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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: BEHAVIORAL BIOMETRICS FOR EHEALTH AND WELL-BEING

The development of non-intrusive technologies to perform continuous health monitoring and enable automatic warnings is a challenging current issue. Behavioral biometrics such as speech, handwriting, and gait can play a crucial role. In fact, these signals convey several components:

- The one related to the physical part which enables the user to make the action (e.g., finger, hand, arm, etc.);
- The cognitive one refers to mental abilities (learning, thinking, reasoning, remembering, problem-solving, decision-making, and attention);
- The learned one which includes culture, habits, personalization, etc.;
- The contingent contour one, the acquisition device, the emotional state, the specific task/action to be performed, and the environment, plays a crucial role.

One or more of these components could be perturbated by a disease at an early stage as well as during its course. Behavioral biometrics in eHealth seek solutions to diagnose, assess, and monitor diseases that are measurable just when the patient performs an action. Behavioral biometrics also deal with the way human beings respond to natural and social events around them and emotions. The adoption of non-intrusive behavioral biometrics techniques in the set of daily activities can be pervasive. In fact, they only require the user to do what they already do normally. The output provided by the systems could be provided to doctors, thus helping them in a deep disease inspection. Nevertheless, behavioral technologies could be directly adopted by doctors. These aspects are extremely important for the development of computer-aided diagnosis (CAD) tools. Moreover, specific behavioral biometrics tasks and activities could be planned to support rehabilitation activities.

This Special Section in IEEE ACCESS aimed to arise the interest of the scientific community and to attract original research to advance the state of the art in behavioral biometrics for e-health and well-being. It is an opportunity to gain a significantly better understanding of the field's current developments and future direction.

The Call for Papers was a success: 97 submissions were received. Out of these, 23 articles were accepted for inclusion in the Special Section after a rigorous peer-review process.

Accepted articles can be categorized according to the following taxonomy based on the behavioral biometrics adopted: gait, handwriting, speech, face/eye, EEG/ECG, and multimodal-based approaches.

Concerning gait, in [A1], Ponce *et al.* report an interesting methodological analysis to determine the minimum number of sensors required for developing an accurate fall detection system. The authors conclude that the best combination is the waist IMU sensor and a lateral viewpoint camera. They also state that a smartphone-based fall detection system can achieve an overall acceptable accuracy. In [A2], Liu *et al.* focus on patients' mobilization problems connected to injured foot and ankle ligaments. The authors propose to solve the problem of reduced training data by generating synthetic data adopting DCGANs: the approach is fruitful and the performance increases with a combination of true human and synthesized features. In [A3], Dentamaro *et al.* inspect the potential of the sigma-lognormal model for gait analysis considering videos of heathy and neurodegenerative disease patients showing improvements in performance. In [A4], Karayaneva *et al.* developed an unsupervised approach for human activity recognition (walking, running, jumping, turning, and standing) by adopting a Doppler radar-based system within a room. In [A5], Zahiri *et al.* consider a specific task related to elbow flexion and extension tests to perform remote frailty assessment. A deep learning approach built upon the video captured by a camera was specifically designed.

Concerning handwriting, in [A6], Mucha *et al.* inspect the potentialities of several fractional-order derivative (FD) approaches to estimate the severity of graphomotor disabilities in school-aged children. In [A7], Cilia *et al.* report a study on feature selection to identify the most effective features for predicting cognitive impairments symptoms by means of handwriting analysis. The authors clearly show that, apart from a few features common to most tasks (e.g., execution time and speed), different writing tasks are characterized by a different set of relevant features.

When speech is considered as the acquired signal, in [A8], Madruga *et al.* consider the cases in which the recording is performed in realistic acoustic environments. To the aim, a multi-condition training is proposed for voice quality

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assessment associated to exudative lesions of Reinke's space. Nevertheless, speech is also a user-friendly interaction modality between a patient and a virtual agent playing the role of a health professional. In this direction, in [A9], Letaifa and Torres focus on multiple emotion recognition for seniors and imbalanced datasets. In [A10], Syed *et al.* deal with the use of speech to identify Alzheimer's dementia. The authors propose the use of bag-of-deep-acoustic-features and bag-of-deep-textual-features achieving state of-the-art performance.

In [A11], videos of faces and eye-tracking approaches have been considered by Mao *et al.* to explore different eye movement behaviors associated with several types of visual field defects. In [A12], Dhaliwal *et al.* report a study on facial analysis considering anthropometric measurements. These measurements and the related classification can be useful to determine references for healthy ranges of the average soft tissue profile of human faces. In[A13], Oiwa *et al.* perform an evaluation of long-term variability of facial ROI along with an estimation of physiological and psychological states related to health condition.

When the electroencephalogram (EEG) signal is acquired, different applications can be implemented. In [A14], Torres *et al.* report on the task of emotion recognition. More specifically, the authors 1) propose and adopt a type of elicitation of feelings useful in provoking emotions, 2) collect data, 3) develop a system for emotion recognition, and 4) perform a study on the relationship between features and the performance of the system. On the other hand, in [A15], Sun *et al.* focus on workload estimation adopting EEG. The authors propose a convolutional neural network and compare it to other approaches achieving state-of-the-art accuracy.

A considerable number of works deal with the analysis of multiple data sources. The use of multiple data is a key value to get robust and explainable results within the field. In [A16], Lai *et al.* deal with multiple data which can be acquired by wearable sensors (placed at chest and wrist) to perform emotion classification and stress detection. Automatic stress and stressor identification is also the topic of [A17] by Elzeiny and Qaraqe. In this case, data are acquired by means of a smart watch. A fusion of the data collected from ambient (smart home) and wearable (smartwatch) sensors is proposed by Cook and Schmitter-Edgecombe in [A18]. A gradient boosting regression algorithm is used to predict clinical scores which include measures of cognitive and mobility-based health. In [A19], Gutowski and Chmielewski present a complete (app, web-app, AI engine, etc.) and sensor-based (mobile device, worn sensors, and additional info) evaluation system for the domain of neurological treatment monitoring and efficiency analysis. The solution includes data fusion with the aim of recognizing and assessing the severity of Parkinson's disease (PD). In [A20], Hssayeni and Ghoraani describe a system for automated momentary estimation of positive and negative affects scores based on signals acquired by a wearable device. Data fusion is performed with a deep CNN model. In [A21], Ryu *et al.* adopt a wide set of input data (ranging from brain structure as obtained by MRI to MMSE results, etc.) and a XGBoost approach to design a prediction model of dementia risk. In [A22], Pustozerov *et al.* propose a system able to predict postprandial glycemic response taking as input data derived from a mobile app diary (including information on the glycemic index), food context (information on previous meals), characteristics of the individual patients, and patient behavioral questionnaires. To the aim, gradient boosting models were adopted. Finally, [A23], by Rashidan *et al.*, is a survey on technology-assisted approaches and their relationship to affective states recognition in individuals with autism spectrum disorder.

The Guest Editors hope that this Special Section will benefit the scientific community and contribute to the knowledge base and would like to take this opportunity to thank all the authors who submitted their research articles. The contributions of the reviewers have been precious to enhancing the quality of the manuscripts. We also thank the IEEE Access Editorial Staff and Editor-in-Chief for their work.

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APPENDIX: RELATED ARTICLES

[A1] H. Ponce, L. Martinez-Villasenor, and J. Nunez-Martinez, "Sensor location analysis and minimal deployment for fall detection system," *IEEE Access*, vol. 8, pp. 166678–166691, 2020.

[A2] X. Liu, C. Zhao, B. Zheng, Q. Guo, Z. Zhang, A. Wulamu, and D. Zhang, "Synthesizing foot and ankle kinematic characteristics for lateral collateral ligament injuries detection," *IEEE Access*, vol. 8, pp. 188429–188440, 2020.

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[A15] Z. Sun, B. Li, F. Duan, H. Jia, S. Wang, Y. Liu, A. Cichocki, C. F. Caiafa, and J. Sole-Casals, "WLnet: Towards an approach for robust workload estimation based on shallow neural networks," *IEEE Access*, vol. 9, pp. 3165–3173, 2021.

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