New Trends in Smart Sensors for Industrial Applications - Part II

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New Trends in Smart Sensors for Industrial Applications—Part II

THIS Special Section is dedicated to the latest trends in smart sensors for industrial applications. It has in total 26 papers, published in two parts, each consisting of 13 papers. In the Guest Editorial of Part I, published in the September 2017 issue, we validate the indispensable role sensors have in modern industry. Productivity, quality, reliability, and safety heavily depend on the performance of the sensors employed. This is because sensors form an interface between the production equipment and the surrounding environment and provide feedback based on the results of the executed operations. Consequently, sensors can be found in an extremely wide range of applications in industrial systems.

Yet sensors in industrial applications often operate under nonoptimal working conditions. They must deliver excellent performance in harsh and inaccessible environments (e.g., very high or very low temperature, high humidity, vacuum, aggresive treatment, vibrations, interferences, limited space, reduced power consumption, etc.) without the possibility of periodic calibration. The durability and reliability of sensors in industrial equipment must be extremely high, as replacing such sensors can be very complex, time consuming, and, therefore, very expensive, even for low-cost sensors.

Besides fulfilling their primary role, sensors used in industry must possess additional functionality features, such as self-diagnostics, self-calibration, and autonomous operation to prevent any unforeseen malfunctioning of the machine, leading to production quality issues and/or unacceptable machine and human hazards.

In order to meet all the above-mentioned requirements, such sensors need to possess a certain level of intelligence or smartness.

Here, we introduce the remaining 13 papers from this "Special Section on New Trends in Smart Sensors for Industrial Applications" of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS.

In item 1) in the Appendix, a review of the latest advances in the field of capacitive, inductive (eddy current), and magnetic sensors, for measurement of absolute displacement, is presented. This paper helps to provide a better understanding of the commonalities among capacitive, inductive, and magnetic displacement sensors, as well as the main performance differences and limitations, which will help one make the best choice for a specific application. This review is based on both a theoretical analysis and experimental results. Special focus is given in the paper to reviewing the recent advances in the interfacing circuits reported for capacitive and inductive sensors. The main performance criteria used in this review are sensitivity, resolution, compactness, long-term stability, thermal drift, and power efficiency.

In item 2) in the Appendix, a smart sensing technique for online and automatic evaluation of the structural integrity of carbon fiber reinforced polymer (CFRP) structures is presented. A compressed sensing-based algorithm framework that integrates sampling and defect evaluation together is also proposed. The proposed smart compressed sensing technique is attractive in quality control of CFRP production.

In item 3) in the Appendix, the focus is on statistical models, descriptive probabilistic data analysis, and data prescriptive signal processing in smart inertial sensors. The contribution of the paper is in the domain of design and deployment of next generation smart sensors, which utilize a front-end microelectronic, a microelectro-mechanical system, and processing technologies.

In item 4) in the Appendix, a novel blood flow volume (BFV) sensor is presented for assessing the quality of arteriovenous fistula in hemodialysis patients via noninvasive, reflectance-type photoplethysmography (PPG). This study is devoted to developing a low-cost, small-sized, portable, and easy-to-use PPG sensor that is capable of continuous BFV measurement. New designs are employed for the front-end analog circuits and signal processing, together with an intelligent neural network calibration method, to finally achieve a high correlation, as opposed to the ultrasound Doppler monitor, with the root mean squared errors successfully controlled below 289 ml/min.

In item 5) in the Appendix, the authors present simulative and experimental studies into ultrasonic sensors to provide void fraction measurements in a chemical bubble column using the ultrasonic tomographictechnique. The sensor electronic design and the procedures for data processing with a back projection image algorithm are discussed.

In item 6) in the Appendix, the authors present the implementation of a single-piece macrofiber composite (MFC) piezoelectric transducer as a multifunctional device for both strain sensing and energy harvesting in the context of an energy harvesting-type wireless sensing system. As shown in the paper, the dynamic strains measured by the MFC in the implemented system match a commercial strain sensor of the extensometer. The proposed approach will be useful for autonomous structural health monitoring of dynamic strain.

In item 7) in the Appendix, the authors report the realization of an electronic unit for a tactile sensor suite based on FPGAs that implements a direct interface with the raw sensor and provides serial communication between the fingertips and the palm.

In item 8) in the Appendix, the authors present two approaches, along with analysis and experimental validation, which integrate the gas sensing cell and the linear variable optical filter (LVOF) at the wafer level for natural gas sensing. The first approach uses 45° inclined mirrors to steer the light beam through the sample gas, whereas in the second approach, the gas-filled LVOF functionally integrates the gas cell into the resonator cavity of the filter. Both devices are self-referenced and are compatible with fabrication in a CMOS process, and are, therefore, highly suitable for smart gas sensing.

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In item 9) in the Appendix, a new class of microwave sensor architecture using a direct conversion principle to eliminate data processing and provide low-power smart sensor nodes is presented. Using a six-port circuit as the modulator, the sensing data are up-converted directly to a microwave frequency and sent by an antenna. At the receiver, a six-port circuit is used as a demodulator to downconvert the received signal and extract the sensing data.

In item 10) in the Appendix, a biopsy microsystem is presented, which is 11.2 mm in diameter and 18.6 mm in length and contains an imaging system with a dedicated image magnification optical microsystem (IMOM) and light emitting diodes (LEDs). Polydimethylsiloxane (PDMS) microlenses have been fabricated using the "hanging droplet" approach and integrated into the IMOM subsystem, achieving image magnification by a factor of 4 and a 30% improvement in optical irradiance from the LED illumination.

In item 11) in the Appendix, the authors introduce a gas mixture explosion risk estimation technique for a catalytic sensor. The main contributions of this work are summarized as follows. First, the authors propose the idea of an explosion estimation of unknown gas mixtures that is based on measuring the heat dissipated when the mixture oxidates at a slow rate. Second, the analysis of a transient oxidation processes is performed to devise the associated computational scheme to be implemented in a low-power microcontroller. Third, the authors implemented the proposed computational scheme in a wireless sensor node and carry out experiments with various gas mixtures to demonstrate the feasibility of the approach.

In item 12) in the Appendix, a new acoustic technique is presented to determine the direction of insulator faults using source localization with 3-D microphone arrays. The advantage provided is in classifying the fault state insulators without human inspection by considering the amount of total noise and 120 Hz harmonic components. The fault detection is determined by a neural network to diagnose the state automatically. The proposed technique was evaluated by distinct, real datasets, and the efficacy was validated. The classification ratio achieved was 96.7%, for three typical conditions.

In item 13) in the Appendix, the authors present a novel dictionary learning method to improve the gas identification performance of electronic nose. It is significantly less complex but leads to very competitive classification results. Experimental results show that the proposed method is not only effective in the signal analysis but is useful for the performance enhancement of current electronic noise as well.

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Appendix
Related Work

1) B. George, Z. Tan, and S. Nihtianov, "Advances in capacitive, eddy current, and magnetic displacement sensors and corresponding interfaces," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9595–9607, Dec. 2017.
2) C. Tang, G. Tian, K. Li, R. Sutthaweekul, and J. Wu, "Smart compressed sensing for online evaluation of CFRP structure integrity," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9608–9617, Dec. 2017.
3) S. Lyshevski, "Signal processing in cyber-physical MEMS sensors: Inertial measurement and navigation systems," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9618–9625, Dec. 2017.
4) P. Chiang, P. Chao, D. Tarng, and C. Yang, "A novel wireless photoplethysmography blood flow volume sensor for assessing arteriovenous fistula of hemodialysis patients," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9626–9635, Dec. 2017.
5) C. Goh, A. Ruzairi, F. Hafiz, and Z. Tee, "Simulative and experimental studies: Void fraction detection in a bubble column of a conducting pipe," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9636–9645, Dec. 2017.
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7) O. Oballe-Peinado *et al.*, "FPGA based tactile sensor suite electronics for real time embedded processing," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9657–9665, Dec. 2017.
8) N. Pelin Ayerden and R. Wolffenbuttel, "The miniaturization of an optical absorption spectrometer for smart sensing of natural gas," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9666–9674, Dec. 2017.
9) R. Mirzavand, M. Honari, and P. Mousavi, "Direct-conversion sensor for wireless sensing networks," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9675–9682, Dec. 2017.
10) J. Ribeiro *et al.*, "PDMS microlenses for optical biopsy microsystems," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9683–9690, Dec. 2017.
11) A. Somov, A. Karelin, A. Baranov, and S. Mironov, "Estimation of a gas mixture explosion risk by measuring the oxidation heat within a catalytic sensor," *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9691–9698, Dec. 2017.

12) K. Park, Y. Motai, and J. Yoon, “Acoustic fault detection technique for high power insulators,” *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9699–9708, Dec. 2017.

13) A. He, G. Wei, J. Yu, Z. Tang, Z. Lin, and P Wang, “A novel dictionary learning method for gas identification with a gas sensor array,” *IEEE Trans. Ind. Electron.*, vol. 64, no. 12, pp. 9709–9715, Dec. 2017.

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Dr. George is one of the Associate Editors for the IEEE SENSORS JOURNAL.