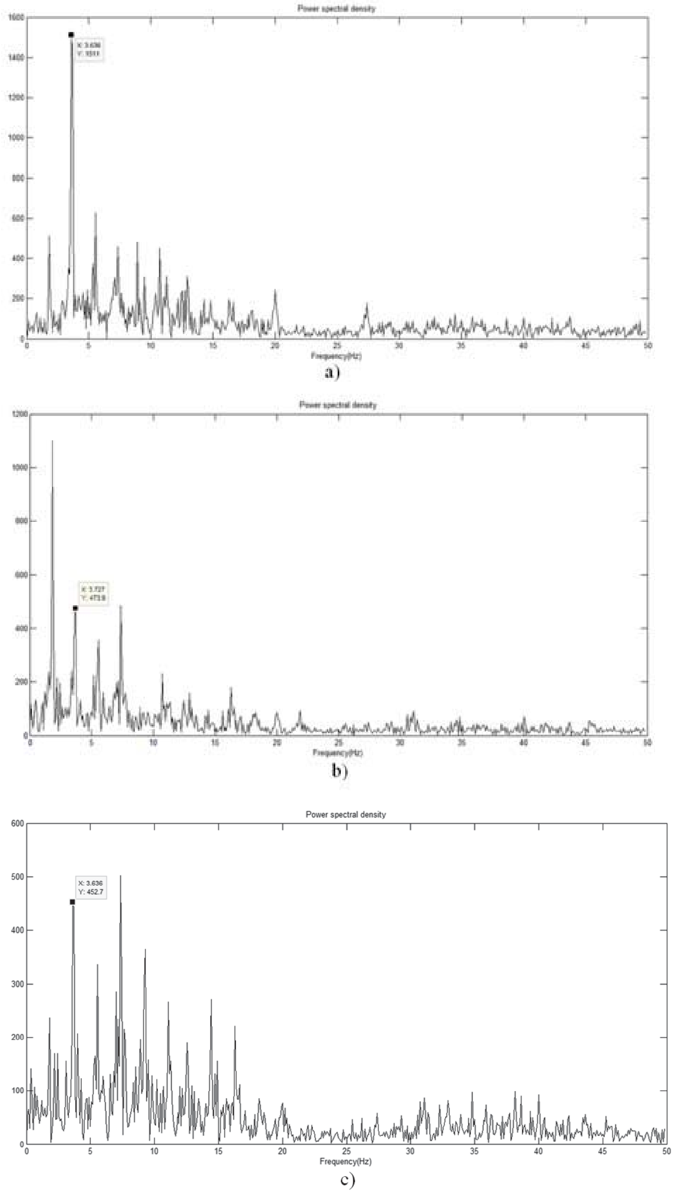


Fig. 7. A typical spectrum belonging to the test subject №13: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

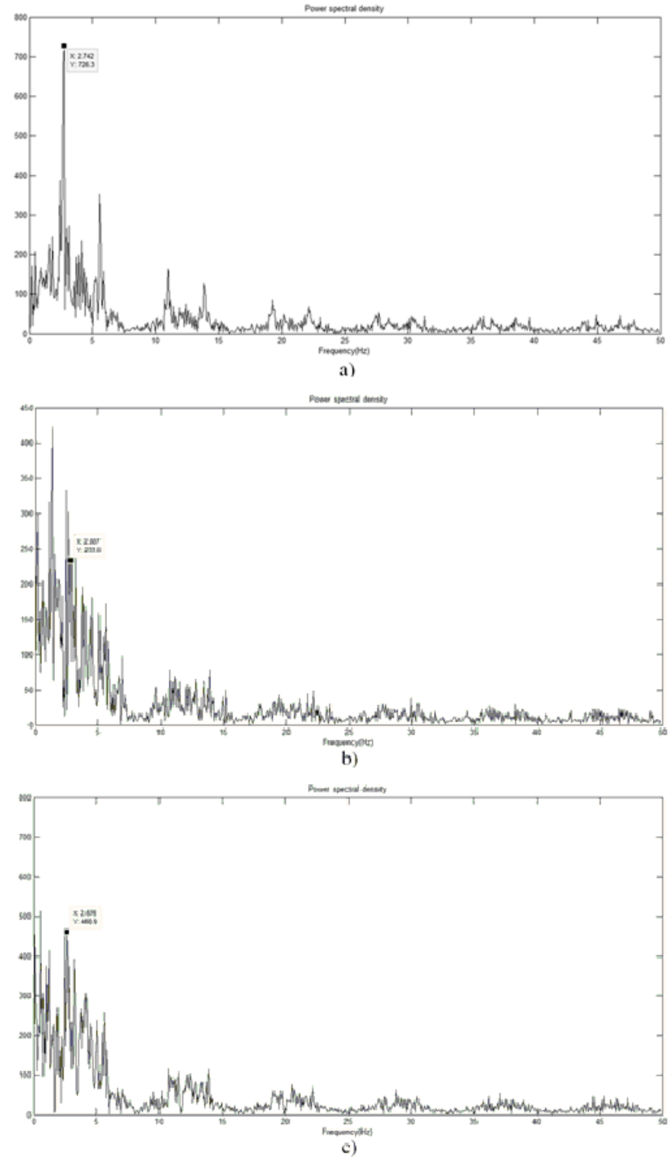


Fig. 8. A typical spectrum belonging to the test subject №29: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

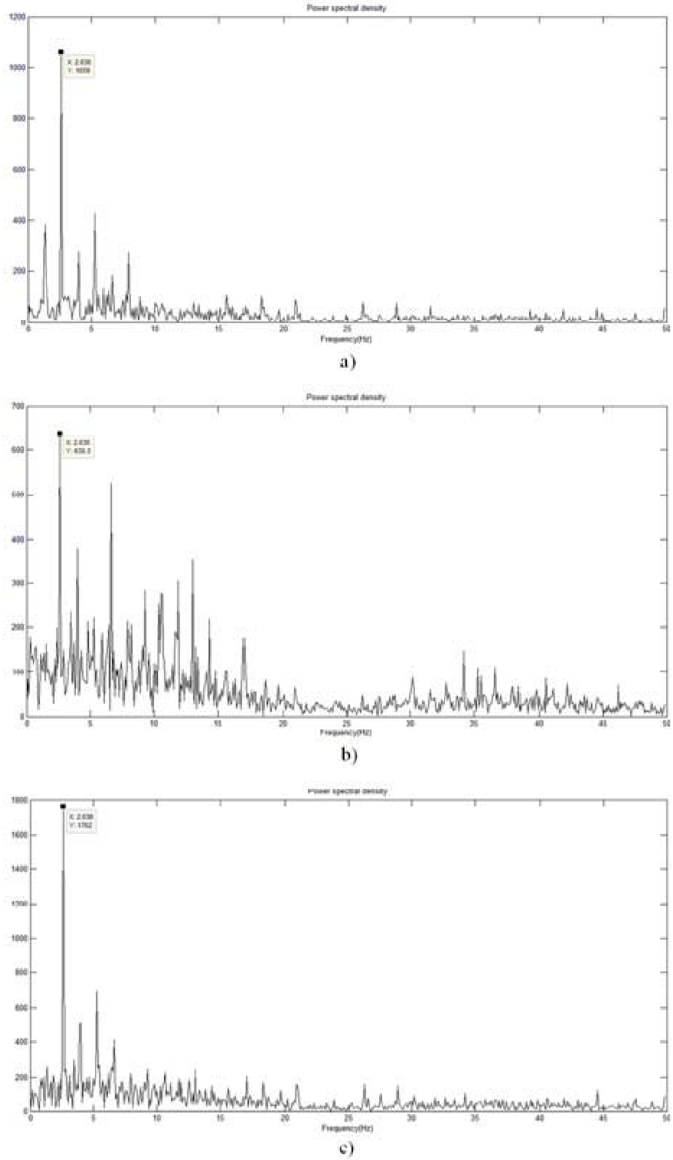


Fig. 9. A typical spectrum belonging to the test subject №14: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

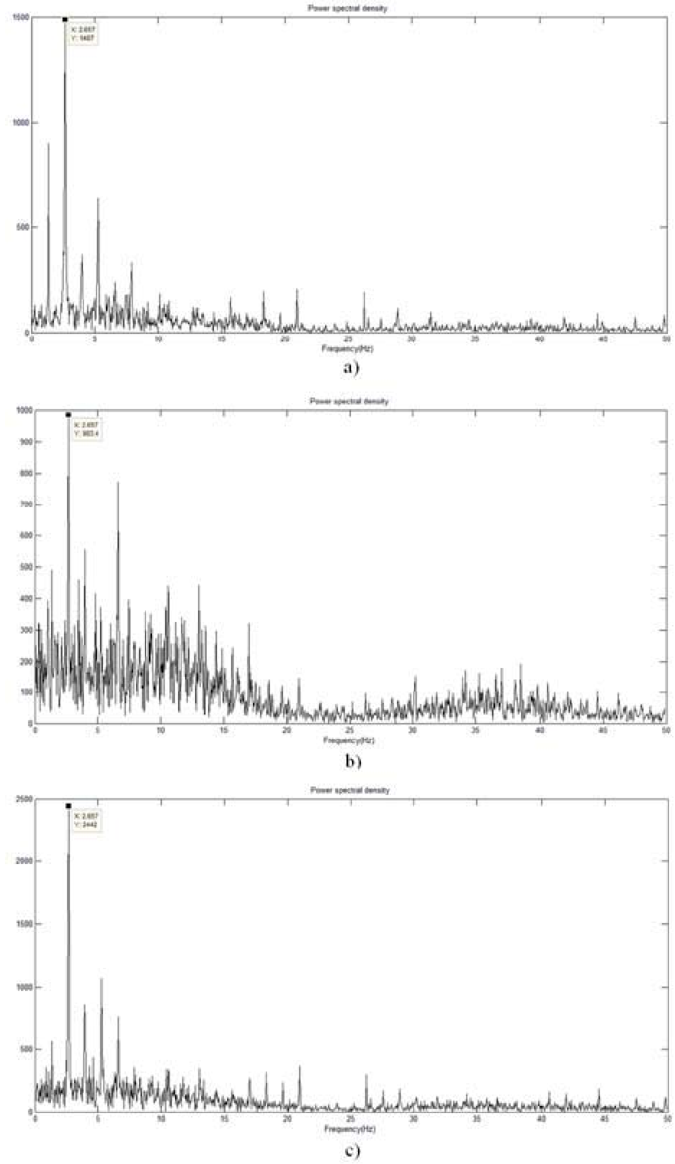


Fig. 10. A typical spectrum belonging to the test subject №17: a) in the direction of the axis up and down; b) in the direction of the axis back and forth, c) in the direction of the axis right and left

D. Change in spectrums with age

During the course of research, an additional algorithm had been developed. Results of this algorithm confirm the well-known property that a person develops high-frequency components in his walk movement spectrum with age, regardless of the presence of diseases of the musculoskeletal system.

Algorithm 4 Converting data for high-frequency components identification

0: After the discrete Fourier transform is performed on the acceleration values related to subject movement in one of the axes, the resulting data array A is searched for the maximum value of the amplitude of fluctuations – $maxA$.

1: The threshold T is calculated:

$$T=k\cdot maxA,$$

where $k \in (0; 1)$ – some coefficient.

2: The resulting vector is obtained as follows:

$$V_i = \frac{\sum_{j=1}^{i} x_j}{\sum_{j=1}^{n} x_j},$$

where $i=\overline{1,n};\ x_j=\begin{cases}0, & A_i<T\\ 1, & A_i\geq T\end{cases}$, n – length of A.

The results of this conversion are shown in Fig. 11, Fig. 12, which illustrate the high-frequency components value increasing with the age of the subject.

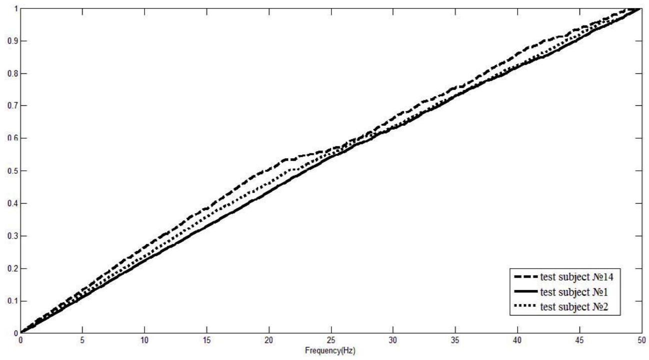


Fig. 11. The increase in high-frequency fluctuations with the age of the person when the value of the coefficient is 0.01: test subjects №14, №1, №2 - Table I

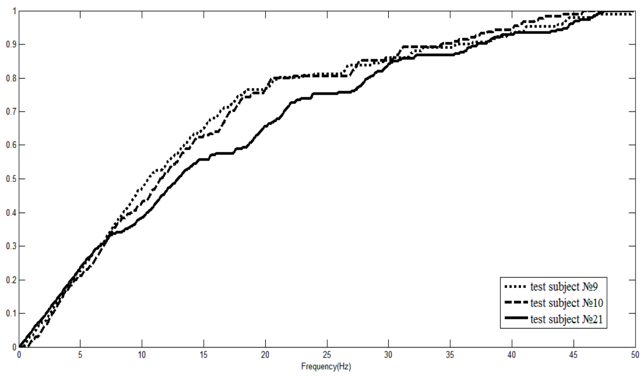


Fig. 12. The increase in high-frequency fluctuations with the age of the person when the value of the coefficient is 0.04: test subjects №9, №10, №12 - Table I

VI. Conclusion

The results of this research show that the proposed approach can be used to create remote monitoring system for patients with musculoskeletal diseases. The article reviews diseases such as coxarthrosis and scoliosis. It is already possible to say that proposed methods allow for reliable scoliosis detecting. Other diseases also have their own signs, but the development of algorithms for specific disease is a matter of further research.

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