Anna Tsvetkova

student, intern researcher of the scientific Laboratory "Digital Technologies in Criminalistics" of the Department of Scientific Research of the V. F. Yakovlev Ural State Law University,

Dmitriy Bakhteev

Professor of the Department of Criminalistics, Principal Researcher of the Department of Scientific Research of the V. F. Yakovlev Ural State Law University, Doctor of Legal Sciences, Associate Professor

FEATURES OF KEYSTROKE DYNAMICS AND THEIR FORENSIC SIGNIFICANCE: LITERATURE REVIEW

DOI: 10.30729/2541-8823-2024-9-3-145-164

Abstract. *Keystroke dynamics is a phenomenon deeply studied in computer science. Its research began in the second half of the 1970s and immediately yielded positive results: keystroke dynamics was found to be unique and relatively stable — ergo, significant for identification. The first studies focused on three features of keystroke dynamics: typing speed, key press time, and the time between two consecutive key presses. Today, research on this topic has not stopped, but, on the contrary, has intensified due to the general increase in interest in biometric characteristics of personality. Scientists identify new features of keyboard handwriting that form the basis of identification: the strength of keystrokes, the use of service keys, the nature of overlapping, the nature and frequency of typing irregularities, arrhythmic input, spatial orientation of keystrokes and others. At the same time, printed texts are rapidly replacing manuscripts every year, which leads to the emergence of a new forensic task: to identify the executor of a printed text with criminal content (extremist material on the Internet; a post in a "death group" on a social network; information on the location of a narcotic substance, etc.). In this case, the legal and forensic study of keystroke dynamics becomes useful,*

because it is through it that it is possible to establish who exactly typed the text, avoiding the prosecution of an innocent person whose account was used by the attackers. However, for this to be possible, lawyers must adapt the results achieved by colleagues from computer science to the normative procedure of criminal proceedings, which requires, first of all, a comprehensive understanding of the current level of research in this area and the features of keystroke dynamics, which will then form a forensically significant set necessary for accurate identification. Scientists already pay their attention to this phenomenon, but the features they suggest are not exhaustive and even the most widespread, in this regard, there is an obvious need to systematize the available developments and identify those features of keystroke dynamics, which are the highest priority for their use in order to solve and investigate crimes. It is to present this information that the present work has been prepared.

Keywords: *keyboard handwriting, biometric characteristic, biometrics, forensic identification, keyboard handwriting features, performer identification, computer crimes.*

Introduction

Biometric data have always been of particular interest to forensic science: just as they are used in the field of personal and commercial (in banks, for example[1]) information security[2], they can be used to identify a person for the purposes of crime detection and investigation[3]. Today, the interest of the professional community in this area is becoming more and more noticeable, as modern technologies allow to study previously inaccessible features of a person, significantly increasing the variety of data that form the basis of biometric identification. Thus, in the works devoted to this topic, the following sources are considered or simply named: appearance

---

[1] *Mondol S. K., Tang W., Hasan S. A.* A Case Study of IoT Based Biometric Cyber Security Systems Focused on the Banking Sector // International Conference on Expert Clouds and Applications, India, March 2023. 2023. Pp. 1–13.

[2] *Golovenchik G. G.* Problemy kiberbezopasnosti v usloviyakh tsifrovoy transformatsii ekonomiki i obshchestva [Problems of cyber security in the conditions of digital transformation of economy and society] // Ekonomika. Upravlenie. Innovatsii [Economics. Management. Innovations]. 2018. No. 2 (4). Pp. 23–33; *Siahaan C. R. P., Chowanda A.* Spoofing keystroke dynamics authentication through synthetic typing pattern extracted from screen-recorded video // Journal of Big Data. 2022. Vol. 9 (111). Pp. 1–29.

[3] For example: *Ekwunife R. A., Ojiaku K., Ukeje I. O.* Evaluation of CCTV And Biometrics as ICT Tools for Curbing Criminality in Nigeria: A Study of Ebonyi State Police Command Abakaliki // Akpauche: International Journal of Arts and Social Sciences. 2020. Vol. 1. No 2. Pp. 96–105; *Amer M., Bari M. A., Khare A.* Fingerprint Image Identification for Crime Detection // International Journal for Advanced Research in Science & Technology. 2022. Vol. 12. Issue 10. Pp. 144–126.

in general, papillary pattern, iris pattern, face shape, ear shape, lip pattern, vein pattern, flexor lines, gait, handwriting, keystroke dynamics, voice[1]. These biometric properties in most works are divided into two groups[2]: the first group, called "hard biometrics" includes biological (morphological, static) characteristics, which are inherent to a person from birth and manifested as an integral part of his body, are visible; the second group — "soft biometrics" — combines dynamic (physiological, behavioral) characteristics, which are manifested in the process of any human activity, and outside its context cannot be recorded by an outsider. The dichotomous approach is the most widespread, but it is not the only one: in scientific papers we can find another classification, within the framework of which morphological (related to the structure of individual body parts), behavioral (coinciding with what we call dynamic) and biological (characterizing the "internal part of the organism's life") traits are distinguished[3]. Today, more and more attention is paid to the latter group of behavioral characteristics, because unlike all the others, they cannot (from the point of view of modern technologies) be stolen or forged, and therefore, they allow to ensure greater information security and achieve more effective identification of the subject-carrier[4].

We will not dwell on the review of all behavioral characteristics, but given the tendency to abandon paper documents and transfer interaction, including official, into electronic form, we believe that the study of keystroke dynamics deserves special attention, especially in the framework of the low study of this issue in the legal sphere.

The present work is aimed at reviewing and systematizing the research of various features of keystroke dynamics, the increasing number of which allows us to talk about the increasing identification significance of this personal characteristic. In addition, we consider it necessary to pay special attention to the assessment of the possibility and admissibility of obtaining information about these or those features in the framework of criminal proceedings.

---

[1] *Zhu H., Li C., Yu B. [et al].* Research on the Key Application of Computer Biometric Technology in Power Self-Service Terminal // Advances in Artificial Intelligence, Big Data and Algorithms / G. Grigoras and P. Lorenz (Eds.). 2023. Pp. 943–948; *Shangina I.Yu.* Tekhnologii biometricheskoy identifikatsii: mirovaya i Rossiyskaya praktiki [Biometric identification technologies: world and Russian practice] // Innovatsii. Nauka. Obrazovanie [Innovations. Science. Education]. 2020. No. 18. Pp. 151–156; *Vacca J. R.* Biometric technologies and verification systems. Oxford: USA Linacre House, 2007. 625 p.

[2] *Dai X., Zhao R., Hu P., Munteanu A.* KD-Net: Continuous Keystroke Dynamics Based Human Identification from RGB-D Image Sequences // Sensor. 2023. Vol. 23 (20). Pp. 2–3.

[3] *Syed I. S. Z.* Soft Biometrics for Keystroke Dynamics. Computer Vision and Pattern Recognition. Universit´e de Caen Basse-Normandie, 2014. P. 2.

[4] *Stylios I., Kokolakis S., Thanou O., Chatzis S.* Behavioral Biometrics & Continuous User Authentication on Mobile Devices: A Survey // Information Fusion. 2021. Volume 66. Pp. 76–99.

Development of knowledge about keystroke dynamics

Keystroke dynamics, which is obvious from the term itself, appeared at the same time (or almost at the same time, as it takes, according to researchers' estimates, 6 months to form the typing skill[1]) with the appearance of the first computers, although some of its prototypes were observed in radio operators[2] and typists[3], with which we can quite agree — when pressing the keys, including typewriter keys, in any case the same muscles and brain departments that give motor commands[4]. However, as a systemic phenomenon, available and really important for scientific study, keystroke dynamics originated only from the era of widespread use of computer devices.

In 1975, the first paper was published that substantiated the possibility of identifying users of computer systems on the basis of fixation of typing patterns[5]. After that, independent scientific teams conducted several experiments among secretaries and programmers, establishing the stability of speed features, their reproducibility and uniqueness, which subsequently made it possible to draw an unambiguous conclusion about the prospect of using keystroke dynamics for information security purposes by granting access to the system only to the person whose keystroke dynamics samples had been stored earlier[6]. In 1980, a detailed scientific report was prepared in which, based on theoretical and experimental

---

[1] *Vorona V. A., Kostenko V. O.* Biometricheskie tekhnologii identifikatsii v sistemakh kontrolya i upravleniya dostupom [Biometric identification technologies in access control and management systems] // Computational Nanotechnology. 2016. No. 3. P. 239.

[2] *Bryan W. L., Harter N.* Studies in the physiology and psychology of the telegraphic language // Psychological review. 1987. № 4 (1). Pp. 27–53.

[3] *Nikulicheva E. O.* Analiz klaviaturnogo pocherka kak metod identifikatsii lichnosti [Analysis of keyboard handwriting as a method of personal identification] // Aktualnye voprosy sudebnoy psikhologicheskoy ekspertizy i kompleksnoy ekspertizy s uchastiem psikhologa. Perspektivy nauchnogo i prikladnogo issledovaniya pocherka: Sbornik materialov III mezhdunarodnoy nauchno-prakticheskoy konferentsii, Kaluga, 16–19 maya 2019 goda [Actual issues of forensic psychological examination and complex examination with the participation of a psychologist. Perspectives of scientific and applied research of handwriting: Collection of materials of the III International Scientific and Practical Conference, Kaluga, 16–19 May 2019] / Pod redaktsiey V. F. Engalycheva, E. V. Leonovoy. Kaluga: FBGOU VPO "Kaluzhskiy gosudarstvennyy universitet im. K. E. Tsiolkovskogo", 2019. P. 56.

[4] *Syed Idrus S. Z.* Soft Biometrics for Keystroke Dynamics. Computer Vision and Pattern Recognition. Universit´e de Caen Basse-Normandie, 2014. P. 9.

[5] *Spillane R.* Keyboard Apparatus for Personal Identification // IBM Technical Disclosure Bulletin. 1975. Vol. 17. № 3346.

[6] For example: *Monrose F., Rubin A.* Authentication via Keystroke Dynamics // Proceedings of the Fourth ACM Conference on Computer and Communication Security. 1997. Pp. 48–56; *Joyce R., Gupta G.* Identity authorization based on keystroke latencies // Commun. ACM. 1990. Vol. 33 (2). Pp. 168–176.

data, the possibility of authenticating users by analyzing the time of a set of digrams (two letters occurring sequentially in the text) was confirmed[1]. Let us point out that in Russia the greater informativeness of digrams (n-grams), compared to single characters, began to be discussed not so long ago[2].

In parallel with private studies, state-supervised studies were conducted. Thus, in 1977, a detailed report was published for the U.S. Armed Forces, which described more than 30 biometric indicators of personality, among which special attention was paid to typing style[3]. Scientists proposed an approximate plan for estimating typing speed for user identification, developed a corresponding program and conducted a successful experiment, which also proved that for one person the speed of typing paired characters in a name and the duration of pauses remain stable and are not reproduced by other persons. It should also be mentioned that the first studies of keystroke dynamics considered only its manifestations when users typed their own name[4], but later they began to talk about the possibility of fixing the features when typing a key phrase or arbitrary text[5].

In domestic science, attention to the phenomenon of keystroke dynamics was paid only at the end of the XX century, immediately defining it as a rather promising technology: for example, S.P. Rastorguev pointed out that identification by keystroke dynamics due to its simplicity seems to be a higher priority than the identification of a person by iris[6]. Today, research into this phenomenon largely repeats the conceptual framework established in the last century, differing in three main areas:

---

[1] *Gaines R., Lisowski W., Press S., Shapiro N.* Authentication by keystroke timing: some preliminary results. Rand Rep. R-2560-NSF, Rand Corporation, 1980. 51 p.

[2] For example: *Varnashina P.D., Bushueva M.E.* Issledovanie emotsionalnogo sostoyaniya cheloveka po klaviaturnomu pocherku [Study of the emotional state of a person by keyboard handwriting] // Informatsionnye sistemy i tekhnologii — 2019: Sbornik materialov XXV Mezhdunarodnoy nauchno-tekhnicheskoy konferentsii, Nizhniy Novgorod, 19 aprelya 2019 goda. Nizhniy Novgorod: Nizhegorodskiy gosudarstvennyy tekhnicheskiy universitet im. R.E. Alekseeva [Information Systems and Technologies — 2019: Proceedings of the XXV International Scientific and Technical Conference, Nizhny Novgorod, 19 April 2019. Nizhny Novgorod: R.E. Alekseev Nizhny Novgorod State Technical University], 2019. Pp. 591–595.

[3] *Forsen G., Nelson M., Staron R.Jr.* Personal attributes authentication techniques. Technical Report RADC-TR-77-333. Rome: Air Development Center, 1977. Pp. D-116–D-122.

[4] *Forsen G., Nelson M., Staron R.Jr.* Personal attributes authentication techniques. Technical Report RADC-TR-77-333. Rome: Air Development Center, 1977. P. D-118; *Brown M., Rogers S.J.* User identification via keystroke characteristics of typed names using neural networks // Int. J. Man-Mach. Stud. 1993. Vol. 39 (6). Pp. 999–1014.

[5] *Pisani P.H., Lorena A.C.* A systematic review on keystroke dynamics // Journal of the Brazilian Computer Society. 2013. Vol. 19 (4). P. 575.

[6] *Rastorguev S.P.* Programmnye metody zashchity informatsii v kompyuterakh i setyakh [Programme methods of information protection in computers and networks]. M.: Izdatelstvo Agentstva "Yakhtsmen", 1993. P. 64.

1) the complexity of technological solutions proposed for automatic identification of users by keystroke dynamics features; 2) the variety and diversity of investigated keystroke dynamics features; 3) the consideration of confounding factors.

We will dwell only on the second aspect, having previously summarized the above described: at the initial stages of development of knowledge about keystroke dynamics, scientists investigated only velocity — i.e. the number of characters typed by the operator per unit of time — or temporal characteristics — the retention time of individual keys and intervals between successive presses. This approach is well-established in science and can rightfully be considered traditional: often modern studies are limited to the description of these indicators[1], and if a wider list of features is given in the work, speed, retention time and interval duration are definitely mentioned.

Modern system of keystroke dynamics features

As it was mentioned earlier, over half a century of research, scientists have revealed a considerable variety of keystroke dynamics features. The analysis of more than 600 works by various authors on the corresponding topic allows us to give a generalized list of these features, structured in descending order of their prevalence (see Table No. 1).

Table No. 1

Frequency of mentioning keystroke dynamics in scientific studies

Feature	Frequency of mentioning (%)[2]
Key hold time	100
Intervals between keystrokes	100

[1] For example: *Guzik V. F., Desyaterik M. N.* Biometricheskiy metod autentifikatsii polzovatelya [Biometric method of user authentication] // Izvestiya TRTU. 2000. No. 2 (16). Pp. 129–133; *Lozhnikov P. S., Sulavko A. E., Buraya E. V., Eremenko A. V.* Sposoby generatsii klyuchevykh posledovatelnostey na osnove klaviaturnogo pocherka [Methods of key sequence generation based on keyboard handwriting] // Dinamika sistem, mekhanizmov i mashin [Dynamics of systems, mechanisms and machines]. 2016. No. 4. P. 265–270; *Khmyz A. I.* Razgranichenie identifikatsionnykh priznakov pri ustanovlenii interaktivnogo polzovatelya [Distinguishing the identification attributes when establishing an interactive user] // Tsifrovaya transformatsiya: obrazovanie, nauka, obshchestvo. Moskva: Avtonomnaya nekommercheskaya organizatsiya Tsentralnyy nauchno-issledovatelskiy institut russkogo zhestovogo yazyka [Digital Transformation: Education, Science, Society. Moscow: Autonomous non-profit organization Central Research Institute of Russian Sign Language], 2019. P. 349.

[2] Of course, we have not studied all the works on this topic, but the available sample allows us to generalize, which is reflected in this table.

Table No. 1

Feature	Frequency of mentioning (%)
Input speed[1].	64
Characteristic of overlaps — the time during which the previous key is not yet released when a key is pressed; sometimes this characteristic is considered as a manifestation of the interval feature (negative interval)[2].	62
Frequency and content of errors made by the user[3]	19
Use of service keys (one can also encounter proposals to consider the frequency of accessing them not in the aggregate, but for each specific key (combination of keys)[4]; in turn, some authors, on the contrary,	15

[1] For example: *Alekseev A. A., Voevodin V. A., Prokhorova V. V.* Klaviaturnyy pocherk kak sredstvo autentifikatsii subekta dostupa k informatsionnym resursam [Keyboard handwriting as a means of authentication of the subject of access to information resources] // Materialy nauchno-tekhnicheskoy konferentsii "Mikroelektronika i informatika — 2022": Sbornik statey konferentsii, Moskva, 21–22 aprelya 2022 goda. Moskva: Natsionalnyy issledovatelskiy universitet "Moskovskiy institut elektronnoy tekhniki" [Proceedings of the Scientific and Technical Conference "Microelectronics and Informatics — 2022": Collection of conference papers, Moscow, 21-22 April 2022. Moscow: National Research University "Moscow Institute of Electronic Technology"], 2022. P. 4; *Boriskin S. M.* Razrabotka protsedur, realizuyushchikh autentifikatsiyu i registratsiyu parametrov kompyuternogo pocherka pri kompleksnom podkhode k autentifikatsii [Development of procedures realising authentication and registration of computer handwriting parameters at the complex approach to authentication] // Estestvennye i tekhnicheskie nauki [Natural and Technical Sciences]. 2010. No. 5 (48). P. 474; *Liu W.-M., Yeh C.-L., Chen P.-W. [et al].* Keystroke Biometrics as a Tool for the Early Diagnosis and Clinical Assessment of Parkinson's Disease // Diagnostics. 2023. Vol. 13 (19). No. 3061. P. 5.

[2] For example: *Sulavko A. E., Shalina E. V.* Biometricheskaya autentifikatsiya polzovateley informatsionnykh sistem po klaviaturnomu pocherku na osnove immunnykh setevykh algoritmov [Biometric authentication of information system users by keyboard handwriting based on immune network algorithms] // Prikladnaya informatika [Applied Informatics]. 2019. V. 14. No. 3 (81). P. 40; *Presnukhin R. S.* Postroenie modeli protsedury autentifikatsii dlya doverennogo nositelya informatsii na baze flash-nakopitelya [Building a model of authentication procedure for a trusted flash-based storage medium] // Vestnik Nauki i Tvorchestva [Bulletin of Science and Creativity]. 2016. No. 5 (5). P. 382.

[3] For example: *Latt Ch. V.* Vliyanie izmerennykh kharakteristik "pocherka" polzovatelya vychislitelnoy seti na veroyatnost ego identifikatsii logicheskoy neyronnoy setyu po etalonu [Influence of the measured characteristics of the "handwriting" of a computer network user on the probability of his identification by a logical neural network according to the standard] // Estestvennye i tekhnicheskie nauki [Natural and Technical Sciences]. 2011. No. 2 (52). P. 171; *Kolakowska A.* Generating training data for SART-2 keystroke analysis module // Proceedings of the 2nd International Conference on Information Technology (ICIT'10). 2010. Pp. 57–60.

[4] *Latt C. V.* Influence of the measured characteristics of the «handwriting» of a computer network user on the probability of his identification by a logical neural network according to the standard // Natural and Technical Sciences. 2011. № 2 (52). P. 420.

Table No. 1

Feature	Frequency of mentioning (%)
propose to specifically exclude the information about pressing service keys from the number of fixed features[1])[2].	
Intervals between presses of dual and strobed sequentially arranged groups of characters (n-graphs / n-grams)[3]	12
Vibro-sound characteristics of printing[4]	8
Arrhythmicity of printing — characteristic of deviations exceeding the confidence interval at normal distribution[5]	6

[1] *Vorona V. A., Kostenko V. O.* Biometricheskie tekhnologii identifikatsii v sistemakh kontrolya i upravleniya dostupom [Biometric identification technologies in access control and management systems] // Computational Nanotechnology. 2016. No. 3. P. 238.

[2] For example: *Turutina E. E.* Analiz metodov elektronnoy i biometricheskoy autentifikatsii v sistemakh kontrolya dostupom [Analysis of electronic and biometric authentication methods in access control systems] // Vestnik NTsBZhD [Bulletin of the Life Safety Research Center]. 2021. No. 2 (48). P. 171; *Varlamova S. A., Vavilina E. A.* Identifikatsiya polzovatelya na osnove klaviaturnogo pocherka [User identification based on keyboard handwriting] // Innovatsionnoe priborostroenie [Innovation Instrument Engineering]. 2023. V. 2. No. 3. Pp. 67–71.

[3] For example: *Princy A. T., Lakshmi P.A, Suvanam S. B.* A Review of Behaviometric Techniques for User Authentication // IOSR Journal of Computer Engineering (IOSR-JCE). 2016. Pp. 11–14; *Varnashina P. D., Bushueva M. E.* Issledovanie emotsionalnogo sostoyaniya cheloveka po klaviaturnomu pocherku [Study of the emotional state of a person by keyboard handwriting] // Informatsionnye sistemy i tekhnologii — 2019: Sbornik materialov XXV Mezhdunarodnoy nauchno-tekhnicheskoy konferentsii, Nizhniy Novgorod, 19 aprelya 2019 goda. Nizhniy Novgorod: Nizhegorodskiy gosudarstvennyy tekhnicheskiy universitet im. R. E. Alekseeva [Information Systems and Technologies — 2019: Proceedings of the XXV International Scientific and Technical Conference, Nizhny Novgorod, 19 April 2019. Nizhny Novgorod: R. E. Alekseev Nizhny Novgorod State Technical University], 2019. Pp. 591–595; *Chen M. H., Leow A., Ross M. K. [et al].* Associations between smartphone keystroke dynamics and cognition in MS // Digital Health. 2022. Vol. 8. P. 3. DOI: 10.1177/20552076221143234.

[4] For example: *Nonaka H., Kurihara M.* Sensing Pressure for Authentication System Using Keystroke Dynamics // International Journal of Computer, Control, Quantum and Information Engineering. 2007. Vol. 1. № 1. Pp. 152–155; *Fedorov V. M., Rublev D. P.* Obrabotka vibroakusticheskikh shumov, voznikayushchikh pri rabote polzovatelya s klaviaturoy [Processing of vibroacoustic noises occurring when a user works with a keyboard] // Izvestiya YuFU. Tekhnicheskie nauki [Bulletin of the Southern Federal University. Technical Sciences]. 2012. No. 12 (137). Pp. 75–81; *Nguyen T. T., Le T. H., Le B. H.* Keystroke dynamics extraction by independent component analysis and bio-matrix for user authentication // Proceedings of the 11th Pacific Rim International Conference on Trends in Artificial Intelligence, Daegu, Republic of Korea. 2010. Pp. 477–486.

[5] For example: *Sapiev A. Z.* Kompyuternyy pocherk kak sposob identifikatsii polzovateley v seti [Computer handwriting as a way to identify users in the network] // Vestnik Vologodskogo gosudarstvennogo universiteta. Seriya: Tekhnicheskie nauki [Bulletin of Vologda State University. Series: Technical Sciences]. 2021. No. 4 (14). P. 17; *Bryukhomitskiy Yu. A., Kazarin M. N.* Vydelenie informativnykh biometricheskikh parametrov v sistemakh klaviaturnogo monitoring [Selection of informative biometric parameters in keyboard monitoring systems] // Informatsionnoe protivodeystvie ugrozam terrorizma [Information counteraction to threats of terrorism]. 2010. No. 14. P. 143.

Table No. 1

Feature	Frequency of mentioning (%)
Press force[1]	3
Spatial orientation of presses[2]	2

Let us briefly characterize the features given in Table No. 1.

1) Key pressing (holding) duration is the time from the beginning of pressure on the key to its complete release, measured in milliseconds (ms) and calculated as the difference between two points: the time of the beginning of pressure on the key and the time of its release.

2) Duration of press intervals — the time between the release of one key and the beginning of pressing the next key. It can take negative values if the next key is pressed while the previous key is still pressed. It is also calculated as the difference between two time events.

As it was mentioned earlier, the interval can be considered between the presses of individual keys linearly or within groups of typical n-grams (letter combinations, most often of 2–3 characters).

3) Input speed — the number of characters typed per unit of time (e.g. a minute).

---

[1] For example: *Le T. H., Le B.* Keystroke dynamics extraction by independent component analysis and bio-matrix for user authentication // *Zhang B. T., Orgun M. A.* (eds) PRICAI 2010: Trends in Artificial Intelligence. PRICAI 2010. Lecture Notes in Computer Science. Vol 6230. Berlin, Heidelberg: Springer, 2010. Pp. 477–478; *Lv H.-R., Wang W.-Y.* Biologic verification based on pressure sensor keyboards and classifier fusion techniques // IEEE Transactions on Consumer Electronics. 2006. Vol. 52 (3). Pp. 1057–1063; *Eremenko A. V., Sulavko A. E., Mishin D. V., Fedotov A. A.* Identifikatsionnyy potentsial klaviaturnogo pocherka s uchetom parametrov vibratsii i sily nazhatiya na klavishi [Identification potential of keyboard handwriting taking into account the parameters of vibration and force of pressing the keys] // Prikladnaya informatika [Applied Informatics]. 2017. V. 12. No. 1 (67). P. 83.

[2] *Nikulicheva E. O.* Analiz klaviaturnogo pocherka kak metod identifikatsii lichnosti [Analysis of keyboard handwriting as a method of personal identification] // Aktualnye voprosy sudebnoy psikhologicheskoy ekspertizy i kompleksnoy ekspertizy s uchastiem psikhologa. Perspektivy nauchnogo i prikladnogo issledovaniya pocherka: Sbornik materialov III mezhdunarodnoy nauchno-prakticheskoy konferentsii, Kaluga, 16–19 maya 2019 goda [Actual issues of forensic psychological examination and complex examination with the participation of a psychologist. Perspectives of scientific and applied research of handwriting: Collection of materials of the III International Scientific and Practical Conference, Kaluga, 16–19 May 2019] / Pod redaktsiey V. F. Engalycheva, E. V. Leonovoy. Kaluga: FBGOU VPO "Kaluzhskiy gosudarstvennyy universitet im. K. E. Tsiolkovskogo", 2019. P. 56; *Batskikh A. V., Drovnikova I. G., Zarubin V. S.* Bazovye aspekty modifikatsii podsistem upravleniya dostupom k informatsii v avtomatizirovannykh sistemakh organov vnutrennikh del na osnove issledovaniya klaviaturnogo pocherka polzovateley [Basic aspects of modification of subsystems of information access control in automated systems of internal affairs bodies on the basis of research of keyboard handwriting of users] // Vestnik Voronezhskogo instituta MVD Rossii [Bulletin of the Voronezh Institute of the Ministry of Internal Affairs of Russia]. 2022. No. 4. P. 22.

4) Characterization of errors made by the user implies evaluation of two independent features: first, the frequency of such violations, i.e. the percentage ratio of errors to the total text volume; second, the typical user errors themselves, i.e. those violations of typing correctness that are peculiar to a particular person and occur regularly.

It should be noted that the works often combine errors and misprints, whereas in our opinion, they are independent types of printing irregularities and allow us to draw various conclusions about the personality of the executor of the printed text.

Thus, errors are made in connection with the presence of certain gaps in education, when a person, not having sufficient knowledge about the correct spelling of a word or the placement of punctuation marks, reproduces the variant that seems to him to correspond to the norms of the language. In turn, systemic typos appear due to movement coordination disorders, when a person knows how a word (sentence) should be written, but at speed loses or duplicates individual letters or signs (in particular, spaces), prints the wrong letter, distorts the ending, which violates coordination, etc.

5) Frequency of using service keys — the number of times the user accesses the keys, the signal from which does not create any readable character, during a working session.

Here it is also necessary to take into account the frequency of user access to the keys that change the functionality of other keys, change the keyboard layer, etc. when combined with other keys.

6) Vibro-sound characteristics of printing are not so much a feature as an indicator from which various attributes can be derived: key holding time, intervals between presses, printing speed, etc. The potential use of this indicator is based on the individuality of the sound of each keyboard key[1].

7) Typing rhythmicity — stability of all other features, determined through the evaluation of deviations from the formed stereotype of the user's keystroke dynamics within the confidence interval.

8) Pressure force — the amount of force with which the user exerts pressure on the key.

This attribute can also be represented through the description of the pressing depth, i.e. the distance between the key position in the "resting" state and the maximum point of its deepening when pressed by the user.

9) Spatial orientation of presses — specific coordinates of the place where the user's fingers make contact with the key.

---

[1] *Harrison J., Toreini E., Mehrnezhad M.* A Practical Deep Learning-Based Acoustic Side Channel Attack on Keyboards (Preprint) // IEEE European Symposium on Security and Privacy Workshop, SiLM'23 (EuroS&PW). 2023. URL: https://arxiv.org/abs/2308.01074 (accessed: 23.12.2023).

It should be noted that the Table No. 1. does not reflect those features that occur in less than 1% of the studied works, in particular, such as the model of making corrections[1], the fact of using the main or additional keyboard and typical techniques and methods of working on the keyboard[2]. Such a rare consideration of them, as it seems, may be due to insufficient scientific elaboration, as well as the low identification significance of these features, which, however, is not a reason to completely ignore them, because together with other characteristics, they are able to form a forensically significant set necessary for the formation of the identification field.

Some authors also propose to pay attention to the stylistic features of the text, words and phrases specific to the user within the study of keystroke dynamics[3]. Without disputing the identification significance of this feature, we note that its study is located in the sphere of linguistic examination, which is designed to complement any handwriting research, but cannot be replaced by the latter.

Features of keystroke dynamics: forensic aspect

Legal works devoted to the topic of keystroke dynamics also consider its features. A very detailed characterization is given by E. I. Foygel, who notes that the most important of them are: the dynamics of input (the time between pressing the keys and the time of their retention), typing speed (the time it takes the user to search for the desired character on the keyboard), typing speed (the result of dividing the number of characters by the typing time), the intensity of pressure (the force of

---

[1] *Panfilova I. E., Karpova N. E.* Issledovanie vliyaniya sostoyaniya polzovatelya na kachestvo autentifikatsii po klaviaturnomu pocherku [Investigation of the influence of the user state on the quality of authentication by keyboard handwriting] // Dinamika sistem, mekhanizmov i mashin [Dynamics of systems, mechanisms and machines]. 2021. V. 9. No. 4. P. 71.

[2] *Nikulicheva E. O.* Analiz klaviaturnogo pocherka kak metod identifikatsii lichnosti [Analysis of keyboard handwriting as a method of personal identification] // Aktualnye voprosy sudebnoy psikhologicheskoy ekspertizy i kompleksnoy ekspertizy s uchastiem psikhologa. Perspektivy nauchnogo i prikladnogo issledovaniya pocherka: Sbornik materialov III mezhdunarodnoy nauchno-prakticheskoy konferentsii, Kaluga, 16–19 maya 2019 goda [Actual issues of forensic psychological examination and complex examination with the participation of a psychologist. Perspectives of scientific and applied research of handwriting: Collection of materials of the III International Scientific and Practical Conference, Kaluga, 16–19 May 2019] / Pod redaktsiey V. F. Engalycheva, E. V. Leonovoy. Kaluga: FBGOU VPO "Kaluzhskiy gosudarstvennyy universitet im. K. E. Tsiolkovskogo", 2019. P. 56.

[3] *Sapiev A. Z.* Priznaki identifikatsii polzovateley informatsionnykh sistem po kompyuternomu pocherku [Signs of identification of information systems users by computer handwriting] // Informatsionnye tekhnologii v modelirovanii i upravlenii: podkhody, metody, resheniya: IV Vserossiyskaya nauchnaya konferentsiya s mezhdunarodnym uchastiem: Sbornik materialov, Tolyatti, 20–22 aprelya 2021 goda [Information technologies in modelling and management: approaches, methods, solutions: IV All-Russian scientific conference with international participation: Proceedings, Togliatti, 20-22 April]. Tolyatti: Tolyattinskiy gosudarstvennyy universitet, 2021. P. 159.

impact on the keyboard key), the duration and structure of pauses and delays, the features of the implementation of keys (use of keys for typing certain characters)[1].

I. Z. Fedorov proposes to limit the list of keystroke dynamics features at the normative level to the following characteristics: "input speed — the ratio of the number of entered characters to the typing time; input dynamics — the time intervals between keystrokes and their retention; frequency of typing errors; characteristic use of keys — which function keys the operator presses when performing certain operations when typing an electronic text"[2].

As we can see, both works almost completely reproduce a single set of features, without justifying their choice and the reasons why they are "the most important". The results of our analysis, reflected in Table No. 1, show that the selected attributes are the most widespread in terms of frequency of their mentioning in specialized computer-technical works, but, for example, the nature of overlapping, which is considered more often than the frequency of errors, has not been reflected in legal studies. It also seems not quite correct to limit the list of features that will be further studied for identification to a "magic number" for memory retention: 4–7 items[3].

This is especially important if we take into account that "the correlation between the features of different categories in almost all cases does not exceed 0.7 and mainly corresponds to a weak dependence on the Cheddock scale[4] or is absent at all, in some cases (no more than 15%) the dependence is moderate, very rarely noticeable (less than 3%). That is, the information in the attributes from different categories is not duplicated, the channels for obtaining the attributes can be considered weakly

---

[1] *Foygel E. I.* Nekotorye vozmozhnosti ispolzovaniya povedencheskoy biometrii v rassledovanii prestupleniy [Some possibilities of using behavioral biometrics in crime investigation] // Razvitie rossiyskogo obshchestva: vyzovy sovremennosti: Materialy natsionalnoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem, posvyashchennoy 90-letiyu Baykalskogo gosudarstvennogo universiteta, Irkutsk, 15–16 oktyabrya 2020 goda. Irkutsk: Baykalskiy gosudarstvennyy universitet [Development of Russian society: challenges of modernity: Proceedings of the national scientific-practical conference with international participation, dedicated to the 90th anniversary of Baikal State University, Irkutsk, 15–16 October 2020. Irkutsk: Baikal State University], 2021. P. 418.

[2] *Fedorov I. Z.* K voprosu ob ustanovlenii ispolnitelya elektronnogo teksta po klaviaturnomu pocherku pri raskrytii i rassledovanii prestupleniy [To the issue of establishing the executor of electronic text by keyboard handwriting in the detection and investigation of crimes] // Vestnik Barnaulskogo yuridicheskogo instituta MVD Rossii [Bulletin of Barnaul Law Institute of the Ministry of Internal Affairs of Russia]. 2019. No. 2 (37). P. 115.

[3] *Miller G. A.* The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information // The Psychological Review. 1956. Vol. 63. Pp. 81–97.

[4] The Cheddock scale is used in statistical research to assess the influence of one (quantitative) indicator on another (qualitative) one, i.e. to determine correlation relations. If the value of the correlation coefficient is from 0.1 to 0.3, the relationship is considered insignificant; 0.4–0.5 — moderate; 0.6–0.7 — appreciable; 0.8–0.9 — high; 0.91–0.99 — strong. In the study whose findings are reported, the mean correlation coefficient was 0.37.

dependent"[1]. It follows that the collection and study of the maximum possible number of various features will increase the accuracy of identification of the executor of the printed text. However, this is not completely possible in the conditions of criminal proceedings.

Thus, for example, to record the force of pressing it is necessary to develop a modernized keyboard, in which it is necessary to install a pressure sensor under each key, which is not economically feasible; when assessing vibration and sound characteristics, additional equipment equipped with an accelerometer is required (in this capacity it can be smartphone, which is constantly accessible to the subjects conducting criminal prosecution); to record the spatial orientation of keystrokes, the number of fingers used, the distribution of zones on the keyboard between different fingers requires constant external observation, which is also very difficult to ensure in the conditions of criminal proceedings and, even more so, before the initiation of criminal proceedings. In turn, all the other features that have been listed, as well as some derivatives of them, can be recorded on a special device — keylogger. Thus, for example, it seems possible, within the framework of operative-search activity of obtaining computer information, to tacitly send a program to the computer device of the person under surveillance, which will record the way this person types and transmit the specified information to the law enforcement agency, after which it will be possible to reliably confirm that the specified person was engaged in the publication and dissemination of criminal (e.g. extremist) texts, carried out a conspiracy to commit a crime in messenger, even if he or she used various means of anonymization.

Conclusion

Interpersonal interaction, work and life in general are rapidly moving into the digital space, accompanied by the replacement of handwritten texts by printed ones. This trend is also observed in the criminal sphere, which is confirmed by the ever-increasing number of computer crimes committed. In this regard, forensics should develop new approaches to investigation, including the use of technological solutions from computer science. One of the possible directions of such borrowing is the study of keystroke dynamics, which will allow to reliably determine the executor of the printed text, as the study of classical handwriting helps to identify the executor of a manuscript. Intensification of work on this topic from the point of view of jurisprudence will increase the disclosure of crimes

[1] *Eremenko A. V., Sulavko A. E., Mishin D. V., Fedotov A. A.* Identifikatsionnyy potentsial klaviaturnogo pocherka s uchetom parametrov vibratsii i sily nazhatiya na klavishi [Identification potential of keyboard handwriting taking into account the parameters of vibration and force of pressing the keys] // Prikladnaya informatika [Applied Informatics]. 2017. V. 12. No. 1 (67). P. 88.

related to the distribution of texts with criminal content on the Internet, creation and maintenance of "death groups", corruption of minors, forgery of documents (e.g., accounting reports), etc.

To date, computer scientists have investigated the phenomenon of keystroke dynamics quite deeply: they have identified a significant number of features that can form the necessary for identification aggregate, resistant to a variety of, including deliberately created, confounding factors; experimentally proved the uniqueness of these features and the possibility of identifying the user of a computer device with a high degree of accuracy; developed a significant number of algorithms for the identification of the executor of the keystroke dynamics. Thus, criminal science now face the task, based on the existing developments, to adapt the technology of identification of a person by the features of keystroke dynamics for the purposes of detection and investigation of crimes, to justify the legal possibility of fixing the features of keystroke dynamics from the standpoint of observing the balance between the interests of justice and human rights and to propose an applied model, according to which the process of fixation, storage, research and use of the information will be realized. In order to effectively combat computer crimes in the creation and dissemination of various electronic texts, it is necessary to start solving these problems today.

Acknowledgements

The research was supported by the grant of the Russian Science Foundation № 23-78-10011, https://rscf.ru/project/23-78-10011/.

References

Alekseev A. A., Voevodin V. A., Prokhorova V. V. Klaviaturnyy pocherk kak sredstvo autentifikatsii subekta dostupa k informatsionnym resursam [Keyboard handwriting as a means of authentication of the subject of access to information resources] // Materialy nauchno-tekhnicheskoy konferentsii "Mikroelektronika i informatika — 2022": Sbornik statey konferentsii, Moskva, 21–22 aprelya 2022 goda. Moskva: Natsionalnyy issledovatelskiy universitet "Moskovskiy institut elektronnoy tekhniki" [Proceedings of the Scientific and Technical Conference "Microelectronics and Informatics — 2022": Collection of conference papers, Moscow, 21–22 April 2022. Moscow: National Research University "Moscow Institute of Electronic Technology"], 2022. Pp. 3–7. (In Russian)

Amer M., Bari M. A., Khare A. Fingerprint Image Identification for Crime Detection // International Journal for Advanced Research in Science & Technology. 2022. Vol. 12. Issue 10. Pp. 144–126. (In English)

Batskikh A. V., Drovnikova I. G., Zarubin V. S. Bazovye aspekty modifikatsii podsistem upravleniya dostupom k informatsii v avtomatizirovannykh sistemakh organov vnutrennikh del na osnove issledovaniya klaviaturnogo pocherka polzovateley [Basic aspects of modification of subsystems of information access control in automated systems of internal affairs bodies on the basis of research of keyboard handwriting of users] // Vestnik Voronezhskogo instituta MVD Rossii [Bulletin of the Voronezh Institute of the Ministry of Internal Affairs of Russia]. 2022. No. 4. Pp. 21–32. (In Russian)

Boriskin S. M. Razrabotka protsedur, realizuyushchikh autentifikatsiyu i registratsiyu parametrov kompyuternogo pocherka pri kompleksnom podkhode k autentifikatsii [Development of procedures realising authentication and registration of computer handwriting parameters at the complex approach to authentication] // Estestvennye i tekhnicheskie nauki [Natural and Technical Sciences]. 2010. No. 5 (48). Pp. 473–478. (In Russian)

Brown M., Rogers S. J. User identification via keystroke characteristics of typed names using neural networks // Int. J. Man-Mach. Stud. 1993. Vol. 39 (6). Pp. 999–1014. (In English)

Bryan W. L., Harter N. Studies in the physiology and psychology of the telegraphic language // Psychological review. 1987. №4 (1). Pp. 27–53. (In English)

Bryukhomitskiy Yu. A., Kazarin M. N. Vydelenie informativnykh biometricheskikh parametrov v sistemakh klaviaturnogo monitoring [Selection of informative biometric parameters in keyboard monitoring systems] // Informatsionnoe protivodeystvie ugrozam terrorizma [Information counteraction to threats of terrorism]. 2010. No. 14. Pp. 139–143. (In Russian)

Chen M. H., Leow A., Ross M. K. [et al]. Associations between smartphone keystroke dynamics and cognition in MS // Digital Health. 2022. Vol. 8. Pp. 1–12. (In English)

Dai X., Zhao R., Hu P., Munteanu A. KD-Net: Continuous Keystroke Dynamics Based Human Identification from RGB-D Image Sequences // Sensor. 2023. Vol. 23 (20). Pp. 1–16. (In English)

Ekwunife R. A., Ojiaku K., Ukeje I. O. Evaluation of CCTV And Biometrics as ICT Tools for Curbing Criminality in Nigeria: A Study of Ebonyi State Police Command Abakaliki // Akpauche: International Journal of Arts and Social Sciences. 2020. Vol. 1. No. 2. Pp. 96–105. (In English)

Eremenko A. V., Sulavko A. E., Mishin D. V., Fedotov A. A. Identifikatsionnyy potentsial klaviaturnogo pocherka s uchetom parametrov vibratsii i sily nazhatiya na klavishi [Identification potential of keyboard handwriting taking into account the parameters of vibration and force of pressing the keys] // Prikladnaya informatika [Applied Informatics]. 2017. Vol. 12. No. 1 (67). Pp. 79–94. (In Russian)

Fedorov I. Z. K voprosu ob ustanovlenii ispolnitelya elektronnogo teksta po klaviaturnomu pocherku pri raskrytii i rassledovanii prestupleniy [To the issue of establishing the executor of electronic text by keyboard handwriting in the detection and investigation of crimes] // Vestnik Barnaulskogo yuridicheskogo instituta MVD Rossii [Bulletin of Barnaul Law Institute of the Ministry of Internal Affairs of Russia]. 2019. No. 2 (37). Pp. 113–116. (In Russian)

Fedorov V. M., Rublev D. P. Obrabotka vibroakusticheskikh shumov, voznikayushchikh pri rabote polzovatelya s klaviaturoy [Processing of vibroacoustic noises occurring when a user works with a keyboard] // Izvestiya YuFU. Tekhnicheskie nauki [Bulletin of the Southern Federal University. Technical Sciences]. 2012. No. 12 (137). Pp. 75–81. (In Russian)

Forsen G., Nelson M., Staron R. Jr. Personal attributes authentication techniques. Technical Report RADC-TR-77-333. Rome: Air Development Center, 1977. 333 p. (In English)

Foygel E. I. Nekotorye vozmozhnosti ispolzovaniya povedencheskoy biometrii v rassledovanii prestupleniy [Some possibilities of using behavioral biometrics in crime investigation] // Razvitie rossiyskogo obshchestva: vyzovy sovremennosti: Materialy natsionalnoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem, posvyashchennoy 90-letiyu Baykalskogo gosudarstvennogo universiteta, Irkutsk, 15–16 oktyabrya 2020 goda. Irkutsk: Baykalskiy gosudarstvennyy universitet [Development of Russian society: challenges of modernity: Proceedings of the national scientific-practical conference with international participation, dedicated to the 90th anniversary of Baikal State University, Irkutsk, 15–16 October 2020. Irkutsk: Baikal State University], 2021. Pp. 417–420. (In Russian)

Gaines R., Lisowski W., Press S., Shapiro N. Authentication by keystroke timing: some preliminary results. Rand Rep. R-2560-NSF, Rand Corporation, 1980. 51 p. (In English)

Golovenchik G. G. Problemy kiberbezopasnosti v usloviyakh tsifrovoy transformatsii ekonomiki i obshchestva [Problems of cyber security in the conditions of digital transformation of economy and society] // Ekonomika. Upravlenie. Innovatsii [Economics. Management. Innovations]. 2018. No. 2 (4). Pp. 23–33. (In Russian)

Guzik V. F., Desyaterik M. N. Biometricheskiy metod autentifikatsii polzovatelya [Biometric method of user authentication] // Izvestiya TRTU. 2000. No. 2 (16). Pp. 129–133. (In Russian)

Joyce R., Gupta G. Identity authorization based on keystroke latencies // Commun. ACM. 1990. Vol. 33 (2). Pp. 168–176. (In English)

Khmyz A. I. Razgranichenie identifikatsionnykh priznakov pri ustanovlenii interaktivnogo polzovatelya [Distinguishing the identification attributes when establishing an interactive user] // Tsifrovaya transformatsiya: obrazovanie,

nauka, obshchestvo. Moskva: Avtonomnaya nekommercheskaya organizatsiya Tsentralnyy nauchno-issledovatelskiy institut russkogo zhestovogo yazyka [Digital Transformation: Education, Science, Society. Moscow: Autonomous non-profit organization Central Research Institute of Russian Sign Language], 2019. Pp. 343–350. (In Russian)

Kolakowska A. Generating training data for SART-2 keystroke analysis module // Proceedings of the 2nd International Conference on Information Technology (ICIT'10). 2010. Pp. 57–60. (In English)

Latt Ch. V. Vliyanie izmerennykh kharakteristik "pocherka" polzovatelya vychislitelnoy seti na veroyatnost ego identifikatsii logicheskoy neyronnoy setyu po etalonu [Influence of the measured characteristics of the "handwriting" of a computer network user on the probability of his identification by a logical neural network according to the standard] // Estestvennye i tekhnicheskie nauki [Natural and Technical Sciences]. 2011. No. 2 (52). Pp. 420–422. (In Russian)

Le T. H., Le B. Keystroke dynamics extraction by independent component analysis and bio-matrix for user authentication // Zhang B. T., Orgun M. A. (eds) PRICAI 2010: Trends in Artificial Intelligence. PRICAI 2010. Lecture Notes in Computer Science. Vol. 6230. Berlin, Heidelberg: Springer, 2010. Pp. 477–486. (In English)

Liu W.-M., Yeh C.-L., Chen P.-W. [et al]. Keystroke Biometrics as a Tool for the Early Diagnosis and Clinical Assessment of Parkinson's Disease // Diagnostics. 2023. Vol. 13 (19). No. 3061. Pp. 1–11. (In English)

Lozhnikov P. S., Sulavko A. E., Buraya E. V., Eremenko A. V. Sposoby generatsii klyuchevykh posledovatelnostey na osnove klaviaturnogo pocherka [Methods of key sequence generation based on keyboard handwriting] // Dinamika sistem, mekhanizmov i mashin [Dynamics of systems, mechanisms and machines]. 2016. No. 4. Pp. 265–270. (In Russian)

Lv H.-R., Wang W.-Y. Biologic verification based on pressure sensor keyboards and classifier fusion techniques // IEEE Transactions on Consumer Electronics. 2006. Vol. 52 (3). Pp. 1057–1063. (In English)

Miller G. A. The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information // The Psychological Review. 1956. Vol. 63. Pp. 81–97. (In English)

Mondol S. K., Tang W., Hasan S. A. A Case Study of IoT Based Biometric Cyber Security Systems Focused on the Banking Sector // International Conference on Expert Clouds and Applications, India, March 2023. 2023. Pp. 1–13. (In English)

Monrose F., Rubin A. Authentication via Keystroke Dynamics // Proceedings of the Fourth ACM Conference on Computer and Communication Security. 1997. Pp. 48–56. (In English)

Nguyen T. T., Le T. H., Le B. H. Keystroke dynamics extraction by independent component analysis and bio-matrix for user authentication // Proceedings of the

11th Pacific Rim International Conference on Trends in Artificial Intelligence, Daegu, Republic of Korea. 2010. Pp. 477–486. (In English)

Nikulicheva E. O. Analiz klaviaturnogo pocherka kak metod identifikatsii lichnosti [Analysis of keyboard handwriting as a method of personal identification] // Aktualnye voprosy sudebnoy psikhologicheskoy ekspertizy i kompleksnoy ekspertizy s uchastiem psikhologa. Perspektivy nauchnogo i prikladnogo issledovaniya pocherka: Sbornik materialov III mezhdunarodnoy nauchno-prakticheskoy konferentsii, Kaluga, 16–19 maya 2019 goda [Actual issues of forensic psychological examination and complex examination with the participation of a psychologist. Perspectives of scientific and applied research of handwriting: Collection of materials of the III International Scientific and Practical Conference, Kaluga, 16–19 May 2019] / Pod redaktsiey V. F. Engalycheva, E. V. Leonovoy. Kaluga: FBGOU VPO "Kaluzhskiy gosudarstvennyy universitet im. K. E. Tsiolkovskogo", 2019. Pp. 56–60. (In Russian)

Nonaka H., Kurihara M. Sensing Pressure for Authentication System Using Keystroke Dynamics // International Journal of Computer, Control, Quantum and Information Engineering. 2007. Vol. 1. № 1. Pp. 152–155. (In English)

Panfilova I. E., Karpova N. E. Issledovanie vliyaniya sostoyaniya polzovatelya na kachestvo autentifikatsii po klaviaturnomu pocherku [Investigation of the influence of the user state on the quality of authentication by keyboard handwriting] // Dinamika sistem, mekhanizmov i mashin [Dynamics of systems, mechanisms and machines]. 2021. Vol. 9. No. 4. Pp. 68–74. (In Russian)

Pisani P. H., Lorena A. C. A systematic review on keystroke dynamics // Journal of the Brazilian Computer Society. 2013. Vol. 19 (4). Pp. 573–585. (In English)

Presnukhin R. S. Postroenie modeli protsedury autentifikatsii dlya doverennogo nositelya informatsii na baze flash-nakopitelya [Building a model of authentication procedure for a trusted flash-based storage medium] // Vestnik Nauki i Tvorchestva [Bulletin of Science and Creativity]. 2016. No. 5 (5). Pp. 378–383. (In Russian)

Princy A. T., Lakshmi P. A., Suvanam S. B. A Review of Behaviometric Techniques for User Authentication // IOSR Journal of Computer Engineering (IOSR-JCE). 2016. Pp. 11–14. (In English)

Rastorguev S. P. Programmnye metody zashchity informatsii v kompyuterakh i setyakh [Programme methods of information protection in computers and networks]. M.: Izdatelstvo Agentstva "Yakhtsmen", 1993. 188 p. (In Russian)

Sapiev A. Z. Kompyuternyy pocherk kak sposob identifikatsii polzovateley v seti [Computer handwriting as a way to identify users in the network] // Vestnik Vologodskogo gosudarstvennogo universiteta. Seriya: Tekhnicheskie nauki [Bulletin of Vologda State University. Series: Technical Sciences]. 2021. No. 4 (14). Pp. 17–19. (In Russian)

Sapiev A. Z. Priznaki identifikatsii polzovateley informatsionnykh sistem po kompyuternomu pocherku [Signs of identification of information systems users by

computer handwriting] // Informatsionnye tekhnologii v modelirovanii i upravlenii: podkhody, metody, resheniya: IV Vserossiyskaya nauchnaya konferentsiya s mezhdunarodnym uchastiem: Sbornik materialov, Tolyatti, 20–22 aprelya 2021 goda [Information technologies in modelling and management: approaches, methods, solutions: IV All-Russian scientific conference with international participation: Proceedings, Togliatti, 20–22 April]. Tolyatti: Tolyattinskiy gosudarstvennyy universitet, 2021. Pp. 157–161. (In Russian)

Shangina I. Yu. Tekhnologii biometricheskoy identifikatsii: mirovaya i Rossiyskaya praktiki [Biometric identification technologies: world and Russian practice] // Innovatsii. Nauka. Obrazovanie [Innovations. Science. Education]. 2020. No. 18. Pp. 151–156. (In Russian)

Siahaan C. R. P., Chowanda A. Spoofing keystroke dynamics authentication through synthetic typing pattern extracted from screen-recorded video // Journal of Big Data. 2022. Vol. 9 (111). Pp. 1–29. (In English)

Spillane R. Keyboard Apparatus for Personal Identification // IBM Technical Disclosure Bulletin. 1975. Vol. 17. № 3346. (In English)

Stylios I., Kokolakis S., Thanou O., Chatzis S. Behavioral Biometrics & Continuous User Authentication on Mobile Devices: A Survey // Information Fusion. 2021. Vol. 66. Pp. 76–99. (In English)

Sulavko A. E., Shalina E. V. Biometricheskaya autentifikatsiya polzovateley informatsionnykh sistem po klaviaturnomu pocherku na osnove immunnykh setevykh algoritmov [Biometric authentication of information system users by keyboard handwriting based on immune network algorithms] // Prikladnaya informatika [Applied Informatics]. 2019. Vol. 14. No. 3 (81). Pp. 39–54. (In Russian)

Syed I. S. Z. Soft Biometrics for Keystroke Dynamics. Computer Vision and Pattern Recognition. Universit´e de Caen Basse-Normandie, 2014. 134 p. (In English)

Turutina E. E. Analiz metodov elektronnoy i biometricheskoy autentifikatsii v sistemakh kontrolya dostupom [Analysis of electronic and biometric authentication methods in access control systems] // Vestnik NTsBZhD [Bulletin of the Life Safety Research Center]. 2021. No. 2 (48). Pp. 168–175. (In Russian)

Vacca J. R. Biometric technologies and verification systems. Oxford: USA Linacre House, 2007. 625 p. (In English)

Varlamova S. A., Vavilina E. A. Identifikatsiya polzovatelya na osnove klaviaturnogo pocherka [User identification based on keyboard handwriting] // Innovatsionnoe priborostroenie [Innovation Instrument Engineering]. 2023. Vol. 2. No. 3. Pp. 67–71. (In Russian)

Varnashina P. D., Bushueva M. E. Issledovanie emotsionalnogo sostoyaniya cheloveka po klaviaturnomu pocherku [Study of the emotional state of a person by keyboard handwriting] // Informatsionnye sistemy i tekhnologii — 2019: Sbornik materialov XXV Mezhdunarodnoy nauchno-tekhnicheskoy konferentsii, Nizhniy Novgorod,

19 aprelya 2019 goda. Nizhniy Novgorod: Nizhegorodskiy gosudarstvennyy tekhnicheskiy universitet im. R. E. Alekseeva [Information Systems and Technologies — 2019: Proceedings of the XXV International Scientific and Technical Conference, Nizhny Novgorod, 19 April 2019. Nizhny Novgorod: R. E. Alekseev Nizhny Novgorod State Technical University], 2019. Pp. 591–595. (In Russian)

Vorona V. A., Kostenko V. O. Biometricheskie tekhnologii identifikatsii v sistemakh kontrolya i upravleniya dostupom [Biometric identification technologies in access control and management systems] // Computational Nanotechnology. 2016. No. 3. Pp. 224–241. (In Russian)

Zhu H., Li C., Yu B. [et al]. Research on the Key Application of Computer Biometric Technology in Power Self-Service Terminal // Advances in Artificial Intelligence, Big Data and Algorithms / G. Grigoras and P. Lorenz (Eds.). 2023. Pp. 943–948. (In English)

Information about the authors

Anna Tsvetkova (Yekaterinburg, Russia) — student, intern researcher of the scientific Laboratory "Digital Technologies in Criminalistics" of the Department of Scientific Research of the V. F. Yakovlev Ural State Law University (21 Komsomolskaya St., Yekaterinburg, 620137, Russia; e-mail: at@crimlib.info).

Dmitriy Bakhteev (Yekaterinburg, Russia) — Professor of the Department of Criminalistics, Principal Researcher of the Department of Scientific Research of the V. F. Yakovlev Ural State Law University, Doctor of Legal Sciences, Associate Professor (21 Komsomolskaya St., Yekaterinburg, 620137, Russia; e-mail: ae@crimlib.info).

Recommended citation

Tsvetkova A. D., Bakhteev D. V. Features of keystroke dynamics and their forensic significance: literature review. Kazan University Law Review. 2024; 3 (9): 145–164. DOI: 10.30729/2541-8823-2024-9-3-145-164.