Результаты Анализа Походки по Данным Акселерометра Мобильного Телефона для Интеллектуальной Системы Аутентификации Пользователя

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Аннотация

В данной работе исследовались параметры походки человека по данным акселерометра мобильного телефона для дальнейшего развития технологии интеллектуального анализа походки в системах биометрической аутентификации. В работе рассматриваются особенности регистрации движений человека на основе различных методов, описываются проблемы при оценке параметров походки на основе акселерометрических данных мобильного телефона. В ходе исследования привлекалось 32 человека в возрасте от 15 до 67 лет мужского и женского пола, с различными физиологическими особенностями (рост, вес, осанка). Так же в экспериментальную группы были привлечены двое близнецов с одинаковыми физиологическими параметрами и человек, перенесший операцию на коленном суставе. Форма одежды была различной – от плотных прилегающих штанов до свободных брюк, а в качестве обуви использовались кроссовки, ботинки и туфли (для женского пола) на не высоком каблуке. В методику исследования были включены основные типы движений, которые совершаются в повседневной жизни человека при ходьбе. В ходе исследования анализировались информативные параметрами: среднее значение, среднеквадратическое отклонение, форма сигнала (значение коэффициента корреляции). В ходе исследования было установлено, что применение одного акселерометрического датчика мобильного телефона позволяет различать совершаемые движения человека при передвижении в различных условиях (форма одежды, тип дороги и т.п.), а так же различать людей по особенностям движений.

Ключевые слова

Интеллектуальная система, походка, носимое устройство, телефон, параметры, диагностика, аутентификация, оценка

The Results of the Analysis of Gait According to Mobile Phone Accelerometer Data for an Intelligent System of Authentication of Users

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Abstract

In this paper, we researched parameters of a person's gait according to the accelerometer of a mobile phone for the further development of the technology of intelligent gait analysis in biometric authentication systems. The paper considers the features of registering human

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movements based on various methods, describes the problems in assessing gait parameters based on accelerometric data of a mobile phone. The study involved 32 people aged 15 to 67 years, male and female, with different physiological characteristics (height, weight, posture). Also, two twins with the same physiological parameters and a person who underwent surgery on the knee joint were involved in the experimental group. 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 research methodology included the main types of movements that are performed in a person's daily life when walking. During the research, informative parameters were analyzed: the average value, the mean square deviation, the signal forms (the value of the correlation coefficient). In the course of the research, it was found that the use of a single accelerometric sensor of a mobile phone allows you to distinguish between the movements of a person when moving in different conditions (form of clothing, type of road, etc.), as well as to distinguish people by the features of movements.

Keywords
Intelligent system, gait, wearable device, phone, parameters, diagnostics, authentication, estimate

1. Introduction

The development of intelligent technologies, the accumulation and processing of heterogeneous data allow us to solve new classes of problems in all areas in practice. In particular, the development of new approaches of the collection and subsequent processing of biometric data contributes to the development of the functionality of intelligent systems. For example, the introduction of new intelligent tools for personalized medicine (remote diagnostics, "transparent" health monitoring, etc.), the improvement of access technology (identification and authentication, etc.) to services [1, 2, 3]. General trends in the development of technologies for collecting, processing and analyzing biometric data are aimed at compactness, invisible, scale, continuity and functioning in real time. There are many biometric parameters, as well as ways to register and process them [4, 5, 6, 7, 8]. At the moment, the most common means of registering biometric parameters are: video and photo cameras, microphones (external and personal devices) [9, 10, 11]. Sensors of wearable devices (mobile devices, smart bracelets) are used less often (on a smaller scale) to record biometric indicators: fingerprint scanner, pressure and pulse sensors, accelerometers and gyroscopes, touch screens [12]. The analyzed biometric parameters are the parameters of the face, gait, behavior, cardiovascular system, voice, and others.

The estimate of movement parameters for the authentication has been considered for more than a decade. It should be noted, that the results of the estimate of movement parameters are used not only in the field of protection against unauthorized access, but also in the field of medicine (diagnostics and rehabilitation). There are several main types of motion parameters registration: based on external sensors (video camera), based on manipulators (joysticks, trackballs, computer mouse, touch screens, etc.) and based on wearable sensors (wearable sensors and sensors of external devices). All of them have their own significant advantages and disadvantages. For example, the assessment of movements using video recording 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 [13, 14]. Methods of registering movements based on manipulators provide information about movements at a local point (any part of a human limb), imply a stationary or similar place of work or clear rules for registering movements (for example, a touch screen) [15, 16, 17, 18]. Measurement of motion parameters based on wearable sensors is performed using several sensors that are placed on kinematic pairs of a person, this significantly reduces the mobility of the technology and aesthetic appearance. Because of this, sensor-based motion detection methods are usually used in specialized laboratories. The exceptions are measurement technologies made on the basis of sensors with a flexible base (including sewn into clothing), but this technology is still under development. The same exception is considered to be registration methods based on an accelerometer or gyroscope, which are embedded in a wearable device – a smart bracelet or a mobile device. However, the software used in these devices only allows you to allocate a small number of movements (walking, running, swimming method), and the results of the work provide small quantitative indicators (number of steps, speed) and are not tied to a specific person [19, 20, 21]. Thus, the determination of informative parameters of signals of sensors of the wearable device is relevant for development of intelligent algorithms in biometric authentication system based on human movements. Data collection about the variation of values of movement parameters of different users is the primary step to developing a model of human motor behavior based on data of the accelerometer of a mobile phone.

The purpose of this work is the research of parameters of accelerometer signals of a mobile phone for the expansion of capabilities of biometric authentication through the development of technologies for intelligent analysis of gait according to mobile phone data.

2. Features of data registration and analysis

The task of estimating human gait 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:

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

To research 32 people involved. They are aged 15 to 67 years, male and female, with different physiological characteristics (height, weight, posture). Also, two twins (with the same physiological parameters) and a person (person have underwent surgery on the knee joint) were involved in the experimental group. The people were divided into 4 persons, so that in each group there were people with approximately the same parameters of height, weight and age.

During the research, each person performed the same moves in a different form of clothing. The form of clothing changed from tight-fitting trousers to loose trousers, and sneakers, shoes and shoes (for women) with low heels were used as shoes – this amounted to 4 different combination of clothes (6 combination for women).

In the experiments, the location of the phone was as follows: the front pocket of the pants, the back pocket of the pants, near the ear (when talking) – this amounted to 3 different positions. The movements performed were: walking, brisk walking, climbing the stairs, descending the stairs – this amounted to 4 different types of movements. Also, each experiment was carried out with a bag on his shoulder, with a bag on a preponderance, with a bag in his hand and without load – this amounted to 4 different types of load of persons. A laptop weighing was used as a load. The total weight of the bag, including the charger and computer mouse, was 3.5 kg. Thus, taking into account various conditions, person performed 192 different exercises - the main movements, that are performed in a person's daily life, were included in the research methodology. The number of repetitions of each exercise (of the same type of movements) ranged from 2000 to 3000.

The data of the accelerometer sensor of a mobile phone was analyzed, namely, the change in the acceleration of free fall (raw data) during gait. The analysis of indirect (calculated) quantities (angles, velocities, displacements, etc.) was not carried out to in order to avoid the accumulation of error during integration and additional calculations. Since a three-axis accelerometer was used in mobile phones, data analysis was carried out for each axis (component) separately.

For each type of exercise, a template signal was selected from set of time series of this type for each person. The template signals were selected from all the signals as the signals with the least noise. All accelerometer data of each repeated exercise, template signals and their envelope form were analyzed in the time and frequency range. The following parameters were analyzed:

- Signal duration.
- Average value.
- Mean square deviation.
- Value of coefficient correlation.
- Frequency components with maximum amplitude (contribution to the total signal of more than 70%).

The research of the frequency spectrum of signals was carried out on the basis of the wavelet decomposition. The B-spline wavelet (type ‘fbsp 2-0,5-1’ for program packet MATLAB) was chosen as the parent wavelet, which most accurately allows you to recreate signals of the accelerometer sensor of a mobile phone when gait (the average value of the correlation coefficient is 0.95, the value of the mean square deviation is 0.03).

For the correlation analysis, the all signals were normalized in time and amplitude. Time normalization was performed using the decimation procedure. This was done in order to align (bring) the durations of the signals to the time of the shortest signal (exercise).

3. Results

Distinguishing of persons causes difficulties based on the average value of signal, since the difference of average values of signals of persons does not exceed hundredths of a fraction in many cases (Figure 1). At the same time, in the pocket of clothing random movements of the phone lead to a decrease in differences (Figure 2).

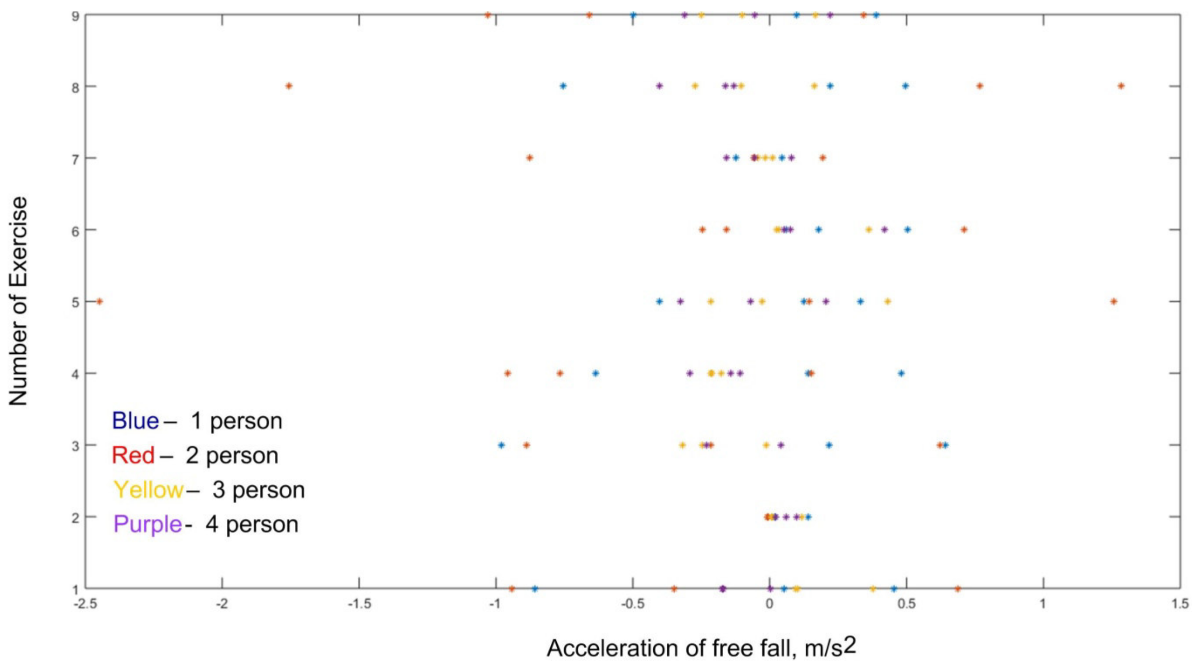

Figure 1: These are estimates of the average value of accelerometer signals for three components for one of the subgroups

The figures show the results of the following types of exercises, which were performed in loose clothes and in sneakers:

1. Walking with a phone in the front pocket.

2. Walking when talking on the phone.
3. Walking with a phone in the front pocket and a bag.
4. Climbing the stairs with a phone in the front pocket.
5. Climbing the stairs when talking on the phone.
6. Climbing the stairs with a phone in the front pocket and a bag.
7. Descending the stairs with a phone in the front pocket.
8. Descending the stairs when talking on the phone.
9. Descending the stairs with a phone in the front pocket and a bag.

In exercises with a different type of clothing, the differences are reduced by 2.6-3 times.

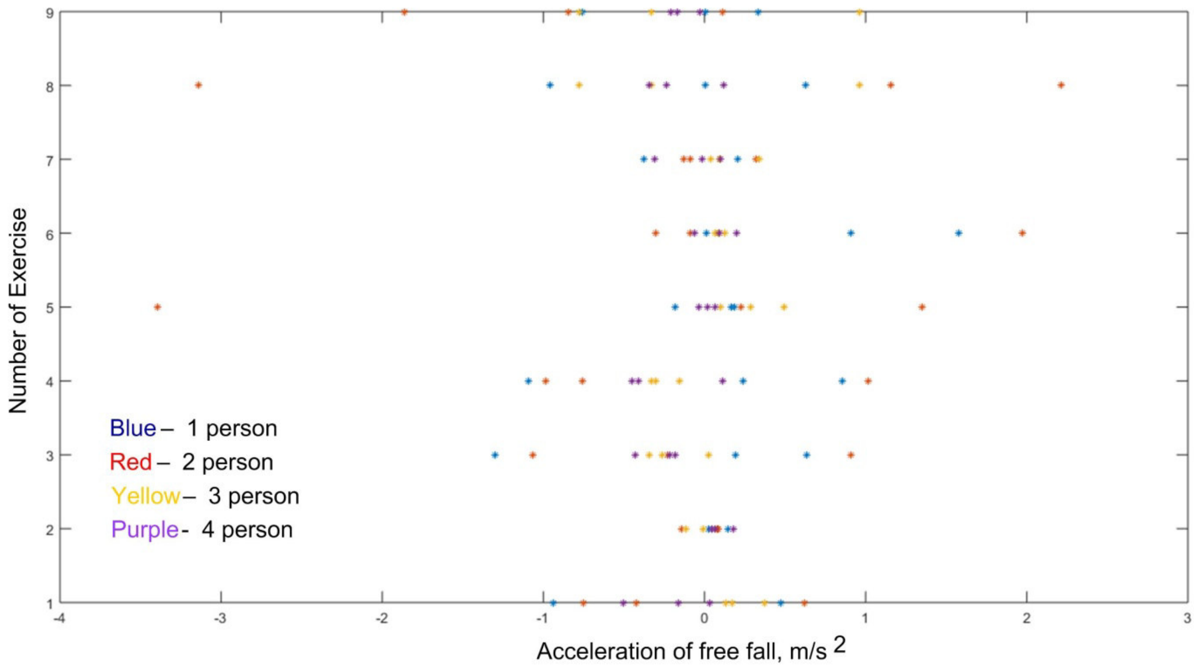

Figure 2: These are estimates of the average value of accelerometer signals for three components for one of the subgroups

The analysis of the spread of the mean square deviation shows a greater distinctness of persons (Figure 3) compared to the distinctness using the average value. The mean square deviation allowed us to see some differences even in twins under the same conditions (3 and 4 entries in Table 1). It should be noted that when talking on the phone, it is quite difficult to distinguish between the persons and their movements (it is not possible). This is due to a decrease in the number of movements of the mobile phone – it turns out that the gait features are "extinguished". However, this feature when climbing or descending the stairs on the contrary can help in distinguishing the persons (Table 2).

Table 1
The mean square deviation during normal walking in one of the subgroups

Person	Component X	Component Y	Component Z
1	3,92	3,88	6,33
2	6,50	5,33	3,53
3	2,12	4,18	2,92
4	2,23	2,02	2,64

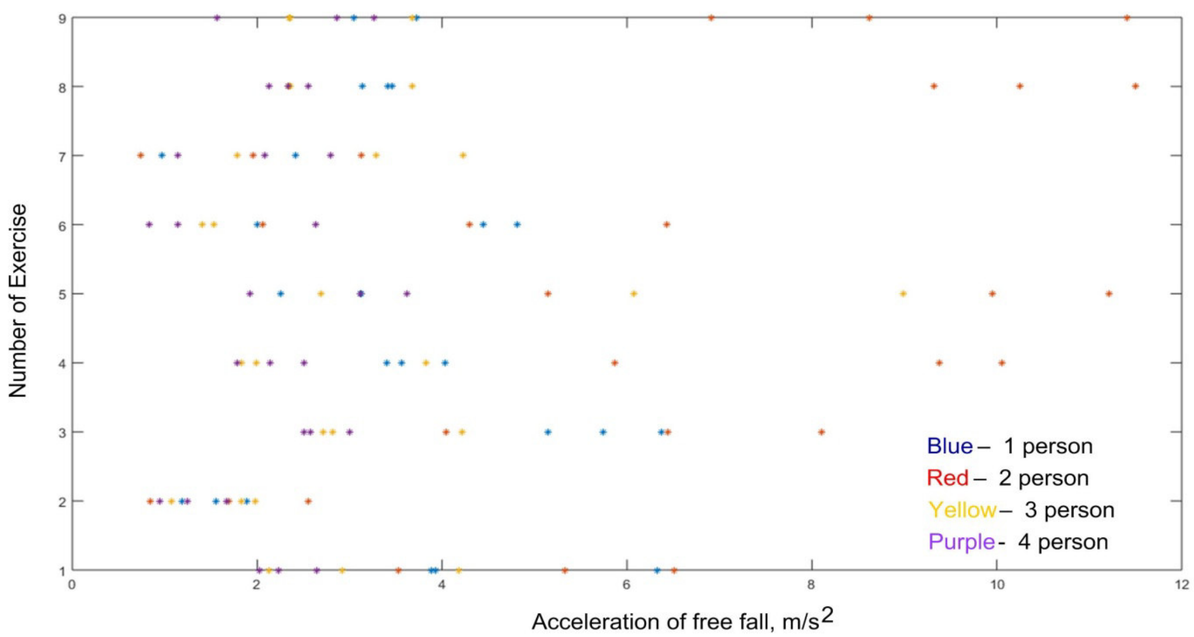

Figure 3: These are estimates of the mean square deviation of accelerometer signals for three components for one of the subgroups

Table 2
The mean square deviation when climbing the stairs with the phone near your ear

Person	Component X	Component Y	Component Z
1	2,25	3,13	3,11
2	9,94	11,21	5,14
3	2,69	8,99	6,07
4	1,92	4,62	3,11

The most informative parameter is the signal form, as well as the spectral composition (Table 3).

Table 3
The main frequency in the spectrum when walking with a bag and a phone in the front pocket

Person	Component X	Component Y	Component Z
1	4,18	4,18	10,27
2	6,23	5,13	3,95
3	3,45	2,69	6,11
4	2,83	9,14	2,95

Although the durations of signals and patterns differ in different experiments for different subjects, bringing them in the same dimension with subsequent estimation of the correlation coefficient value gives a good result. In the worst case option (in loose clothing and sneakers), at least 90% of movements can be distinguished at a threshold value of the correlation coefficient of more than 0.8 (Table 4), in good conditions (tight clothing, shoes), this percentage is achieved at a threshold of 0.7. A correlation receiver was used as a signal detector. The most similar movements are performed during ascents and descents of the stairs. It should be noted that such a comparison is performed with the same duration of the exercise performed, which was not recorded during the research. This means that the probability of recognizing movements and subjects by individual movement patterns increases significantly.

Table 4
An example of the correlation of normalized signal patterns in one of the subgroup when climbing stairs with a phone in the front pocket

Person	1	2	3	4
1	1	0,54	0,38	0,42
2	0,54	1	0,6	0,47
3	0,38	0,6	1	0,68
4	0,42	0,47	0,68	1

4. Conclusion

In the course of the research, it was found that the use of a single accelerometric sensor of a mobile phone allows you to distinguish between the movements of a person when moving in different conditions (form of clothing, type of road, etc.), as well as to distinguish people by the features of movements. The material collected as a result of the research will allow us to apply neural network technologies to improve the quality of distinguishing movements and people, and implement these developments both in individual devices (in the form of software) and in information systems of medical, law enforcement and banking profile. It should also be noted that in order to improve the quality of analysis of biometric data of a person's gait according to the data of a wearable device, it is necessary to conduct an analysis with other factors not considered, as well as to attract a larger number of subjects with various physiological features and deviations in the functioning of the musculoskeletal system to form a database.

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6. References

[1] C. Lei, Y. Chuang, Privacy protection for telecare medicine information systems with multiple servers using a biometric-based authenticated key agreement scheme, IEEE Access 7 (2019) 186480-186490. doi:10.1109/ACCESS.2019.2958830.
[2] Z. Mehmood, A. Ghani, G. Chen, A. S. Alghamdi, Authentication and secure key management in E-health services: a robust and efficient protocol using biometrics, IEEE Access 7 (2019) 113385-113397. doi:10.1109/ACCESS.2019.2935313.
[3] N. V. Dorofeev, A. V. Grecheneva, V. S. Buzhinsky, Assessment of human gait parameters base on accelerometer data, Biomedical Engineering 55 (2021) 92-96. doi:10.1007/s.10527-021-10078-y.
[4] G. L. Marcialis, P. Mastinu, F. Roli, Serial fusion of multi-modal biometric systems, IEEE Workshop on Biometric Measurements and Systems for Security and Medical Applications, 2010, pp. 1-7. doi:10.1109/BIOMS.2010.5610438.
[5] A. E. Sulavko, D. A. Volkov, S. S. Zhumazhanova, R. V. Borisov, Subjects Authentication Based on Secret Biometric Patterns Using Wavelet Analysis and Flexible Neural Networks, XIV International Scientific-Technical Conference on Actual Problems of Electronics Instrument Engineering (APEIE), IEEE, Novosibirsk Russia, 2018, pp. 218-227. doi:10.1109/APEIE.2018.8545676.
[6] Vandana, N. Kaur, A Study of Biometric Identification and Verification System, International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), IEEE, New Deli India, 2021, pp. 60-64.

[7] S. Raju, V. Udayashankara, Biometric person authentication: A review, International Conference on Contemporary Computing and Informatics (IC3I), IEEE, Mosore India, 2014, pp. 575-580. doi:10.1109/IC3I.2014.7019771
[8] S. K. Singla, M. Singh, N. Kanwal, Biometric System - Challenges and Future Trends, 8th International Conference on Computing for Sustainable Global Development, INDIACom, New Delhi India, 2021, pp. 647-651.
[9] D. S. Krutokhvostov, V. E. Khitsenko, Password and continuous authentication by keyboard handwriting by means of mathematical statistics, Cybersecurity 24 (2017) 91-99. doi:10.21681/2311-3456-2017-5-91-99.
[10] A. E. Sulavko, E. V. Shalina, Biometric authentication of users of information systems by keyboard handwriting based on immune network algorithms, Applied Informatics 14 (2019) 39-45.
[11] M. Faundez-Zanuy, J. Fierrez, M. A. Ferrer, M. Diaz, R. Tolosana, R. Plamondon, Handwriting Biometrics: Applications and Future Trends in e-Security and e-Health, Cognitive Computation 12, 1 September (2020) 940-953. doi: 10.1007/s12559-020-09755-z.
[12] N. V. Dorofeev, A. V. Grecheneva, The assessment of gait features according to the data of a portable acceleration sensor in an intelligent monitoring system, IOP Conference Series: Materials Science and Engineering 873 (2020) 1-7. doi:10.1088/1757-899X/873/1/012017.
[13] O. C. Reyes, R. Vera-Rodriguez, P. J. Scully, K. B. Ozanyan, Analysis of Spatio-Temporal Representations for Robust Footstep Recognition with Deep Residual Neural Networks. pp. 1-15 doi:10.1109/TPAMI.2018.2799847.
[14] A. I. Sokolov, A. S. Konushin, Methods of human identification by gait in video, Proceedings of ISP RAS, 1 (2019) 69-82. doi:https://doi.org/10.15514/ISPRAS-2019-31(1)-5.
[15] A. L. Yerokhin, S. N. Lednev, Methods of gesture recognition based on the data of three-axial accelerometers Android devices, Bulletin of NTU KHPI 21 (2017) 1-4.
[16] A. V. Khelvas, N. G. Belyakina, A. A. Gilya-Zetinov, D. D. Chernikova, V. M. Shabunin, E. O. Yapryntsev, Gesture recognition using a neural network and the application of this approach to create a new generation of gaming gadgets, Proceedings of MIPT 34 (2017) 1-12.
[17] P. S. Teh, N. Zhang, S.-Y. Tan, Q. Shi, W. H. Khoh, R. Nawaz, Strengthen user authentication on mobile devices by using user's touch dynamics pattern, J. of Ambient Intelligence and Humanized Computing 11-10 (2020) 4019-4039. doi: 10.1007/s12652-019-01654-y.
[18] X. Zhang, L. Yao, C. Huang, T. Gu, Z. Yang, Y. Liu, DeepKey: A Multimodal Biometric Authentication System via Deep Decoding Gaits and Brainwaves, ACM Transactions on Intelligent Systems and Technology 11-4 (2020) 1-24. doi:10.1145/3393619.
[19] A. G. Kazantseva, D. N. Lavrov, Personality recognition by gait based on wavelet parameterization of accelerometer readings, Mathematical Structures and Modeling 23 (2011) 31-37.
[20] Y. Chen [et al.] LSTM Networks for Mobile Human Activity Recognition, Atlantis Press, BangKok Thailand, 2016, pp. 50-53. doi:10.2991/icaita-16.2016.13.
[21] D. Anguita, A. Ghio, L. Oneto, X. Parra, J. L. Reyes-Ortiz, Human Activity Recognition on Smartphones using a Multiclass Hardware-Friendly Support Vector Machine, International Workshop on Ambient Assisted Living IWAAL 2012: Ambient Assisted Living and Home Care, Springer, Victoria-Gasteiz, Spain, 2012, pp 216-223. URL: https://upcommons.upc.edu/bitstream/handle/2117/101769/IWAAL2012.pdf.
[22] D. V. Skvortsov, Clinical analysis of movements, Gait analysis: Publishing house of SPC - Stimulus, Ivanovo, Standartinform, Moscow, 1996, pp. 344.
[23] I. A. Sutchenkov, Informativeness of biomechanical parameters in pathological walking before and after the course of electrostimulation of muscles during walking, Russian Journal of Biomechanics 2 (1999) 1-5.