Estimation of Human Biomechanics during Registration with a Wearable Device

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Abstract. In article research of human biomechanics is carried out in the case of registering his movements using a single accelerometer, which is located in a wearable device. Mobile phones, smart watches or fitness bracelets can act as a wearable device. It should be noted that the research is oriented at evaluating biomechanics using a mobile phone, but the results obtained in the form of algorithms and a general approach can be transferred to cases of using other wearable devices.

1. Introduction

The development of the computing power of microprocessor systems, their miniaturization, as well as the development of the Internet of Things and big data technology provides great prospects for the development of automation tools and their implementation in various fields [1-4]. One of the promising areas is the automation of the collection, processing and analysis of human biometric data [5-8], in particular for authentication tasks [9-13] and personalized medicine [14, 15]. The development and distribution of portable wearable devices contributes to the high rate of introduction of new technologies. However, in practice, to solve new problems, it is necessary to develop new models, algorithms, methods and approaches.

Research in the field of human biomechanics has been conducted for a long time, and there are many different approaches to assessing the parameters of movement and the features of the functioning of the musculoskeletal system and the nervous system by movements [14-21]. When registering human movements and evaluating the parameters of his biomechanics, various sensors are used [22-24], but all of them imply an assessment of biomechanics based on data obtained from a group of sensors [25-26]. There are devices and methods for fixing motion parameters based on a single sensor [16, 17] – this is a video camera or an accelerometer (or gyroscope) of a smart bracelet or smart watch. However, the registration of movements using a video camera has its own specifics: it depends on the lighting and the position of the person relative to the camera, in addition, the assessment of movements requires a constant presence of the camera opposite the person, which is currently not possible to provide [27, 28]. In turn, the software used in smart watches and bracelets allows you to allocate a small number of movements (walking, running, swimming method), and the results of the work reflect small quantitative indicators (number of steps, speed) and are not tied to a specific person [29-31].

As an exception, it should be noted the developments in the field of assessing human biomechanics when registering movements using wearable (embedded) sensors and manipulators. Motion measurement technologies based on sensors with a flexible base (including those sewn into clothing)
are currently under development. And methods of registering movements based on manipulators provide information about movements at a local point (any part of a person's limb), imply a stationary or similar place of work or clear rules for registering movements (for example, a touch screen) [32].

Thus, research in the field of registration and processing of human movement parameters based on mobile phone data is an urgent task. In accordance with this, the purpose of this work is to automate the process of authentication and personalized diagnostics of human health through the research and development of a model of human biomechanics formed using the accelerometer data of a wearable microprocessor device.

2. **Assessment of biomechanics**

The task of evaluating human movements based on the readings of one sensor is incorrect. This is due to the fact that when moving, a person uses a significant number of muscles, ligaments and joints, which leads to a multiparametric (multidimensional) model of movement [22, 23]. It is impossible to correctly evaluate all types of movement based on a single sensor, but such a feature of movements indicates a unique behavior (movement) of one sensor during the movements performed. The solution of the problem of parameter estimation is also complicated by the following aspects:

- The location of the phone can be arbitrary.
- In a short period of time, the mobile phone can change its location, and it can also change its orientation in space.
- There is no rigid fixation of the phone. Even one person can wear different clothes that fit and fix the phone in different ways.
- Different phone models have different location of the accelerometer sensor on the board.
- The location of the accelerometer axes relative to the front surface of the mobile phone may differ for different models.
- Various metrological characteristics of accelerometers.
- The accelerometric sensor measures the projection of the acceleration of free fall, which is a disadvantage when registering movements in specific conditions.

To evaluate biomechanics based on the accelerometer of a wearable device, a description model is proposed, the structure of which is shown in figure 1.

Basic movements are used to evaluate biomechanics. This paper considers the simplest basic movements of a person that are performed during his movement: walking and running. Other types of movement, including those related to the stationary position of a person, are beyond the scope of this article, but still require research. It should be noted that the movements considered in the work are performed both on a flat surface, and when climbing or descending (in particular, on the stairs). In addition, the analysis of movements was carried out taking into account the interfering factors that are often present in everyday life: different types of clothing and shoes, the position of the mobile device in space (in particular, in the front and back pockets of trousers, near the ear as when talking), additional load (a bag on the shoulder, in the hand or overweight).

Each type of movement in a person is characterized by its own parameters in the frequency and time domain. The set of features of each movement characterizes the individuality of a person – it is difficult to repeat them. Taking into account the fact that the style of his clothes, physiological characteristics or the manner of carrying cargo (for example, bags) contributes its own individual noise components to the movements, it becomes even more difficult to form the same biometric trace by different people. Thus, a set of parameters about movement, registered even by a single sensor, identifies a person with a high degree.
In this case, the human biomechanics recorded by one accelerometer sensor is described by a multiparametric model, which can be represented as the following vector containing the parameters of each type of movement:

\[ \tilde{M} = \{ \tilde{M}_1, \tilde{M}_2, \ldots, \tilde{M}_i \}, \]

where \( \tilde{M} \) – the general vector describing the features of human movements; \( \tilde{M}_i \) is the vector of the parameters of the \( i \)-th movement (2).

\[ \tilde{M}_i = \{ P_1, P_2, \ldots, P_k, \tilde{N}_1, \tilde{N}_2, \ldots, \tilde{N}_j \}, \]

where \( P_k \) – is the \( k \)-th parameter of dimension 1x1; the \( j \)-th parameter is a vector of dimension \( n \) by \( m \). In expression (2), the parameters of type \( P \) include: the standard deviation, the frequency with the maximum amplitude, the duration of movement, the maximum and minimum amplitude, etc. To the parameters-vectors of the type \( \tilde{N}_j \), these include time series (for example, a signal registered during time \( t \) from a sensor), the spectral composition or spectral-time decomposition of the registered signal, etc. - in fact, these are motion patterns.

### 3. Formatting the text

For practical testing of the possibility of distinguishing people by the parameters of the model (1), built according to the data of the accelerometer sensor of a mobile phone, 32 people aged 15 to 67 years, male and female, with different physiological characteristics (height, weight, posture) were involved. Also, two twins with the same physiological parameters were involved in the experimental
The form of clothing was different—from tight-fitting trousers to loose trousers, and sneakers, shoes and shoes (for women) with low heels were used as shoes.

The basic movements were: walking, brisk walking, climbing stairs, descending stairs. Also, each experiment was carried out with a load-weighing 3.5 kg.

As a result of data processing, it was found that it is possible to distinguish the subjects already at the stage of preliminary data processing. For example, the standard deviation allows you to distinguish between the subjects (figure 2, where the color of the dots corresponds to a specific subject) when performing some exercises (in particular, ordinary walking). It should be noted that this parameter allows you to distinguish the movements of twins. However, the assessment of the entire volume of basic movements only by this parameter gives a high level of errors—more than 80%.

![Standard deviation of signal patterns](image)

**Figure 2.** Example of evaluating movements based on the standard deviation of movement patterns.

The most informative parameter is the signal shape, as well as the spectral composition. Although the durations of signals and patterns in different experiments differ for different subjects, bringing them in the same dimension with subsequent evaluation of the value of the correlation coefficient gives a good result. In the worst-case scenario (in loose clothing and sneakers), at least 90% of the movements can be distinguished at a threshold value of the correlation coefficient of more than 0.8. The most similar movements are performed when climbing and descending stairs.

### 4. Conclusion

Thus, by registering the apparent acceleration of gravity using the accelerometer sensor built into the mobile phone, as well as determining the parameters of the developed motion model, it is possible to distinguish the subjects from each other with a high probability (more than 90%). However, for a more accurate assessment of the probability of distinguishing subjects by the above parameters, it is necessary to conduct researches on a larger sample. In this case, the probability of distinguishing the subjects by their movements may be significantly lower (50% or less). Despite this, the use of this algorithm for evaluating a person's biometric parameters, in addition to the existing basic means of authentication or health assessment, is promising. In addition, the use of neural network technologies, and in particular recurrent networks, will expand the possibilities of the described approach for evaluating biometric indicators.
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