Guest Editorial: Biometrics in Industry 4.0: Open Challenges and Future Perspectives

THE paradigm of Industry 4.0 aims at reinventing procedures and business strategies in all industrial/factory fields. On the other hand, such a renovation generates massive amounts of data, lying from traditional tracking information of goods and services but also source codes, technology information, and intellectual property. This represents a serious threat for corporations that must invest, more than in the past, in protocols and procedures to keep their data secure from being stolen or widespread over networks. Therefore, this special section is devoted to selected papers focused on open challenges in the context of security and safety of Biometrics in Industry 4.0. Strong authentication mechanisms represent the key to ensure such a high level of security of data and biometrics may play a crucial role in this scenario. Biometric traits, both physical and behavioral, can be used to build up strong authentication platforms and infrastructure of trust enabling big corporations to protect their data against criminal attacks. On the other hand, the use of authentication mechanisms based on biometric solutions can often collide with national and international regulations which tend to protect sensitive information.

While the use of biometrics for security can be developed in full awareness of the users, in case of safety the collection of biometric data concerns a more subtle concept of privacy. In a private context, the security aims at guaranteeing controlled access/use to spaces and devices for a limited number of users. In public, is the safety to be guaranteed, involving a wider number of users whose biometrics data need to be acquired and protected. The ethical and practical implication of the use of biometrics data in safety needs to be further explored. The choice of the biometric traits (either hard or soft) as well as the mechanism to put in place to protect those data and the user's privacy ask for meticulous studies of the minimum number of traits to be involved in the monitored environment to achieve systems that are privacy preserving as well as robust and reliable.

Augmented reality applications have been intensively promoted by Industry 4.0 but their usage in operative environments is not free from risks for employees and trainees. The analysis of behavioral biometric traits, and soft biometrics in general, can provide useful estimations on postures and gestures during augmented reality training sessions. They can be used to assess the suitability of the augmented reality application and indicate excessive physical workload that may attempt personnel safety. Similarly, behavioral biometrics can be exploited in real working environments to estimate the attention status of the employees while working with complex and advanced equipment, which could not be supported by user/ergonomic study. The analysis of behavioral patterns can assist the employees to detect harmful attitudes thus preventing accidents and risks for people and equipment.

Motivated by the above, this special session aims to provide a platform for researchers from both academic and industrial sessions to report their recent results and overlook emerging research directions in security and safety using biometrics in industrial 4.0. After a strict peer-review progress, eight papers are included in this special session. We will review them in the following context.

Industry 4.0 system involves a variety of agents, from factories to end customers, in which the high connectivity and cooperation can optimize operational processes, products, and services. However, a security breach at any point may have adverse effects and even serious consequences on industry 4.0 system. As a result, security is a priority in an industrial 4.0 system, which requires secure, reliable, and user-friendly authentication. Lopez et al. [A1] investigated continuous authentication using machine learning for industry 4.0 systems, particularly focusing on its precision, performance, robustness, and the issue about if or when to retrain the models. In this article, the supervised and nonsupervised machine learning based continuous-authentication techniques were compared and analyzed, and the experimental results showed the supervised models outperformed the nonsupervised models, and voice was the most robust dimension when new workers were added.

With the improvement in productivity and the emergence of new business models in the era of Industry 4.0, safety in workplace is prominent to be concerned and solved. Investigating the attention states of the workers using biometric technologies, particularly their drowsiness levels, may provide a way to improve the safety. Bisogni et al. [A2] discussed the applicable technologies using biometrics in real scenarios of Industry 4.0. From the viewpoint of biometrics, the available datasets and the limitations for drowsiness detection applications for Industry 4.0 were analyzed, and the accuracies, and computational costs of recent drowsiness detection methods were discussed, and the link between the accuracies and subject-dependent architectures was addressed. Finally, conclusions about the real applicability of recent drowsiness techniques to workplace safety were highlighted.

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By integrating intelligent systems and internet of things technologies, smart factories play a crucial role in the spread of the industry 4.0 and the economic growth. Equipped with multiple sensors, smart factories may become cleverer, however there is still an urgent demand to ensure security and safety in a smart factory. Abate et al. [A3] developed a novel framework by using multiple sensors to monitor various physical and behavioral biometric features to support smart devices in smart factories. With the fusion of various biometric traits using machine learning technologies and different kinds of sensors, one can implement continuous authentication, drowsiness recognition, and liveness detection to significantly improve the safety of operators and avoid fatal accidents. By using the COTS-hardware experiments, the proposed scheme was demonstrated easy to implement in a large-scale smart factory.

Understanding body language, it would make human–machine interaction in an industry 4.0 system more natural, secure, and effective. However, a conventional camera may suffer low framerate and dynamic range so that it is challenging to recognize frequent instantaneous microexpressions of human faces. Motivated by the above, Becattni et al. [A4] used event-cameras and bioinspired vision sensors to capture motion at millisecond-rates even under challenging conditions such as low illumination and highly dynamic scenes. It is noted that such cameras are privacy-preserving which is fascinating for industry. It was showed that human reactions can be recognized by observing facial expressions using event-cameras only. The effectiveness and robustness were finally demonstrated by comparing with the RGB camera-based modeling techniques.

Wang et al. [A5] proposed a user authentication system, namely acoustical palmprint-based noncontact identity authentication system, where acoustic signals were used to describe palmprint features to identify different individuals. Specifically, the unique characteristics of the entire palmprint were extracted through the frequency modulated continuous wave sound signal, and a model was then to establish to verify the user's identity. The palmprint echo neural network was proposed to build the model, where transfer learning was used to achieve an ideal model that can be trained with a small amount of data. From the experiments on 15 volunteers in three real environments, it was showed that the proposed authentication system can verify user identities accurately and resist malicious signal attacks effectively.

Multimodal image fusion is the process of blending relevant biological information for automated industrial application. Gu et al. [A6] presented a novel framework by integrating fractal constraint with group sparsity to achieve an optimal fusion quality. First, the idea of patch division and componentwise separation was adopted to perceive the fractal characteristics across multimodality sources. Second, the group sparsity was addressed to preserve the spatial information against the redundancy of component entanglement. A dual variable weighting rule was then intrinsically employed to alleviate the overfitting across the component penalty. Finally, the alternating direction method of multipliers was used for model optimization. The effectiveness of the proposed algorithm was demonstrated by the experiment using images from the Whole Brain Atlas, and the clinical segmentation application using the positron emission tomography and computed tomography image fusion.

To fight the threat of privacy leakage, privacy protection is an important issue in industrial big data enabling entities. However, this brings huge challenges for fault diagnosis and predictive maintenance for such industrial systems as wind turbines. It remains an open issue on how to improve the diagnostic accuracy of decentralized machines without data transfer. Lu et al. [A7] proposed a class-imbalance privacy-preserving federated learning framework for fault diagnosis in decentralized wind turbines by using biometric authentication technique and federated learning algorithms. A real-world industrial wind turbine dataset was used to verify the effectiveness of the proposed framework. By comparison studies, the proposed framework outperformed the conventional approaches in the literature. An ablation study indicated the proposed framework can achieve excellent diagnostic performance under privacy data protection.

For accurate and reliable classification, biometric authentication requires the distributed biosignals to be sampled simultaneously and well aligned. Zong et al. [A8] modified the packet-coupled oscillators protocol by using a dynamic controller to synchronize data sampling clocks in a cluster of wireless body sensor network nodes for biometric authentication. Only one-way single packet exchange was involved in this protocol to reduce the communication cost. To ensure a precise sampling of these body sensor network nodes subjected to drifting clock frequency and varying delays, a dynamic controller was designed to ensure all the node sampling jitters to be bounded. The effectiveness of the proposed techniques was demonstrated by using IEEE 802.15.4 network.

We have reviewed the eight selected papers of the special session "Biometrics in Industry 4.0: Open Challenges and Future Perspectives," which have reflected most recent progress in biometrics and applications. We hope this special session can further stimulate the research and applications in this direction. It is worth to point out, due to the strict publication schedule, some submissions have to be moved to regular issue as either the review processes of them were not accomplished or their final versions were not ready when finalizing this editorial. It is a bit pity we cannot include all the accepted submissions into this special session in order to meet the publication deadline. Encouragingly, these accepted papers including "Privacy preserving ear recognition system using transfer learning in industry 4.0," "LDCNet: Limb direction cues-aware network for flexible human pose estimation in industrial behavioral biometrics systems" and so forth, are anticipated in regular issues, which can be regarded as the supplement of this special session.

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APPENDIX
RELATED ARTICLES

[A1] J. M. Espin Lopez, A. Huertas Celdran, F. Esquembre, G. Martinez, and J. G. Marin-Blazquez, "A supervised ML biometric continuous authentication system for industry 4.0," *IEEE Trans. Ind. Inform.*, to be published, doi: 10.1109/TII.2022.3171321.

[A2] C. Bisogni, F. Hao, V. Loia, and F. Narducci, "Drowsiness detection in the era of industry 4.0: Are we ready?," *IEEE Trans. Ind. Inform.*, to be published, doi: 10.1109/TII.2022.3173004.

[A3] A. F. Abate, L. Cimmino, I. Cuomo, M. Nardo, and T. Murino, "On the impact of multi-modal and multi-sensor biometrics in smart factories," *IEEE Trans. Ind. Inform.*, to be published, doi: 10.1109/TII.2022.3178376.

[A4] F. Becattni, F. Palai, and A. D. Bimbo, "Understanding human reactions looking at facial micro-expressions with an event camera," *IEEE Trans. Ind. Inform.*, 2022, to be published, doi: 10.1109/TII.2022.3195063.

[A5] L. Wang, W. Chen, N. Jing, Z. Chang, B. Li, and W. Liu, "AcoPalm: acoustical palmprint-based non-contact identity authentication," *IEEE Trans. Ind. Inform.*, to be published, doi: 10.1109/TII.2022.3176627.

[A6] G. Xu, X. Deng, X. Zhou, M. Pedersen, L. Cimmino, and H. Wang, "FCFusion: fractal component-wise modeling with group sparsity for medical image fusion," *IEEE Trans. Ind. Inform.*, 2022, to be published, doi: 10.1109/TII.2022.3185050.

[A7] S. Lu, Z. Gao, Q. Xu, C. Jiang, A. Zhang, and X. Wang, "Class-imbalance privacy-preserving federated learning for decentralized fault diagnosis with biometric authentication," *IEEE Trans. Ind. Inform.*, 2022, to be published, doi: 10.1109/TII.2022.3190034.

[A8] Y. Zong, S. Liu, X. Liu, S. Gao, X. Dai, and Z. Gao, "Robust synchronised data acquisition for biometric authentication," *IEEE Trans. Ind. Inf.*, 2022, to be published, doi: 10.1109/TII.2022.3182326.

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Dr. Castiglione was within the organization in more than 230 international conferences (some of which ranked A+/A/A- in the Italian GRIN/GII ranking). In 2014, one of his papers (published on the journal IEEE TRANSACTIONS ON DEPENDABLE AND SECURE COMPUTING) has been selected as Featured Article for the IEEE Cyber Security Initiative. In 2017, according to the Essential Science Indicator (WoS), one of his papers (published on the journal IEEE Transactions on Computers) was mentioned as Highly Citer Paper as well as Research Front Paper since it was in the top 1% in the Computer Science field. In 2018, an additional paper (published on the *IEEE Cloud Computing Magazine*) has been selected as Featured Article for the IEEE Cloud Computing Initiative. In October 2020 and October 2021, he was included into the top 100 000 (for 2019 and 2020) most influent scientists according to the standardized metrics on the citations published by the *PLoS Biology* journal. He is a Reviewer for more than 120 journals. He seats into the Editorial Board of more than 20 journals (including IEEE TRANSACTIONS ON SUSTAINABLE COMPUTING, IEEE ACCESS, and *IET Image Processing*), is the Co-Editor-in-Chief for the Special Issues for the Q1 JAIHC (Springer). He edited more than 30 Special Issues in top ranked journals. In his scientific production, and specifically his journal papers, more than 70 of them are ranked Q1 on Scopus and more than 60 are ranked Q1 on ISI-WoS. His academic profile is shared with his more than 90 international coauthors who belong to over 80 different institutions in more than 20 countries.

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