TECHNISCHE UNIVERSITÄT
IN DER KULTURHAUPTSTADT EUROPAS
CHEMNITZ

Faculty of Electrical Engineering and Information Technology
Institute for Microsystems and Semiconductor Technology
Professorship Measurement and Sensor Technology

Publications Report

Editor: Prof. Dr.-Ing. Olfa Kanoun
Stand: 31.12.2022

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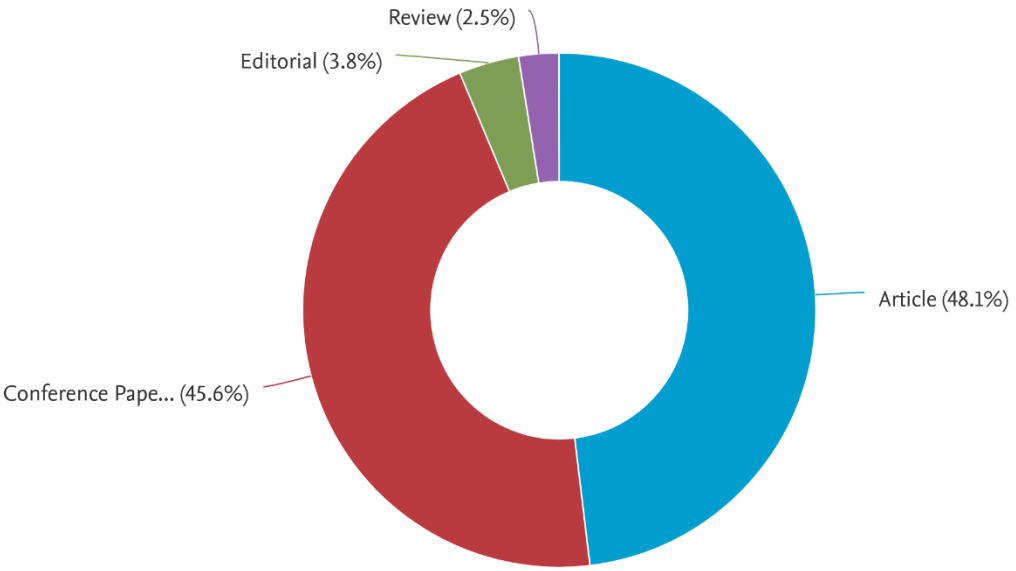
1 Publications Overview

1.1 Documents by Type



1.2 Main Keywords and Topics

- Energy Harvesting – Autonomous Wireless Sensors– Piezo Electric Converters – Inductive Power Transmission – Electromagnetic Energy Converter – Energy Management
- Compressive Sensing – Data Aggregation – Low Power Communication– Internet Of Things
- Nanocomposite and Filament Sensors based on: Multiwalled Carbon Nanotubes – Graphene – Polymers – Ceramics
- Pressure Sensors – Strain Sensors – Temperature Sensors – Humidity Sensors – Pressure Distribution Sensors – Temperature Self-Compensated Sensors – High-Temperature Sensors – RFID Sensors
- Functional Integration of Sensors in Structures – Materials and Textiles
- Nanogenerators – Piezoelectric Nanogenerator – Structural Health Monitoring
- Impedance Spectroscopy – Inductance Spectroscopy – Inductive Sensors – Bioimpedance Spectroscopy – Battery Diagnosis – Cable Identification – Cable Diagnosis – Electric Impedance Tomography (EIT) –Frequency Domain Analysis
- Electrochemical Sensors – Biosensors – Gas Sensors – Volatile Organic Compounds (VOC) – Cyclic Voltammetry – Electrochemical Impedance Spectroscopy – Electrodes
- Wearable Sensors – Gesture Recognition – Hand-gesture Recognition – American Sign Language – Surface Electromyography – Gait Analysis
- Machine Learning – Classification (of Information) – Learning Algorithms – Feature Extraction
- Industrial Applications – Industry 4.0 – Automotive applications – Environmental Applications – Medical Applications – Materials

1.3 International Co-Authorship

Tunisia - Italy – Jordan – Brazil – China - Russian Federation - .Canada .- Finland – Netherlands - Saudi Arabia - United Arab Emirates

2 Impedance Spectroscopy and Measuring Systems

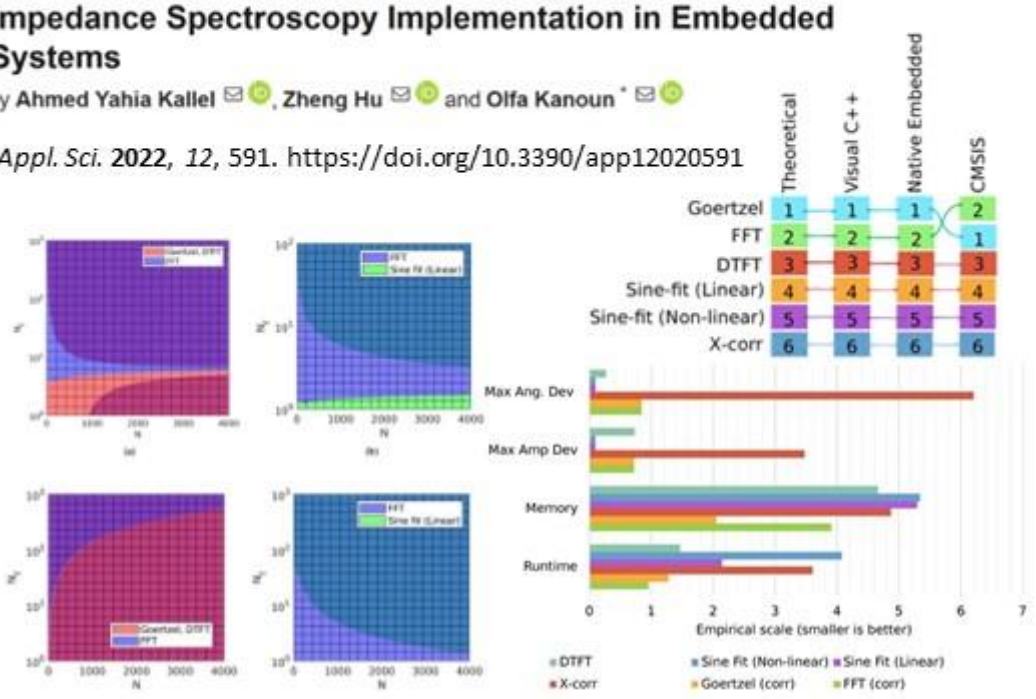
applied sciences MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Comparative Study of AC Signal Analysis Methods for Impedance Spectroscopy Implementation in Embedded Systems

by Ahmed Yahia Kallel, Zheng Hu and Olfa Kanoun *

Appl. Sci. **2022**, *12*, 591. https://doi.org/10.3390/app12020591



Abstract: For embedded impedance spectroscopy, a suitable method for analyzing AC signals needs to be carefully chosen to overcome limited processing capability and memory availability. This paper compares various methods, including the fast Fourier transform (FFT), the FFT with barycenter correction, the FFT with windowing, the Goertzel filter, the discrete-time Fourier transform (DTFT), and sine fitting using linear or nonlinear least squares, and cross-correlation, for analyzing AC signals in terms of speed, memory requirements, amplitude measurement accuracy, and phase measurement accuracy. These methods are implemented in reference systems with and without hardware acceleration for validation. The investigation results show that the Goertzel algorithm has the best overall performance when hardware acceleration is excluded or in the case of memory constraints. In implementations with hardware acceleration, the FFT with barycentre correction stands out. The linear sine fitting method provides the most accurate amplitude and phase determinations at the expense of speed and memory requirements.

Keywords: AC signal processing; embedded impedance spectroscopy; impedance spectroscopy; multisine; Fast-Fourier transform; Goertzel algorithm; curve-fitting

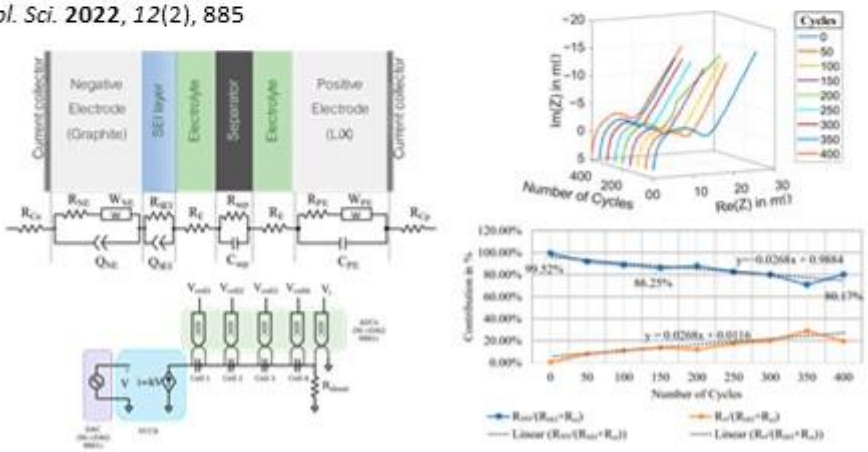
applied sciences MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Feature Paper Article

State-of-Health of Li-ion Battery Estimation Based on the Efficiency of the Charge Transfer Extracted from Impedance Spectra

by Ahmed Yahia Kallel, Viktor Petrychenko and Olfa Kanoun *

Appl. Sci. **2022**, *12*(2), 885



Abstract

Several studies show that impedance spectroscopy is a suitable method for online battery diagnosis and State-of-Health (SoH) estimation. However, the most common method is to model the acquired impedance spectrum with equivalent circuits and focus on the most sensitive parameters, namely the charge-transfer resistance. This paper introduces first a detailed model of a battery cell, which is then simplified and adapted to the observable spectrum behavior. Based on the physical meaning of the model parameters, we propose a novel approach for SoH assessment combining parameters of the impedance spectrum by building the ratio of the solid electrolyte interphase (SEI) resistance to the total resistance of SEI and the charge transfer. This ratio characterizes the charge-transfer efficiency at the electrodes' surfaces and should decrease systematically with SoH. Four different cells of the same type were cycled 400 times for the method validation, and impedance spectroscopy was performed at every 50th cycle. The results show a systematic correlation between the proposed ratio and the number of cycles on individual cell parameters, which build the basis of a novel online method of SoH assessment.

Keywords: electrochemical impedance spectroscopy; Lithium batteries; State-of-Health; charge transfer; solid electrolyte layer

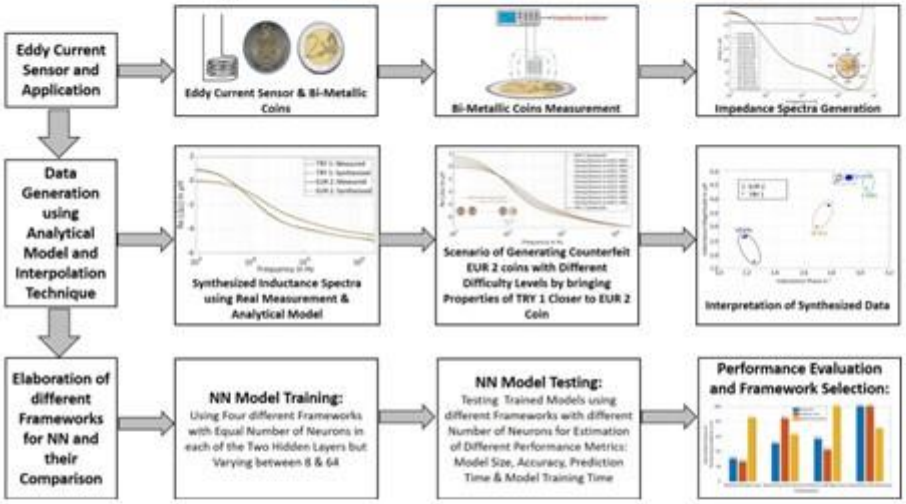
sensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Comparative Study of Machine-Learning Frameworks for the Elaboration of Feed-Forward Neural Networks by Varying the Complexity of Impedimetric Datasets Synthesized Using Eddy Current Sensors for the Characterization of Bi-Metallic Coins

by Rohan Munjal, Sohaib Arif, Frank Wendler and Olfa Kanoun *

Sensors 2022, *22*(4), 1312; https://doi.org/10.3390/s22041312



Abstract

A suitable framework for the development of artificial neural networks is important because it decides the level of accuracy, which can be reached for a certain dataset and increases the certainty about the reached classification results. In this paper, we conduct a comparative study for the performance of four frameworks, Keras with TensorFlow, Pytorch, TensorFlow, and Cognitive Toolkit (CNTK), for the elaboration of neural networks. The number of neurons in the hidden layer of the neural networks is varied from 8 to 64 to understand its effect on the performance metrics of the frameworks. A test dataset is synthesized using an analytical model and real measured impedance spectra by an eddy current sensor coil on EUR 2 and TRY 1 coins. The dataset has been extended by using a novel method based on interpolation technique to create datasets with different difficulty levels to replicate the scenario with a good imitation of EUR 2 coins and to investigate the limit of the prediction accuracy. It was observed that the compared frameworks have high accuracy performance for a lower level of difficulty in the dataset. As the difficulty in the dataset is raised, there was a drop in the accuracy of CNTK and Keras with TensorFlow depending upon the number of neurons in the hidden layers. It was observed that CNTK has the overall worst accuracy performance with an increase in the difficulty level of the datasets. Therefore, the major comparison was confined to Pytorch and TensorFlow. It was observed for Pytorch and TensorFlow with 32 and 64 neurons in hidden layers that there is a minor drop in the accuracy with an increase in the difficulty level of the dataset and was above 90% until both the coins were 80% closer to each other in terms of electrical and magnetic properties. However, Pytorch with 32 neurons in the hidden layer has a reduction in model size by 70% and 16.3% and predicts the class, 73.6% and 15.6% faster in comparison to TensorFlow and Pytorch with 64 neurons. View Full-Text

Keywords: eddy current sensor; impedance spectroscopy; machine learning; neural network; comparative study; Keras; Tensorflow; Pytorch; CNTK

IEEE SENSORS JOURNAL

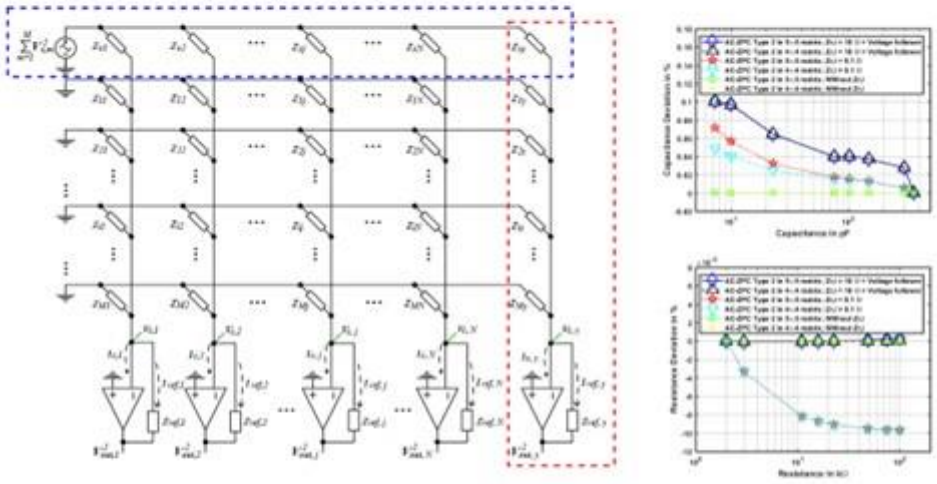
IEEE

MST MEASUREMENT AND SENSOR TECHNOLOGY

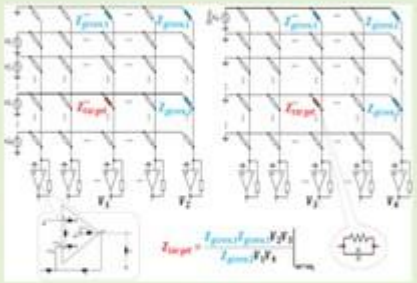
Self-Calibrated AC Zero Potential Circuit for Two-Dimensional Impedimetric Sensor Matrices

Zheng Hu, Dayu Chen, Ahmed Yahia Kallel, Shihao Wang, and Olfa Kanoun, *Senior Member, IEEE*

IEEE Sensors Journal, **2022**, doi: 10.1109/JSEN.2022.3147038



***Abstract*— Zero potential circuits (ZPC) can be used for reducing cross-talk effects within the two-dimensional matrices. ZPC using AC excitation signals (AC-ZPC) with different frequencies in every row can address all the sensors in a matrix simultaneously. The main challenge thereby is the remaining deviations. To analyze the reasons for this, an analytical model of the column-side output voltages is elaborated, which takes into account the non-ideal characteristics of the operational amplifiers, including the input impedance, finite open-loop gain factor, leakage current, output impedance, and load impedance. Based on this model, a novel method is proposed to realize a higher AC measurement accuracy by suppressing the matrix row side impedance through voltage followers and compensating the matrix column side non-ideal amplifiers through reference units. For compensation, one row and one column of given impedimetric units are included in the target matrix as reference elements. The measurement deviations are reduced by comparing the output differences between the targeted sensor and the reference elements. In a simulation for a 4×4 impedimetric sensor matrix composed of RC elements from $1.9\ k\Omega\ ||\ 361.7\ pF$ to $100.4\ k\Omega\ ||\ 7.3\ pF$, this new method achieves measurement deviations below 0.1%, which is a significant improvement over previous works that reached deviations above 1%.**



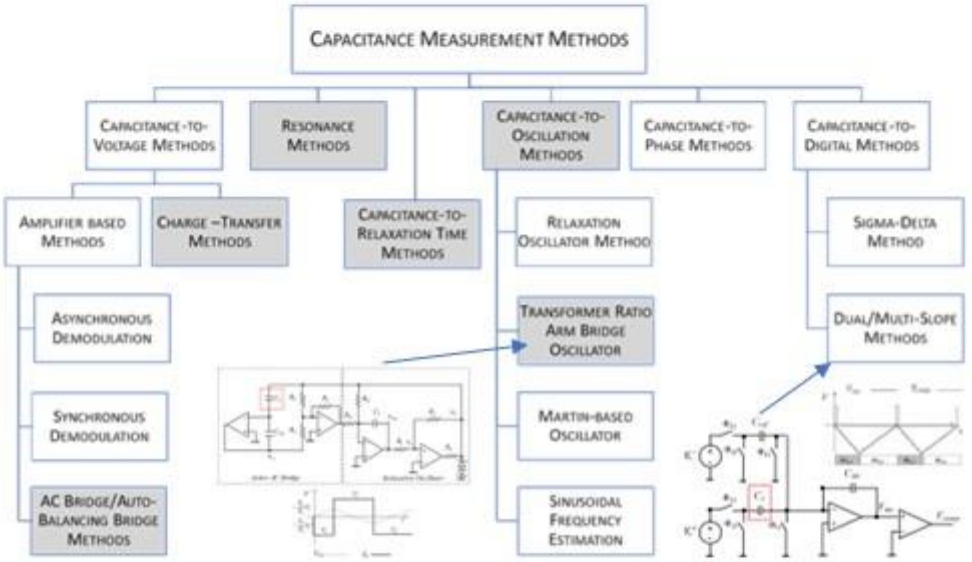
***Index Terms*—Two-dimensional matrix; cross-talk effect; zero potential circuit; AC-ZPC; impedimetric sensor; impedance spectroscopy.**

Measurement
Volume 195, 31 May 2022, 111067

Measurement Methods for Capacitances in the Range of 1 pF–1 nF: A review

Olfa Kanoun *, Ahmed Yahia Kallel, Ahmed Fendri

https://doi.org/10.1016/j.measurement.2022.111067



ABSTRACT

The rising use of capacitive sensors imposes the need of numerous measuring circuits with different characteristics. Stray fields and conductance losses are thereby key influencing factors that must be taken into account. In this paper, we provide an actual overview of capacitance measurement circuits considering well-known and modern measurement methods, such as lock-in amplifier, relaxation methods, and Martin-based oscillators as well as completely novel classes of capacitance measurement circuits converting the capacitance value directly to digital signals via sigma-delta and dual-slope converter circuit architectures. We classify the capacitance measurement circuits into six categories and address their properties and implementation aspects and compare their performance in a wide the capacitance range. The comparison shows that immunity to stray capacitances and conductive losses is not always given. Capacitance-to-Voltage, Auto-Balancing Bridge, and Capacitance-to-Digital show the best performance in this aspect and are therefore relevant for use in dielectric spectroscopy.

IEEE Sensors Letters

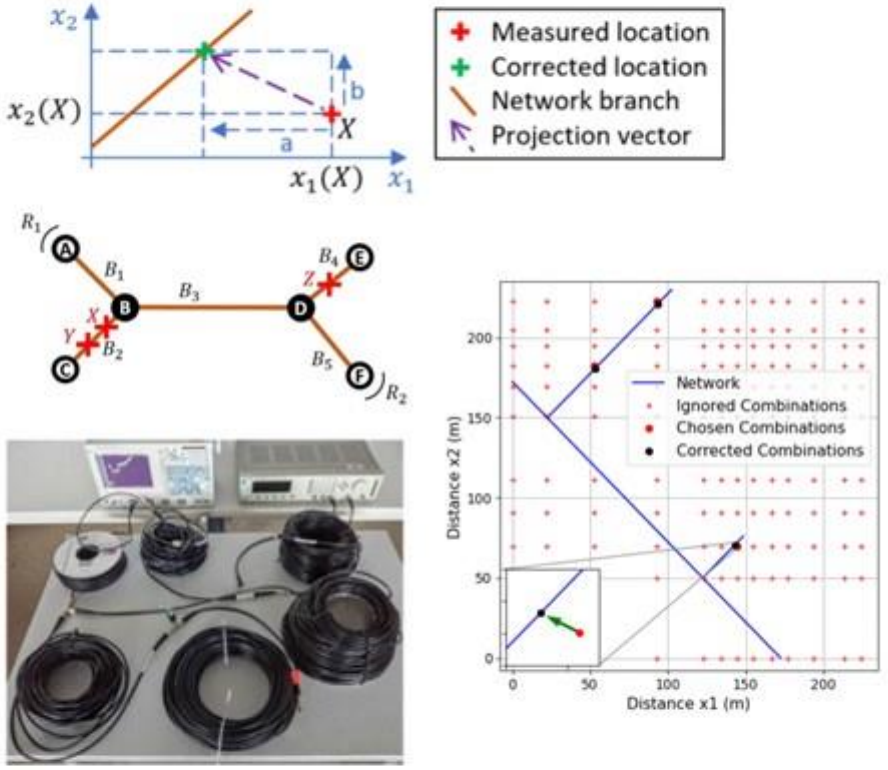
IEEE

MST MEASUREMENT AND SENSOR TECHNOLOGY

Multiple Faults Detection and Location in Bus-Shaped Cable Networks by Distributed Time-Domain Reflectometry

Dhia Haddad[1,2*], Ahmed Yahia Kallel[1], Najoua Essoukri Ben Amara[2**], and Olfa Kanoun[2**]

IEEE Sensors Letters, vol. 6, no. 5, pp. 1-4, May 2022, Art no. 6001604
doi: 10.1109/LSENS.2022.3170645



Abstract—Cables are the primary transmission media for electric power and communication in modern systems. Faults in cable networks affect the system's reliability and have serious consequences, leading to significant interruptions, failures, and accidents. In this letter, we propose a new method for detecting and locating multiple faults in bus-shaped cable networks based on distributed time-domain reflectometry. The proposed method can detect multiple faults existing simultaneously within one or more network branches. We use analytical modeling and adjacency matrix to categorize reflections measured at the terminations of a bus-shaped network. The proposed method can recognize redundant reflections by distinguishing the first reflection of each error. It detects the faults and identifies their corresponding network branches. The method has been validated on a network with two junctions, one soft fault, one open circuit, and one short circuit. It achieves a maximal relative position deviation of 1.05% and a maximal absolute deviation of 0.98 m.

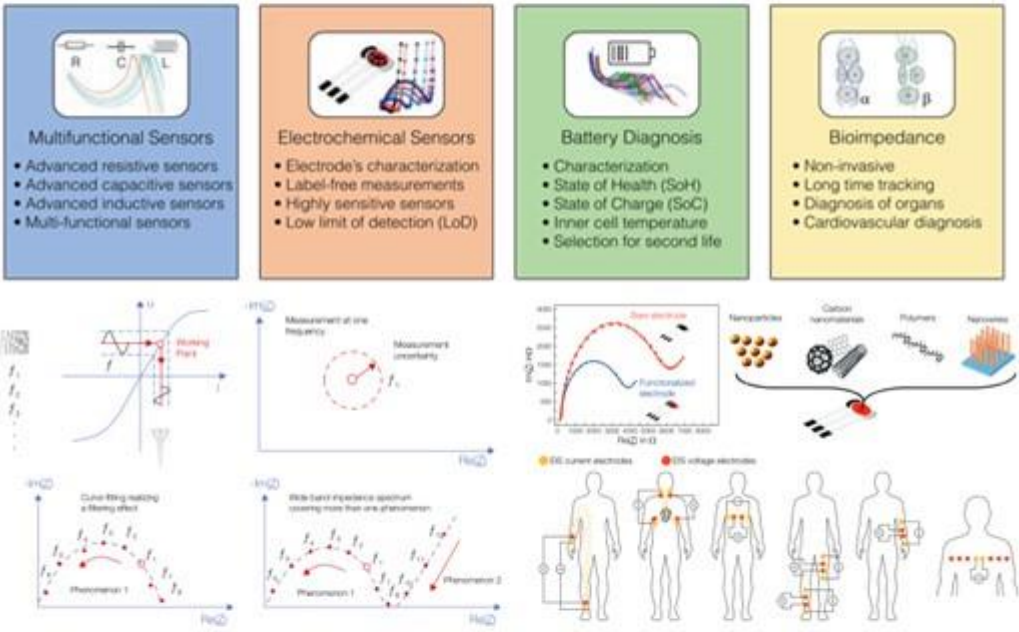
Index Terms—Sensor applications, complex cable network diagnosis, distributed reflectometry, multiple faults, time-domain reflectometry (TDR), transmission lines.

instrumentation & measurement MAGAZINE
IEEE
MST MEASUREMENT AND SENSOR TECHNOLOGY

Impedance Spectroscopy: Applications, Advances and Future Trends

Olfa Kanoun, Ahmed Yahia Kallel, Hanen Nouri, Bilel Ben Abitallah, Dhia Haddad, Zheng Hu, Malak Talbi, Ammar Al-Hamry, Rohan Munjal, Frank Wendler, Rim Barioul, Thomas Keutel, and Andreas Mangler

IEEE Instrumentation & Measurement Magazine (Volume: 25, Issue: 3, May 2022)
DOI: 10.1109/MIM.2022.9759355



Abstract:

Impedance spectroscopy is a powerful measurement method having decisive advantages in several application fields. It allows the measurements of non-accessible quantities, supports high measurement accuracy, and enables simultaneous measurements of more than one quantity. The method provides deep insights in systems and materials, is non-invasive, and is highly efficient, considering measurement time, measurement procedures and possibilities for implementation in embedded systems for in-field measurements. In this contribution, we point out the potential, recent advances and future trends of the method to provide insight into the powerfulness of the method for future applications.

Spectroscopy, Impedance measurement, Embedded systems, Market research, Time measurement, Impedance

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT

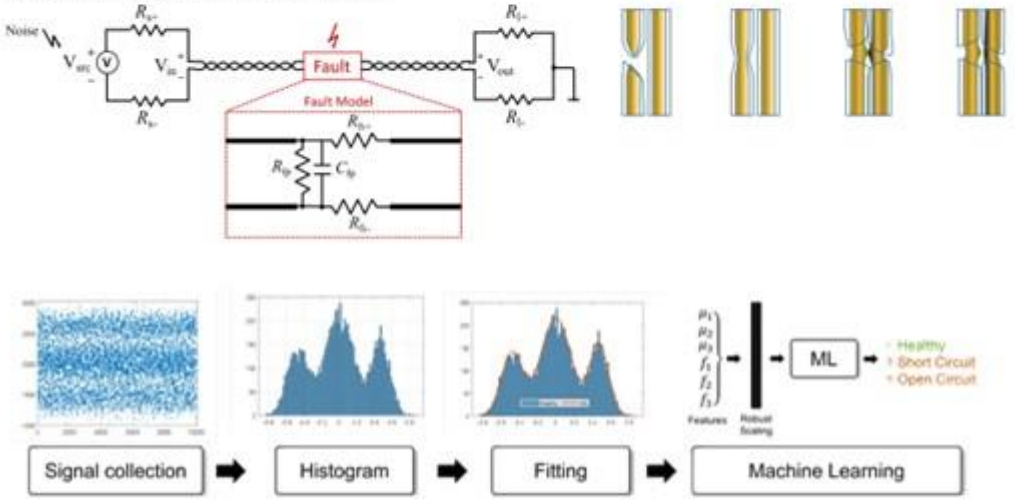
IEEE

MST MEASUREMENT AND SENSOR TECHNOLOGY

Real-Time Monitoring of Cables Based on Network Interface Controllers for Predictive Maintenance

Ahmed Yahia Kallel, Dhia Haddad, *Member, IEEE*, Thomas Keutel, *Member, IEEE*, and Olfa Kanoun, *Senior Member, IEEE*

IEEE Transactions on Instrumentation and Measurement, vol. 71, Art 2516008,
DOI: 10.1109/TIM.2022.3197799



***Abstract*— Conventional cable diagnostic methods require an interruption of the communication link and are therefore unsuitable for real-time quality monitoring and predictive maintenance. In this article, we propose a novel diagnosis method, which can be implemented on regular low-cost network interface controllers by just implementing dedicated signal acquisition and processing. The novel method passively monitors the state transitions between voltage levels, during the running communication, by undersampling and sorting the collected data into a histogram. By fitting the collected histogram to a sum of three Gaussian distribution functions, robust features can be extracted, having more independence on noise and the transmitted signals. Based on the extracted features, an early fault detection can be realized using a linear support vector classifier (SVC). The novel method has been validated for fast Ethernet cables using STM32-based microcontroller measurements. Open circuit and short circuit faults could be accurately identified. Classification accuracy of 100% could be realized even by *k*-fold cross-validation and testing. Furthermore, the proposed method can easily be applied to other cable types after adaptation to the corresponding communication signals.**

***Index Terms*— Cable diagnosis, cable faults, Ethernet cables, impedance spectroscopy, resampling, time-domain method.**

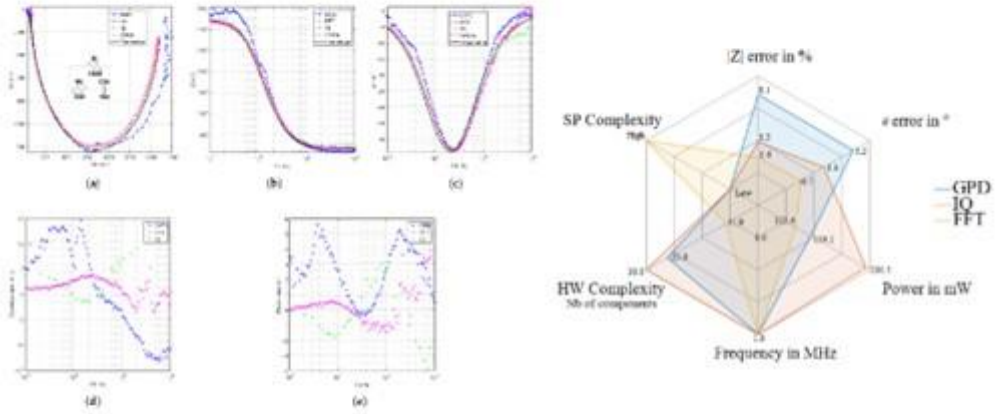
sensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Comparative Study of Measurement Methods for Embedded Bioimpedance Spectroscopy Systems

by Bilel Ben Atitallah [1,2,*], Ahmed Yahia Kallel [1], Dhouha Bouchaala [2], Nabil Derbel [2] and Olfa Kanoun [1]

Sensors **2022**, *22*(15), 5801; https://doi.org/10.3390/s22155801



Abstract

Bioimpedance spectroscopy (BIS) is an advanced measurement method for providing information on impedance changes at several frequencies by injecting a low current into a device under test and analyzing the response voltage. Several methods have been elaborated for BIS measurement, calculating impedance with a gain phase detector (GPD), IQ demodulation, and fast Fourier transform (FFT). Although the measurement method has a big influence on the measurement system performance, a systematical comparative study has not been performed yet. In this paper, we compare them based on simulations and experimental studies. To maintain similar conditions in the implementation of all methods, we use the same signal generator followed by a voltage-controlled current source (VCCS) as a signal generator. For performance analysis, three DUTs have been designed to imitate the typical behavior of biological tissues. A laboratory impedance analyzer is used as a reference. The comparison addresses magnitude measurement accuracy, phase measurement accuracy, signal processing, hardware complexity, and power consumption. The result shows that the FFT-based system excels with high accuracy for amplitude and phase measurement while providing the lowest hardware complexity, and power consumption, but it needs a much higher software complexity. View Full-Text

Keywords: **bioimpedance spectroscopy; bioimpedance; FFT; GPD; IQ demodulation; embedded impedance spectroscopy**

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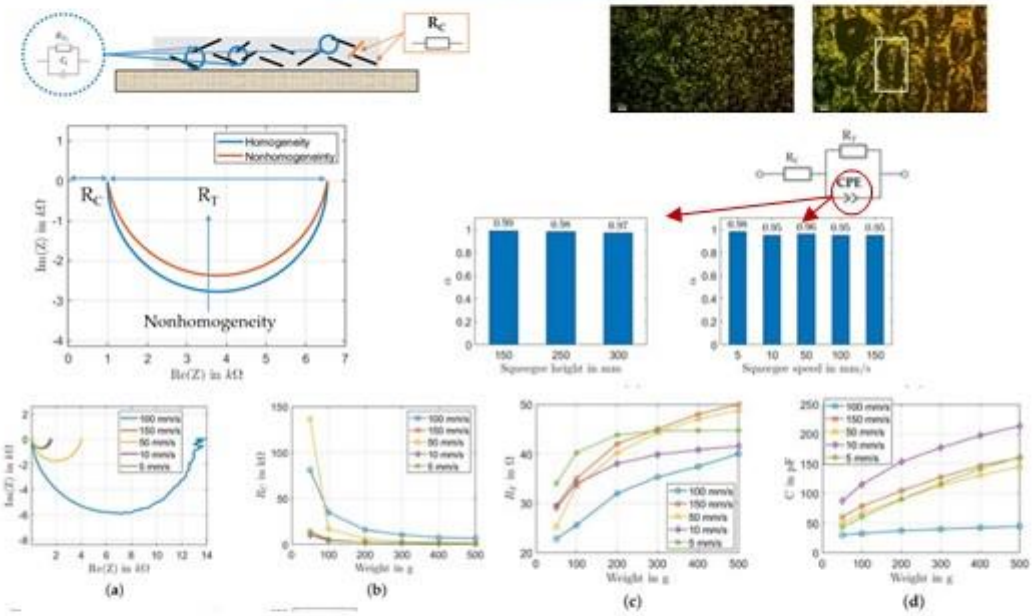
Open Access Article

Homogeneity Characterization of Textile-Integrated Wearable Sensors Based on Impedance Spectroscopy

by Hanen Nouri, Dhivakar Rajendran, Rajarajan Ramalingame and Olfa Kanoun *

Sensors **2022**, *22*(17), 6530; https://doi.org/10.3390/s22176530



Abstract

One of the main challenges during the integration of a carbon/polymer-based nanocomposite sensor on textile substrates is the fabrication of a homogeneous surface of the nanocomposite-based thin films, which play a major role in the reproducibility of the sensor. Characterizations are therefore required in every fabrication step to control the quality of the material preparation, deposition, and curing. As a result, microcharacterization methods are more suitable for laboratory investigations, and electrical methods can be easily implemented for in situ characterization within the manufacturing process. In this paper, several textile-based pressure sensors are fabricated at an optimized concentration of 0.3 wt.% of multiwalledcarbon nanotubes (MWCNTs) composite material in PDMS. We propose to use impedance spectroscopy for the characterization of both of the resistive behavior and capacitive behavior of the sensor at several frequencies and under different loads from 50 g to 500 g. The impedance spectra are fitted to a model composed of a resistance in series with a parallel combination of resistance and a constant phase element (CPE). The results show that the printing parameters strongly influence the impedance behavior under different loads. The deviation of the model parameter α of the *CPE* from the value 1 is strongly dependent on the nonhomogeneity of the sensor. Based on an impedance spectrum measurement followed by parameter extraction, the parameter α can be determined to realize a novel method for homogeneity characterization and in-line quality control of textile-integrated wearable sensors during the manufacturing process. View Full-Text

Keywords: multiwalled carbon nanotubes; textile sensors; pressure sensor; wearable sensors; impedance spectroscopy; constant phase element

3 Wireless Energy-Aware Sensors

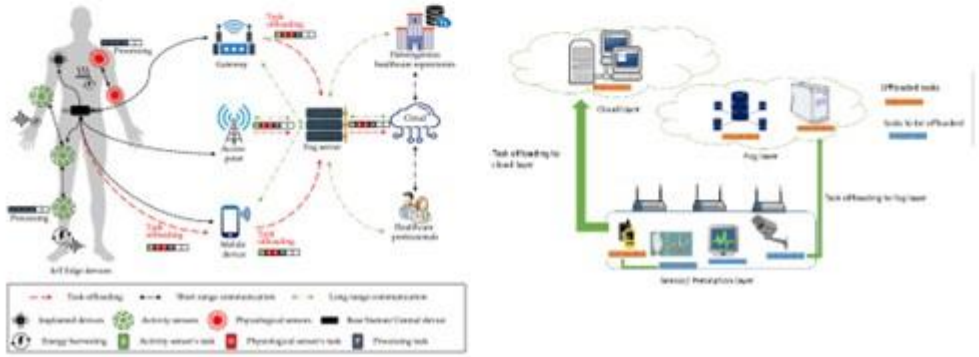
electronics MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Review

Requirements for Energy-Harvesting-Driven Edge Devices Using Task-Offloading Approaches

by Meriam Ben Ammar [1,2,3,*], Imed Ben Dhaou [4,5,6], Dhouha El Houssaini [1], Salwa Sahnoun [2,3], Ahmed Fakhfakh [2,3] and Olfa Kanoun [1]

Electronics **2022**, *11*(3), 383; https://doi.org/10.3390/electronics11030383



Abstract

Energy limitations remain a key concern in the development of Internet of Medical Things (IoMT) devices since most of them have limited energy sources, mainly from batteries. Therefore, providing a sustainable and autonomous power supply is essential as it allows continuous energy sensing, flexible positioning, less human intervention, and easy maintenance. In the last few years, extensive investigations have been conducted to develop energy-autonomous systems for the IoMT by implementing energy-harvesting (EH) technologies as a feasible and economically practical alternative to batteries. To this end, various EH-solutions have been developed for wearables to enhance power extraction efficiency, such as integrating resonant energy extraction circuits such as SSHI, S-SSHI, and P-SSHI connected to common energy-storage units to maintain a stable output for charge loads. These circuits enable an increase in the harvested power by 174% compared to the SEH circuit. Although IoMT devices are becoming increasingly powerful and more affordable, some tasks, such as machine-learning algorithms, still require intensive computational resources, leading to higher energy consumption. Offloading computing-intensive tasks from resource-limited user devices to resource-rich fog or cloud layers can effectively address these issues and manage energy consumption. Reinforcement learning, in particular, employs the Q-algorithm, which is an efficient technique for hardware implementation, as well as offloading tasks from wearables to edge devices. For example, the lowest reported power consumption using FPGA technology is 37 mW. Furthermore, the communication cost from wearables to fog devices should not offset the energy savings gained from task migration. This paper provides a comprehensive review of joint energy-harvesting technologies and computation-offloading strategies for the IoMT. Moreover, power supply strategies for wearables, energy-storage techniques, and hardware implementation of the task migration were provided. View Full-Text

Keywords: energy harvesting; IoMT devices; energy autonomous; wearables; energy-storage; energy management; fog edge computing; task offloading; deep learning; reinforced learning; IoMT

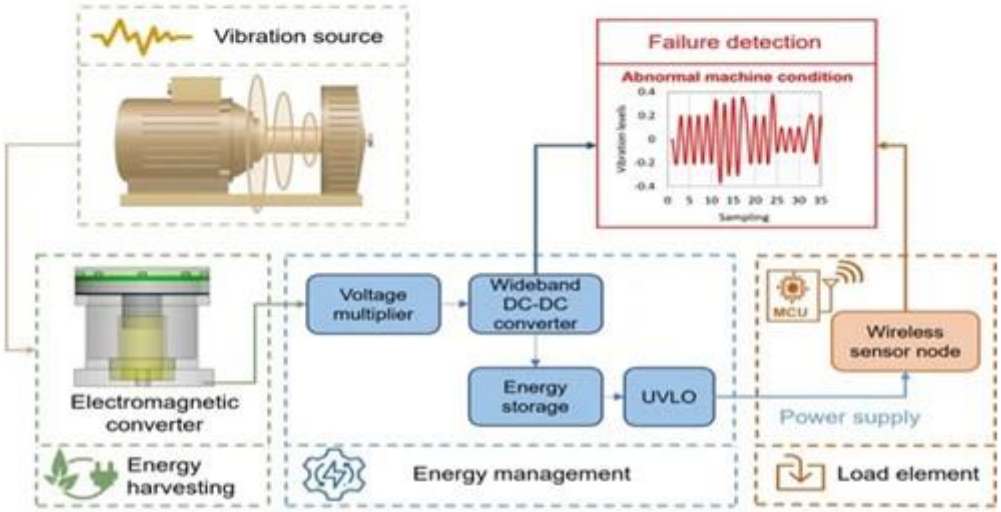
energies MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Vibration Converter with Passive Energy Management for Battery-Less Wireless Sensor Nodes in Predictive Maintenance

by Sonia Bradai, Ghada Bouattour, Dhouha El Houssaini and Olfa Kanoun *

Energies 2022, *15*(6), 1982; https://doi.org/10.3390/en15061982



Abstract

Predictive maintenance is becoming increasingly important in industry and requires continuous monitoring to prevent failures and anticipate maintenance processes, resulting in reduced downtime. Vibration is often used for failure detection and equipment conditioning as it is well correlated to the machine's operation and its variation is an indicator of process changes. In this context, we propose a novel energy-autonomous wireless sensor system that is able to measure without the use of batteries and automatically deliver alerts once the machine has an anomaly by the variation in acceleration. For this, we designed a wideband electromagnetic energy harvester and realized passive energy management to supply a wireless sensor node, which does not need an external energy supply. The advantage of the solution is that the designed circuit is able to detect the failure without the use of additional sensors, but by the Analog Digital Converter (ADC) of the Wireless Sensor Nodes (WSN) themselves, which makes it more compact and have lower energy consumption. The electromagnetic converter can harvest the relevant energy levels from weak vibration, with an acceleration of 0.1 g for a frequency bandwidth of 7 Hz. Further, the energy-management circuit enabled fast recharging of the super capacitor on a maximum of 31 s. The designed energy-management circuit consists of a six-stage voltage multiplier circuit connected to a wide-band DC-DC converter, as well as an under-voltage lock-out (UVLO) circuit to connect to the storage device to the WSN. In the failure condition with a frequency of 13 Hz and an acceleration of 0.3 g, the super capacitor recharging time was estimated to be 24 s. The proposed solution was validated by implementing real failure detection scenarios with random acceleration levels and, alternatively, modus. The results show that the WSN can directly measure the harvester's response and decide about the occurrence of failure based on its characteristic threshold voltage without the use of an additional sensor. View Full-Text

Keywords: energy harvesting; autonomous wireless sensor; passive energy management; weak vibration; electromagnetic converter; wideband; planar spring; voltage multiplier; rectifier; predictive maintenance; failure detection; WSN

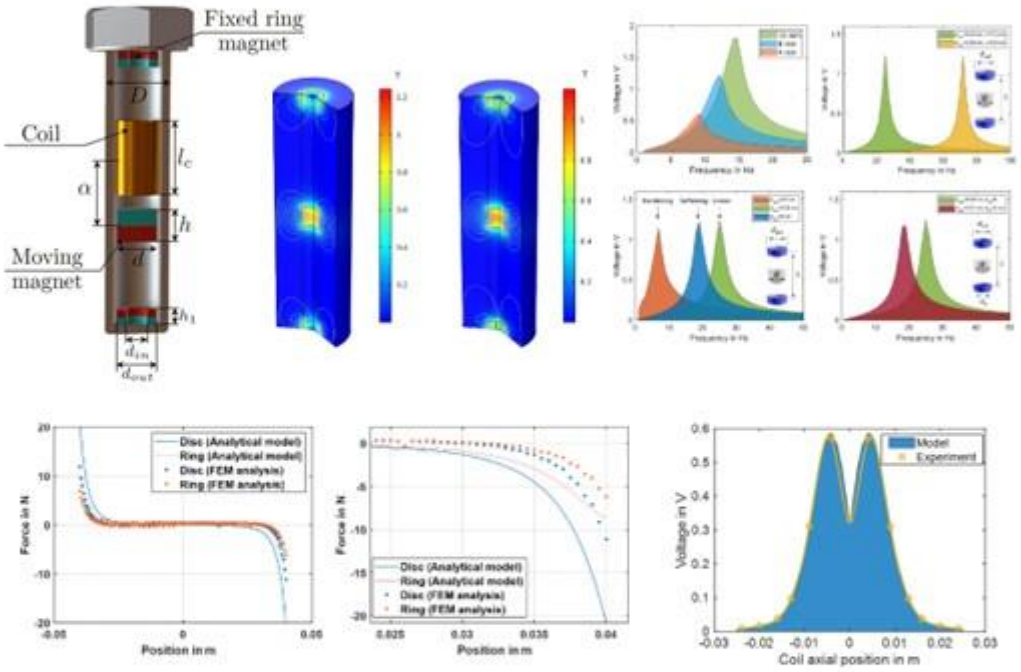
THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

MST MEASUREMENT AND SENSOR TECHNOLOGY

Design study of a nonlinear electromagnetic converter using magnetic spring

Slim Naifar[a], Sonia Bradai, and Olfa Kanoun

Eur. Phys. J. Spec. Top. (2022). https://doi.org/10.1140/epjs/s11734-022-00498-6



Abstract In this paper, an experimental and theoretical study for designing a nonlinear electromagnetic converter-based magnetic spring is performed. The governing equation of the converter is investigated. A special focus is given to the magnetic force acting on the moving magnet in dependence of its volume and the geometry of the two fixed magnets, i.e., disc or ring. For the developed analytical and numerical model, the same converter volume has been used for all conducted investigations. Several parameters have been studied that can be used to tune the nonlinearity behavior. Further, the coil axial position was investigated analytically and experimentally. An energy harvesting prototype consisting of an oscillating cylindrical magnet levitated between two stationary magnets is fabricated and evaluated through experiments. The open-circuit voltage obtained through the analytical model has been compared to the experiment and solutions to tune the harvester resonant frequency while maintaining its output power density were proposed.

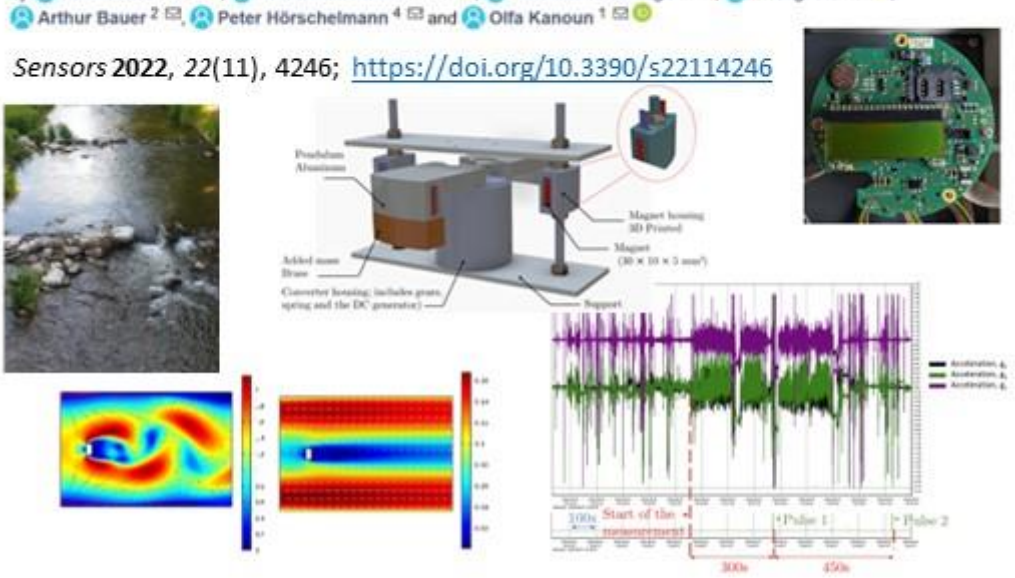
sensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Pendulum-Based River Current Energy Converter for Hydrometric Monitoring Systems

by Slim Naifar [1,*], Felix Grimmeisen [2,3], Christian Viehweger [1], Zheng Hu [1], Arthur Bauer [2], Peter Hörschelmann [4] and Olfa Kanoun [1]

Sensors **2022**, *22*(11), 4246; https://doi.org/10.3390/s22114246



Abstract

Energy harvesting from flowing water is important for supplying hydrometric monitoring systems. Nevertheless, it is challenging due to the chaotic water flow in only one main direction and the relatively weak energy profile. In this paper, a novel energy harvester has been proposed, designed, and validated. The converter consists of a pendulum, a gearbox, two overrunning clutches, a spiral spring, and a generator. By coupling the kinetic energy via an oscillating mass equipped with a magnetic spring, it is possible to accommodate the power supply, electronics, and sensors with data transmission in a completely closed, encapsulated, stable housing without an interface to the outside. In addition, an energy management circuit and a battery charging circuit were developed that could be housed in the sealed enclosure. The pendulum transducer prototype was tested with the developed online hydrometric measurement station, which consists of a multi-channel data logger with a cellular modem and a tipping bucket rain gauge sensor. The overall system was successfully validated by experimental studies in a river.

Keywords: energy harvesting; kinetic converter; hydrometric monitoring system; autonomous systems; water flow

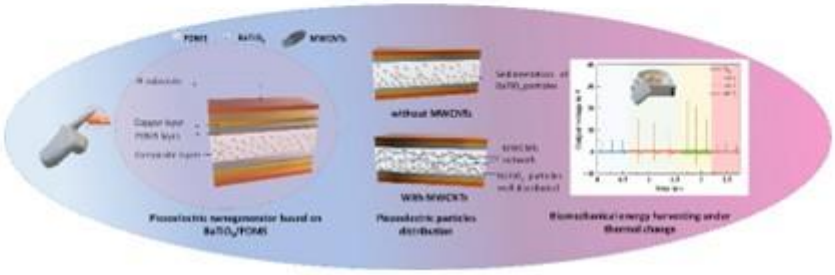
sensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

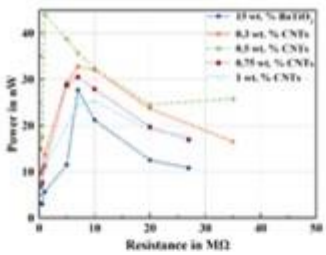
Open Access Article

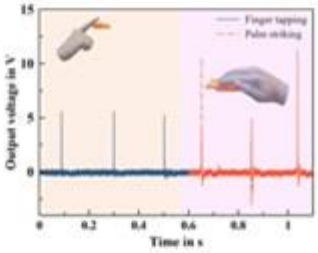
Collaborative Filler Network for Enhancing the Performance of $BaTiO_3$/PDMS Flexible Piezoelectric Polymer Composite Nanogenerators

by Ayda Bouhamed [1,*], Nathanael Jöhrmann [2], Slim Naifar [1], Benny Böhm [3], Olav Hellwig [3], Bernhard Wunderle [2] and Olfa Kanoun [1]

Sensors **2022**, *22*(11), 4181; https://doi.org/10.3390/s22114181







Abstract

Wearable sensors are gaining attention in human health monitoring applications, even if their usability is limited due to battery need. Flexible nanogenerators (NGs) converting biomechanical energy into electrical energy offer an interesting solution, as they can supply the sensors or extend the battery lifetime. Herein, flexible generators based on lead-free barium titanate ($BaTiO_3$) and a polydimethylsiloxane (PDMS) polymer have been developed. A comparative study was performed to investigate the impact of multiwalled carbon nanotubes (MWCNTs) via structural, morphological, electrical, and electromechanical measurements. This study demonstrated that MWCNTs boosts the performance of the NG at the percolation threshold. This enhancement is attributed to the enhanced conductivity that promotes charge transfer and enhanced mechanical property and piezoceramics particles distribution. The nanogenerator delivers a maximum open-circuit voltage (V_{OC}) up to 1.5 V and output power of 40 nW, which is two times higher than NG without MWCNTs. Additionally, the performance can be tuned by controlling the composite thickness and the applied frequency. Thicker NG shows a better performance, which enlarges their potential use for harvesting biomechanical energy efficiently up to 11.22 V under palm striking. The voltage output dependency on temperature was also investigated. The results show that the output voltage changes enormously with the temperature.

Keywords: PDMS/$BaTiO_3$ nanocomposite; MWCNTs; flexible piezoelectric nanogenerators; biomechanical energy harvesting; temperature dependency

TECHNISCHES MESSEN

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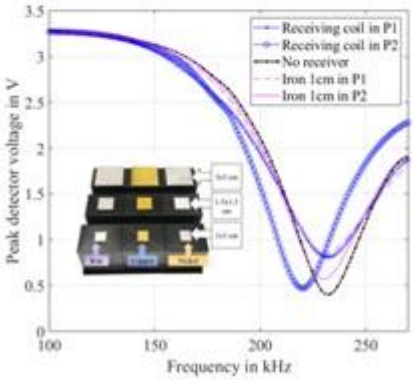
MST MEASUREMENT AND SENSOR TECHNOLOGY

Ghada Bouattour*, Bilel Kallel, Christian Viehweger, and Olfa Kanoun

Compact multi-coil inductive power transfer system with a passive peak detector circuit for wireless sensor nodes

tm - Technisches Messen, https://doi.org/10.1515/teme-2021-0113



Abstract: In Inductive Power Transfer (IPT) the misalignment between sending and receiving coils is critical and significantly influences both transfer efficiency and charging time. It can be compensated by the use of multiple coils on the sender side. However, by increasing the number of sending coils, the supply circuit on the sending side becomes big, complex and not easy to control compared to the sending coil size.

In this paper, we propose a compact and efficient supply circuit for multi-coil IPT systems, which activates only the coil under the receiving coil. The receiver detection is based on a compact passive peak voltage detector measuring the sending coil voltage variation. The receiver coil position determination is supported by measurements of the sending coil neighbours voltages, so that a stable power transfer to battery-free wireless sensor nodes can be realized. The investigation of the influence of the type, the shape, and the size of conductive materials between sender and receiver shows that the system can distinguish between the receiver coil and different metallic objects made of iron, coins, and copper.

Keywords: Coil matrix, multi-coil system, wireless power transfer (WPT), IoT, inductive power transfer (IPT), passive peak voltage detector, wireless sensor node (WSN), battery-free, multi-input single output (MISO), multi-input multi-output (MIMO).

Zusammenfassung: Bei der induktiven Energieübertragung (IPT) ist die Fehlausrichtung zwischen Sende- und Empfangsspulen kritisch und beeinflusst sowohl die Übertragungseffizienz als auch die Ladezeit erheblich. Sie kann durch den Einsatz mehrerer Spulen auf der Senderseite kompensiert werden. Mit zunehmender Anzahl von Sendespulen wird der Versorgungsschaltkreis auf der Sendeseite jedoch groß, komplex und im Vergleich zur Größe der Sendespule nicht einfach zu kontrollieren.

Dieser Beitrag befasst sich mit einer kompakten und effizienten Versorgungsschaltung für IPT-Systeme mit mehreren Spulen, die nur die Spule unter der Empfangsspule aktiviert. Die Empfängererkennung basiert auf einem kompakten passiven Spitzenspannungsdetektor, der die Spannungsschwankungen der Sendespule misst. Die Positionsbestimmung der Empfängerspule wird durch Messungen der Nachbarspannungen der Sendespule unterstützt, sodass eine stabile Energieübertragung zu batterielosen drahtlosen Sensorknoten realisiert werden kann. Die Untersuchung des Einflusses des Typs, der Form und der Größe der leitenden Materialien zwischen Sender und Empfänger zeigt, dass das System zwischen der Empfängerspule und verschiedenen metallischen Objekten aus Eisen, Münzen und Kupfer unterscheiden kann.

Schlagwörter: Spulenmatrix, Mehrspulensystem, Wireless Power Transfer (WPT), IoT, Inductive Power Transfer (IPT), passiver Spitzenspannungsdetektor, Wireless Sensor Node (WSN), batterielos, Multi-Input Single Output (MISO), Multi-Input Multi-Output (MIMO).

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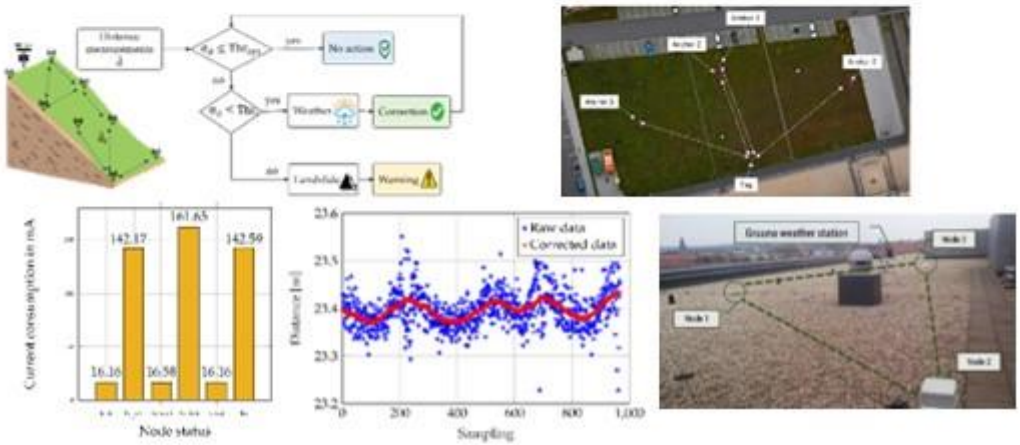
MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Feature Paper Article

Location-Aware IoT-Enabled Wireless Sensor Networks for Landslide Early Warning

by Dhouha El Houssaini *, Sabrine Khriji, Christian Viehweger, Thomas Keutel and Olfa Kanoun *

Electronics **2022**, *11*(23), 3971; https://doi.org/10.3390/electronics11233971



Abstract

Wireless Sensor Networks (WSNs) represent an interesting technology for designing early warning systems for landslides as they can ensure real-time and continuous monitoring. Through accurate localization techniques, changes in the position of installed nodes can be detected even during the early stage of field instability. This is through an accurate detection of nodes position changes independently from systematic deviations resulting from outdoor environmental conditions. In this study, we propose an accurate measurement system for distance measurement between wireless sensor nodes based on an ultra-wideband (UWB) localization method. In particular, distance measurements at different real weather conditions were performed to identify the impact of weather changes on distance measurement deviations. A proptotype for a landslide warning system has been developed realizing a localization accuracy of 98%.

Keywords: WSN; localization; ultra-wideband; two-way ranging; environment changes; early warning; landslide; SVM; internet of things

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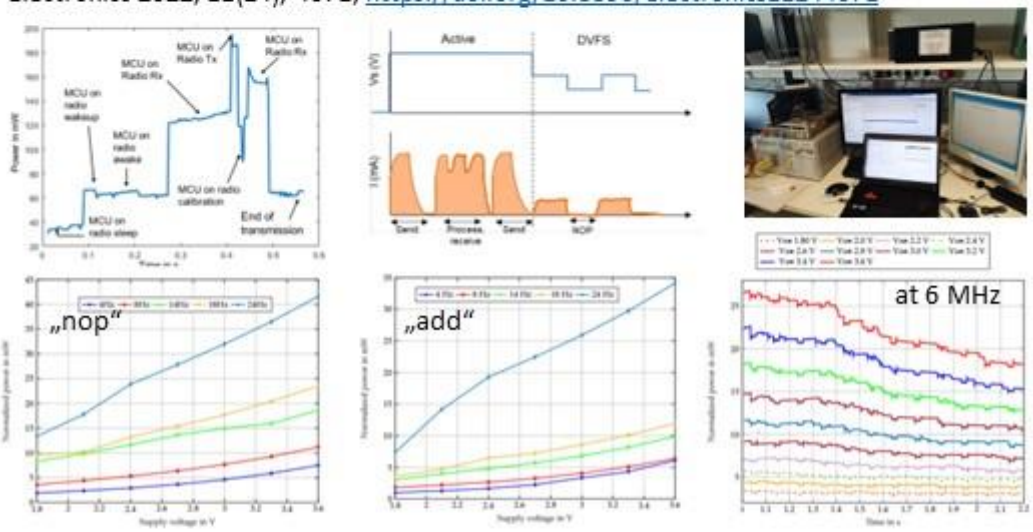
MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Dynamic Voltage and Frequency Scaling and Duty-Cycling for Ultra Low-Power Wireless Sensor Nodes

by Sabrine Khriji [1,*], Rym Chéour [2] and Olfa Kanoun [1]

Electronics **2022**, *11*(24), 4071; https://doi.org/10.3390/electronics11244071



Abstract

Energy efficiency presents a significant challenge to the reliability of Internet of Things (IoT) services. Wireless Sensor Networks (WSNs) present as an elementary technology of IoT, which has limited resources. Appropriate energy management techniques can perform increasing energy efficiency under variable workload conditions. Therefore, this paper aims to experimentally implement a hybrid energy management solution, combining Dynamic Voltage and Frequency Scaling (DVFS) and Duty-Cycling. The DVFS technique is implemented as an effective power management scheme to optimize the operating conditions during data processing. Moreover, the duty-cycling method is applied to reduce the energy consumption of the transceiver. Hardware optimization is performed by selecting the low-power microcontroller, MSP430, using experimental estimation and characterization. Another contribution is evaluating the energy-saving design by defining the normalized power as a metric to measure the consumed power of the proposed model per throughput. Extensive simulations and real-world implementations indicate that normalized power can be significantly reduced while sustaining performance levels in high-data IoT use cases.

Keywords: IoT; wireless sensor networks; WSN; power management; energy saving; DVFS; duty-cycling; communication

4 Flexible and Nanocomposite Sensors

TECHNISCHES MESSEN

DE GRUYTER

MST MEASUREMENT AND SENSOR TECHNOLOGY

Olfa Kanoun*, Ayda Bouhamed*, Salem Nasraoui, Ammar Al-Hamry, Amina Brahem, Amoog Lakshmanan and Rajarajan Ramalingame

Potential of flexible and highly sensitive sensors based on polymer-carbon-nanomaterials composites: towards a new generation of sensors

Technisches Messen 2022, https://doi.org/10.1515/teme-2022-0071

Abstract: Nanocomposite films based on carbonaceous materials and polymers offer an innovative technological approach for realizing scalable and flexible sensors with high sensitivity and low manufacturing costs. This novel approach leads to sensors; which outperform conventional sensors and have decisive advantages, e.g., adjustable measurement range, high sensitivity, high robustness, flexibility, and scalability. Manifold carbonaceous nanomaterials-based sensors having new principles can be realized for measurands such as temperature, humidity, strain, and pressure. These sensors can be realized with low costs without the need for cleanrooms and are affordable even if only a small number of sensors is produced. Due to their flexibility and low layer thickness, they can be easily integrated into materials and structures. In this paper, we provide a critical survey on the potential of sensors based on carbonaceous nanomaterials and polymers and highlight their principles, manufacturing procedures, and resulting properties. We discuss sensor properties going much beyond sensors realized with classical technologies, mainly due to novel principles and outstanding properties of nanomaterials.

Keywords: carbon nanomaterials; gas sensors; humidity sensors; ion sensors; pressure and strain sensors; temperature sensors.

Journal of Composites Science
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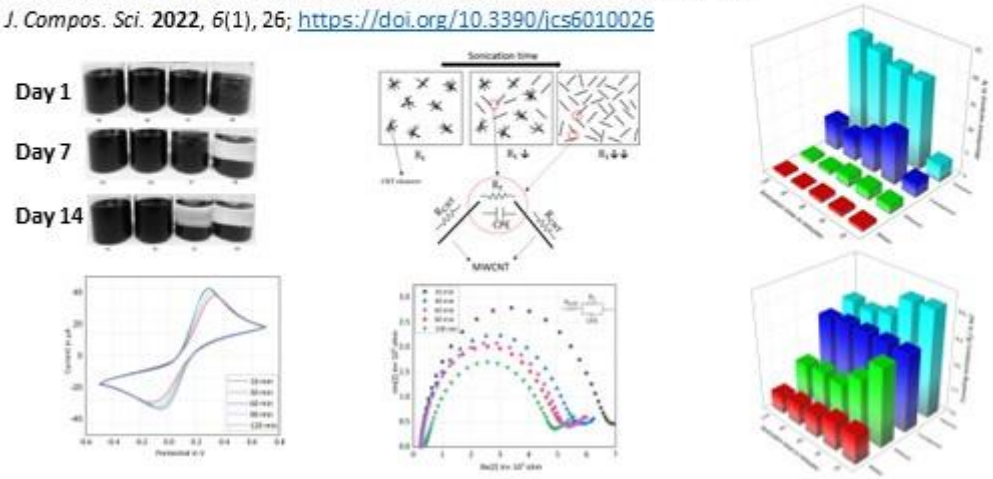
Article

Role of Solvent Polarity on Dispersion Quality and Stability of Functionalized Carbon Nanotubes

Dhivakar Rajendran [1], Rajarajan Ramalingame [1], Hanen Nouri [1], Anurag Adiraju [1] and Olfa Kanoun [1,*]

J. Compos. Sci. **2022**, *6*(1), 26; https://doi.org/10.3390/jcs6010026



Abstract: Dispersion of carbon nanotubes (CNT) in solvents and/or polymers is essential to reach the full potential of the CNTs in nanocomposite materials. Dispersion of CNTs is especially challenging due to the van-der-Waals attraction forces between the CNTs, which let them tend to re-bundle and/or re-aggregate. This paper presents a brief analysis of the quality and stability of functionalized multiwalled carbon nanotubes (fMWCNT) dispersion on polar solvents. A comparative study of functionalized CNT dispersion in water, methyl, and alcohol-based organic solvents has been carried out and the dispersion has been characterized by UV-VIS spectroscopy, electrochemical characterization such as cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). Visual analysis of the dispersion has been investigated for up to 14 days to assess the dispersion's stability. Based on the material characterization, it was observed that the degree of affinity fMWCNT with -COOH group highly depends on the polarity of the solvent, where the higher the polarity, the better the interaction of fMWCNT with solvents.

Keywords: carbon nanotubes; polar solvents; UV-VIS analysis; electrochemical impedance spectroscopy (EIS)

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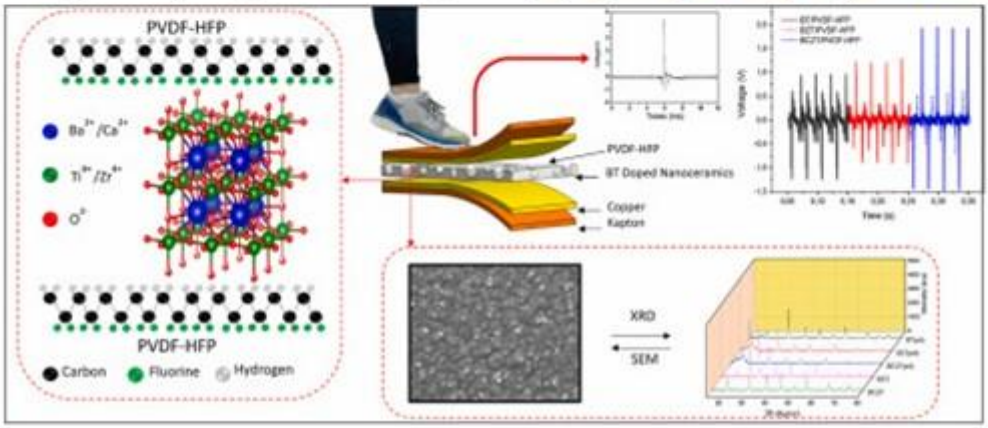
MST MEASUREMENT AND SENSOR TECHNOLOGY

Enhancement of the performance of flexible lead-free nanogenerators by doping in $BaTiO_3$ nanoparticles

Khawla Jeder [a], Ayda Bouhamed [b], Hanen Nouri [b], Najmeddine Abdelmoula [a], Nathanael Jöhrmann [c], Bernhard Wunderle [c], Hamadi Khemakhem [a], Olfa Kanoun [b]

Energy, Vol. 261, Part B, 15 December 2022, 125169; https://doi.org/10.1016/j.energy.2022.125169



ABSTRACT

Barium Titanate ($BaTiO_3$) lead-free ceramic has recently gained attention for the fabrication of nanogenerators. Herein, lead-free piezoceramics (Ba, Ca) (Zr, Ti)O_3 was synthesized using the sol-gel method. In order to improve the material properties, Ca^{2+} and Zr^{4+} were introduced into the $BaTiO_3$ crystal network to replace Ba^{2+} and Ti^{4+}, respectively. Subsequently, three flexible nanocomposites were chemically fabricated by mixing polyvinylidene fluoride-co-hexafluoropropylene (PVDF-HFP) with the commercial BT, the synthesized BZT and BCZT, using the solution-casting technique. The microstructure and morphology were characterized by X-ray diffraction (XRD), Fourier transforms infrared spectroscopy (FTIR), and (SEM). This study illustrates that the combination of both addition Ca^{2+} and Zr^{4+} in barium titanate is promising for forming the electroactive β-phase in the nano-composite. The XRD and FTIR confirmed the formation of the polar β-phase, enhancing piezoelectric properties. The electrical conductivity of the nanocomposite increased with doping in both sites. A maximum output voltage (−1.8 V) and power (−1.9 μW) were achieved for composite including BCZT particles. Besides, different sizes and concentrations of BCZT/PVDF-HFP based nanogenerators were constructed. The optimal performance was with nanogenerators of size 2 cm × 2.5 cm and 10 wt % of BCZT powders. Biomechanical foot-tapping achieved a maximum output voltage of 4.55 V, which was high enough to become a potential candidate for a self powered device in future applications.

Keywords

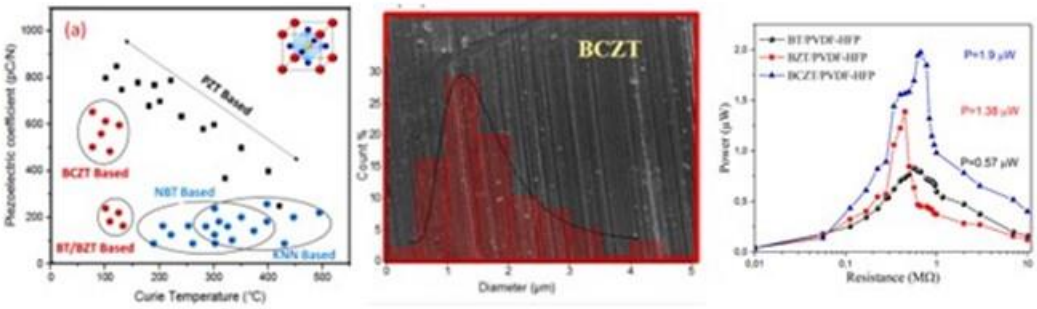
BT Doped nanoceramics; Biomechanical energy harvesting; Flexible nanogenerator; Lead-free; Piezoelectric nanocomposites; Sol-gel

ELSEVIER ENERGY MST MEASUREMENT AND SENSOR TECHNOLOGY

Enhancement of the performance of flexible lead-free nanogenerators by doping in $BaTiO_3$ nanoparticles

Khawla Jeder [a,*], Ayda Bouhamed [b,**], Hanen Nouri [b], Najmeddine Abdelmoula [a], Nathanael Jöhrmann [c], Bernhard Wunderle [c], Hamadi Khemakhem [a], Olfa Kanoun [b]

Energy 261 (2022) 125169. https://doi.org/10.1016/j.energy.2022.125169



A B S T R A C T

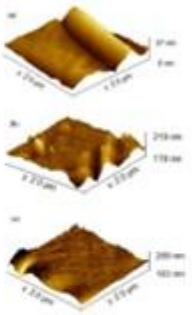
Barium Titanate ($BaTiO_3$) lead-free ceramic has recently gained attention for the fabrication of nanogenerators. Herein, lead-free piezoceramics (Ba, Ca) (Zr, Ti)O_3 was synthesized using the sol-gel method. In order to improve the material properties, Ca^{2+} and Zr^{4+} were introduced into the $BaTiO_3$ crystal network to replace Ba^{2+} and Ti^{4+}, respectively. Subsequently, three flexible nanocomposites were chemically fabricated by mixing polyvinylidene fluoride-co-hexafluoropropylene (PVDF-HFP) with the commercial BT, the synthesized BZT and BCZT, using the solution-casting technique. The microstructure and morphology were characterized by X-ray diffraction (XRD), Fourier transforms infrared spectroscopy (FTIR), and (SEM). This study illustrates that the combination of both addition Ca^{2+} and Zr^{4+} in barium titanate is promising for forming the electroactive β-phase in the nano-composite. The XRD and FTIR confirmed the formation of the polar β-phase, enhancing piezoelectric properties. The electrical conductivity of the nanocomposite increased with doping in both sites. A maximum output voltage (~1.8 V) and power (~1.9 μW) were achieved for composite including BCZT particles. Besides, different sizes and concentrations of BCZT/PVDF-HFP based nanogenerators were constructed. The optimal performance was with nanogenerators of size 2 cm × 2.5 cm and 10 wt % of BCZT powders. Biomechanical foot-tapping achieved a maximum output voltage of 4.55 V, which was high enough to become a potential candidate for a self powered device in future applications.

5 Electrochemical Sensors

sensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

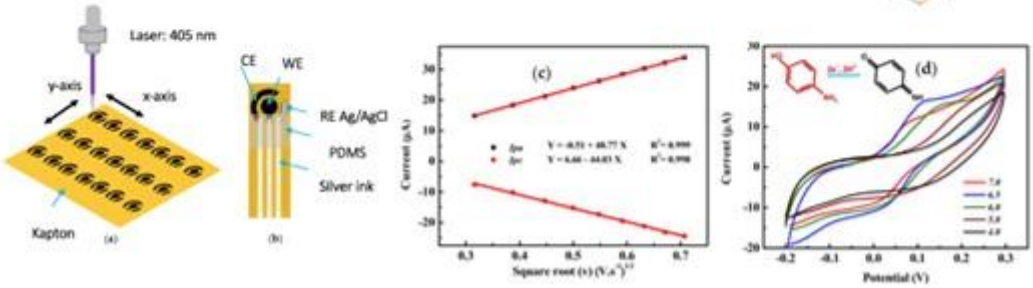
Open Access Article

Development of an Efficient Voltammetric Sensor for the Monitoring of 4-Aminophenol Based on Flexible Laser Induced Graphene Electrodes Modified with MWCNT-PANI



by Salem Nasraoui [1,2,*], Sami Ameur [2,3], Ammar Al-Hamry [1], Mounir Ben Ali [2,4] and Olfa Kanoun [1,*]

Sensors **2022**, *22*(3), 833; https://doi.org/10.3390/s22030833



Abstract

Sensitive electrodes are of a great importance for the realization of highly performant electrochemical sensors for field application. In the present work, a laser-induced carbon (LIC) electrode is proposed for 4-Aminophenol (4-AP) electrochemical sensors. The electrode is patterned on a commercial low-cost polyimide (Kapton) sheet and functionalized with a multi-walled carbon nanotubes polyaniline (MWCNT-PANI) composite, realized by an in-situ-polymerization in an acidic medium. The LIC electrode modified with MWCNT-PAPNI nanocomposite was investigated by SEM, AFM, and electrochemically in the presence of ferri-ferrocyanide $[Fe(CN)_6]^{3-/4-}$ by cyclic voltammetry and impedance spectroscopy. The results show a significant improvement of the electron transfer rate after the electrode functionalization in the presence of the redox mediators $[Fe(CN)_6]^{3-/4-}$, related directly to the active surface, which itself increased by about 18.13% compared with the bare LIG. The novel electrode shows a good reproducibility and a stability for 20 cycles and more. It has a significantly enhanced electro-catalytic activity towards electrooxidation reaction of 4-AP inferring positive synergistic effects between carbon nanotubes and polyaniline PANI. The presented electrode combination LIC/MWCNT-PANI exhibits a detection limit of 0.006 µM for the determination of 4-AP at concentrations ranging from 0.1 µM to 55 µM and was successfully applied for the monitoring in real samples with good recoveries.

Keywords: laser induced carbon; MWCNT-PANI; electrochemical sensor; 4-Aminophenol

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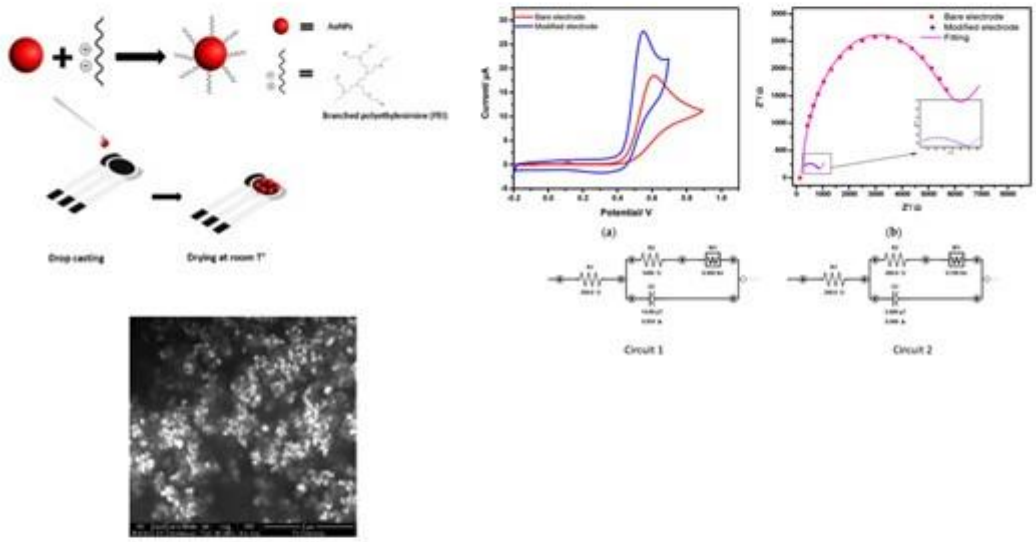
MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

Enhanced Nitrite Detection by a Carbon Screen Printed Electrode Modified with Photochemically-Made AuNPs

by Malak Talbi [1,2,*], Ammar Al-Hamry [1], Priscila Rios Teixeira [3], Leonardo G. Paterno [3], Mounir Ben Ali [2,4] and Olfa Kanoun [1]

Chemosensors **2022**, *10*(2), 40; https://doi.org/10.3390/chemosensors10020040



Abstract

Excessive nitrite amounts harm the environment and put public health at high risk. Therefore, accurate and sensitive detection of nitrite in surface and groundwater is mandatory for mitigating its adverse effects. Herein, a highly sensitive electrochemical sensor based on carbon screen-printed electrodes (CSPE) surface-modified with photochemically-made gold nanoparticles (AuNPs, ~12 nm) is proposed for nitrite detection. Scanning electron microscopy, cyclic voltammetry, and electrochemical impedance spectroscopy show that AuNPs uniformly coat the CSPE, increase its surface area, and contribute to oxidizing nitrite to much lower potential (+0.5 V vs. Ag/AgCl) and faster rate. Under optimized differential pulse voltammetry conditions, the CSPE/AuNPs-PEI electrode responds linearly ($R^2 > 0.99$) to nitrite within a wide concentration range (0.01–4.0 µM), showing a sensitivity of 0.85 $\mu A \cdot \mu M^{-1} \cdot cm^{-2}$ and limit of detection as low as 2.5 nM. The CSPE/AuNPs-PEI electrode successfully detects nitrite in tap water and canned water of olives, showing no influence of those matrices. In addition, the electrode's response is highly reproducible since a relative standard deviation lower than 10% is observed when the same electrode is operated in five consecutive measurements or when electrodes of different fabrication batches are evaluated. View Full-Text

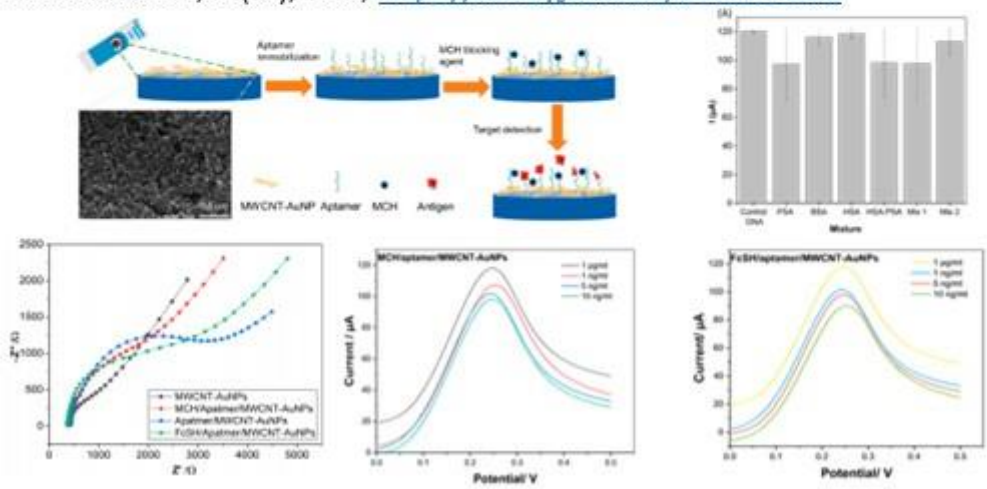
Keywords: nitrite detection; gold nanoparticles; carbon screen-printed electrode; differential pulse voltammetry; electrochemical impedance spectroscopy

biosensors MDPI MST MEASUREMENT AND SENSOR TECHNOLOGY

Gold Nanoparticles-MWCNT Based Aptasensor for Early Diagnosis of Prostate Cancer

by Aseel Alnaimi [1,2,*], Ammar Al-Hamry [2], Yahia Makableh [3], Anurag Adiraju [2] and Olfa Kanoun [2,*]

Biosensors **2022**, *12*(12), 1130; https://doi.org/10.3390/bios12121130



Abstract

Prostate cancer is one of the most frequently diagnosed male malignancies and can be detected by prostate-specific antigen (PSA) as a biomarker. To detect PSA, several studies have proposed using antibodies, which are not economical and require a long reaction time. In this study, we propose to use self-assembled thiolated single-strand DNA on electrodes functionalized by multi-walled carbon nanotubes (MWCNT) modified with gold nanoparticles (AuNPs) to realize a low-cost label-free electrochemical biosensor. In this regard, the PSA aptamer was immobilized via electrostatic adsorption on the surface of a screen-printed MWCNT/AuNPs electrode. The immobilization process was enhanced due to the presence of Au nanoparticles on the surface of the electrode. Surface characterization of the electrode at different stages of modification was performed by electrochemical impedance spectroscopy (EIS), atomic force microscopy (AFM) and Fourier transform infrared spectroscopy (FTIR) and contact angle for surface tension properties. The results showed an increase in surface roughness due to the absorbance of the aptamer on the electrode surfaces. The developed sensor has an extended linear range of 1–100 ng/mL, and a very low limit of detection down to 1 pg/mL. In addition, the reaction has a binding time of only five minutes on the developed electrodes. Investigations of the biosensor selectivity against several substances revealed an efficient selectivity for PSA detection. With this approach, low-cost biosensors with high sensitivity can be realized which have a wide linearity range and a low limit of detection, which are necessary for the early detection of prostate cancer.

Keywords: aptasensor; prostate cancer; prostate-specific antigen; carbon nanotubes; gold nanoparticles

chemosensors MDPI

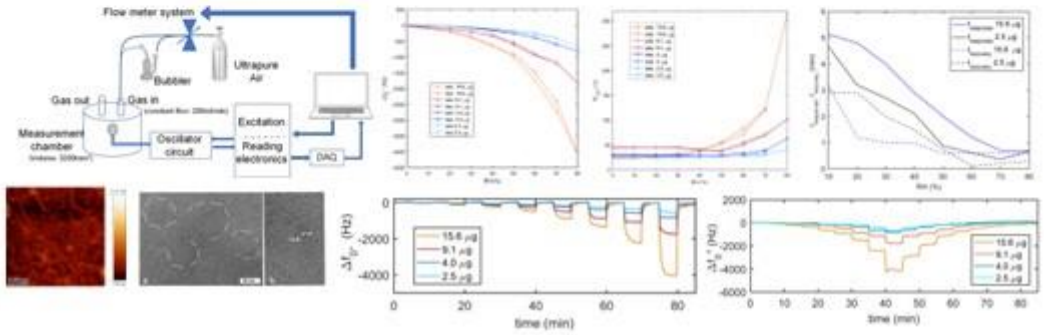
MST MEASUREMENT AND SENSOR TECHNOLOGY

Open Access Article

QCM Measurements of RH with Nanostructured Carbon-Based Materials: Part 2-Experimental Characterization

by Ada Fort [1], Anna Lo Grasso [1], Marco Mugnaini [1], Enza Panzardi [1,*], Lorenzo Parri [1], Valerio Vignoli [1], Cecilia Viti [2], Ammar Al-Hamry [3] and Olfa Kanoun [3]

Chemosensors **2022**, *10*(8), 320; https://doi.org/10.3390/chemosensors10080320



Abstract

In this series of two papers, the humidity sensing of a carbon nanotube (CNT) network-based material is transduced and studied through quartz crystal microbalance (QCM) measurements. To this aim, quartzes functionalized with different amounts of sensing material were realized, exposed to different humidity levels, and characterized. In this second paper, the experimental results are presented and discussed. The sensing mechanisms are elucidated exploiting the theory presented in the first paper of this series. The presented results show that the investigated material functionalization induces a large response of QCM to humidity in terms of resonant frequency even at low RH levels, with a sensitivity of about 12 Hz/%RH (at RH < 30% and room temperature and 10 ug of deposited SWCNT solution) and an increase in sensitivity in the high RH range typical of nanostructured film. Regarding the response in terms of motional resistance, a large response is obtained only at intermediate and high humidity levels, confirming that condensation of water in the film plays an important role in the sensing mechanism of nanostructured materials. View Full-Text

Keywords: QCM; humidity sensors; CNT water absorption; CNT-based humidity sensors; QCM humidity; carbon-based sensing film

Carbon

ELSEVIER

MST
MEASUREMENT AND SENSOR TECHNOLOGY

Photoinduced flexible graphene/polymer nanocomposites: Design, formation mechanism, and properties engineering

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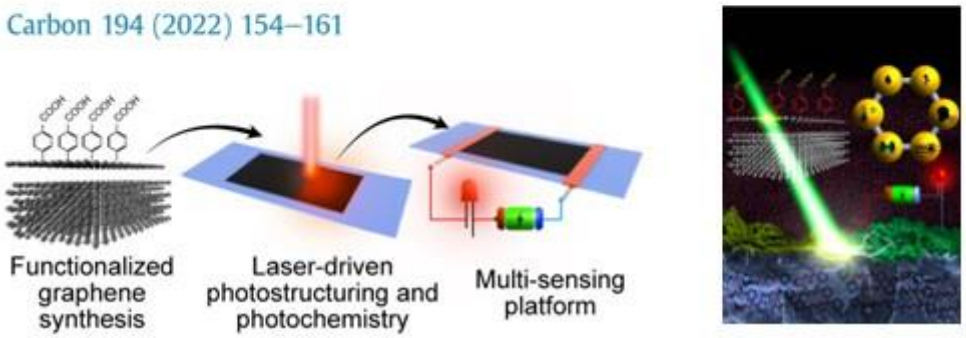

ABSTRACT

Flexible electronics is a new paradigm with strong implications from healthcare to energy applications. In this context, electrically conductive polymers are the critical components. Here, we report the design, formation mechanism, and applications of a polymer nanocomposite obtained by single-step laser integration of functionalized graphene into a polymer matrix. Laser processing manipulates the physical-chemical properties of this nanocomposite in a controlled and straightforward way, tuning the electrical resistance from a dielectric (MΩ sq^{-1}) to a highly conductive material (Ω sq^{-1}). We combine experimental and computational approaches to elucidate graphene nanocomposite's nature and formation mechanism, evidencing different processes from photothermal polymer melting to shock wave mixing in a liquid phase within a millisecond time scale. We exploit these fundamental insights on the graphene/polymer nanocomposite in the design and fabrication of electrochemical sensing and antenna devices, showing the potential for healthcare and the Internet of Things.

CRITICAL REVIEWS IN ANALYTICAL CHEMISTRY
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Surface-enhanced Raman Spectroscopy & Electrochemistry: The Ultimate Chemical Sensing and Manipulation Combination

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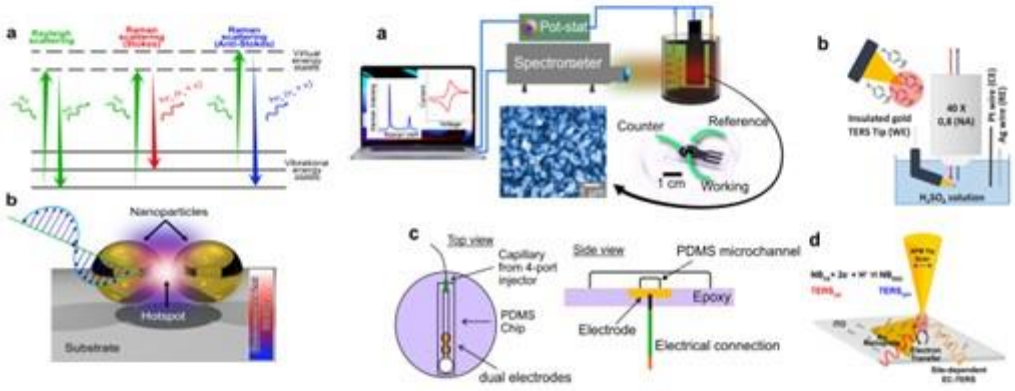

Abstract

One of the lessons we learned from the COVID-19 pandemic is that the need for ultrasensitive detection systems is now more critical than ever. While sensors' sensitivity, portability, selectivity, and low cost are crucial, new ways to couple synergistic methods enable the highest performance levels. This review article critically discusses the synergetic combinations of optical and electrochemical methods. We also discuss three key application fields—energy, biomedicine, and environment. Finally, we selected the most promising approaches and examples, the open challenges in sensing, and ways to overcome them. We expect this work to set a clear reference for developing and understanding strategies, pros and cons of different combinations of electrochemical and optical sensors integrated into a single device.

Journal of Composites Science
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Article

Stability Enhancement of Laser-Scribed Reduced Graphene Oxide Electrodes Functionalized by Iron Oxide/Reduced Graphene Oxide Nanocomposites for Nitrite Sensors

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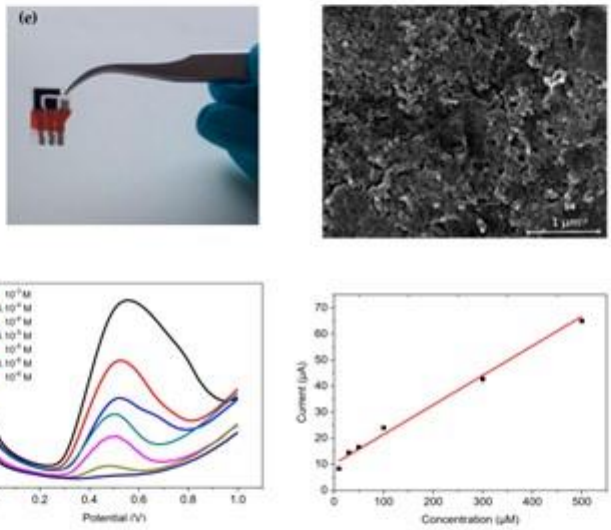

Abstract

An iron oxide/reduced graphene oxide (ION-RGO) nanocomposite has been fabricated to functionalize a low-cost electrochemical nitrite sensor realized by light-scribed reduced graphene oxide (LRGO) electrodes on a PET substrate. To enhance the stability and adhesion of the electrode, the PET substrate was modified by RF oxygen plasma, and a thin layer of the cationic poly (diallyl dimethyl ammonium chloride) was deposited. Raman spectroscopy and scanning electron microscopy coupled to energy-dispersive X-ray spectroscopy (SEM-EDX) reveal that the light-scribing process successfully reduces graphene oxide while forming a porous multilayered structure. As confirmed by cyclic voltammetry, the LRGO electrochemical response to ferri-ferrocyanide and nitrite is significantly improved after functionalization with the ION-RGO nanocomposite film. Under optimized differential pulse voltammetry conditions, the LRGO/ION-RGO electrode responds linearly (R2 = 0.97) to nitrite in the range of 10–400 µM, achieving a limit of detection of 7.2 µM and sensitivity of 0.14 µA/µM. A single LRGO/ION-RGO electrode stands for 11 consecutive runs. The novel fabrication process leads to highly stable and reproducible electrodes for electrochemical sensors and thus offers a low-cost option for the rapid and sensitive detection of nitrite. View Full-Text

Keywords: laser-scribing; reduced graphene oxide; iron oxide nanoparticles; voltammetric sensors; stability; nitrite

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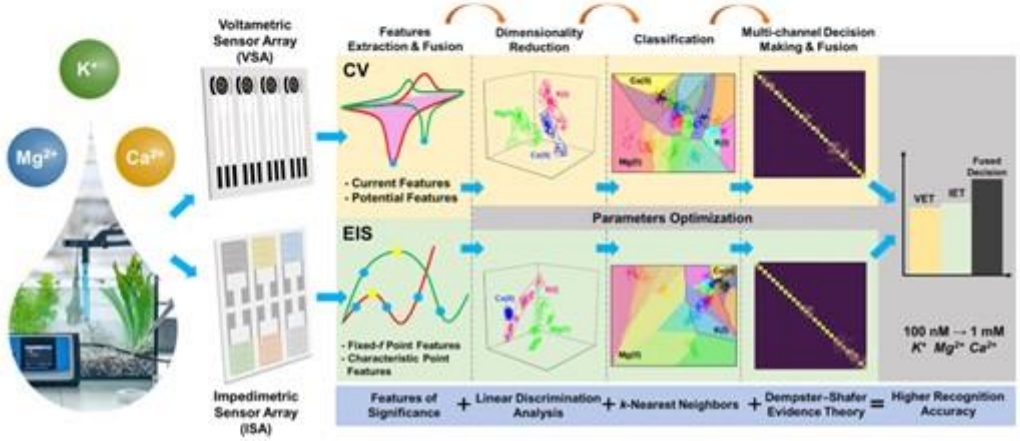
Open Access Article

Machine Learning-Based Multi-Level Fusion Framework for a Hybrid Voltammetric and Impedimetric Metal Ions Electronic Tongue

by Tianqi Lu †, Ammar Al-Hamry †, Junfeng Hao, Yang Liu, Yunze Qu and Olfa Kanoun *

Chemosensors **2022**, *10*(11), 474; https://doi.org/10.3390/chemosensors10110474



Abstract

Electronic tongues and artificial gustation for crucial analytes in the environment, such as metal ions, are becoming increasingly important. In this contribution, we propose a multi−level fusion framework for a hybrid impedimetric and voltammetric electronic tongue to enhance the accuracy of K^+, Mg^{2+}, and Ca^{2+} detection in an extensive concentration range (100.0 nM–1.0 mM). The proposed framework extracts electrochemical-based features and separately fuses, in the first step, impedimetric features, which are characteristic points and fixed frequency features, and the voltammetric features, which are current and potential features, for data reduction by LDA and classification by kNN. Then, in a second step, a decision fusion is carried out to combine the results for both measurement methods based on Dempster–Shafer (DS) evidence theory. The classification results reach an accuracy of 80.98% and 81.48% for voltammetric measurements and impedimetric measurements, respectively. The decision fusion based on DS evidence theory improves the total recognition accuracy to 91.60%, thus realizing significantly high accuracy in comparison to the state-of-the-art. In comparison, the feature fusion for both voltammetric and impedimetric features in one step reaches an accuracy of only 89.13%. The proposed hierarchical framework considers for the first time the fusion of impedimetric and voltammetric data and features from multiple electrochemical sensor arrays. The developed approach can be implemented for several further applications of pattern fusion, e.g., for electronic noses, measurement of environmental contaminants such as heavy metal ions, pesticides, explosives, and measurement of biomarkers, such as for the detection of cancers and diabetes.

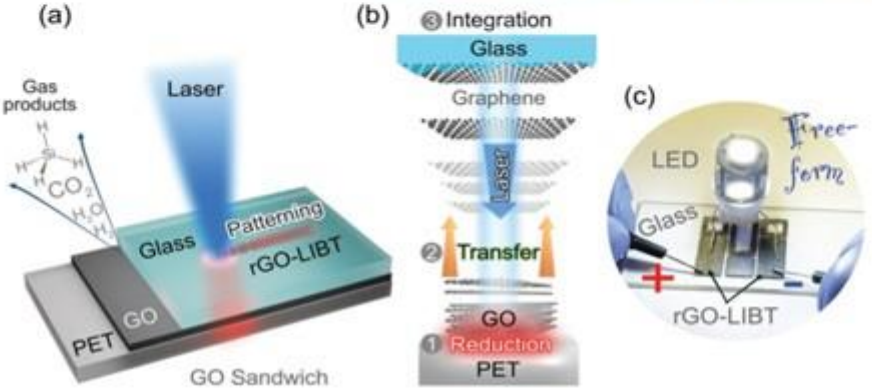
Keywords: electronic tongue; metallic ions detection; sensor array fusion; voltammetric sensor array; impedimetric sensor array; decision fusion; chemometrics; smart agriculture.

ADVANCED MATERIALS WILEY MST MEASUREMENT AND SENSOR TECHNOLOGY

Laser-Engineered Multifunctional Graphene–Glass Electronics

Raul D. Rodriguez, Maxim Fatkullin, Aura Garcia, Ilia Petrov, Andrey Averkiev, Anna Lipovka, Liliang Lu, Sergey Shchadenko, Ranran Wang, Jing Sun, Qiu Li, Xin Jia, Chong Cheng, Olfa Kanoun, and Evgeniya Sheremet*

Advanced Materials **2022**, *34 (43)* https://doi.org/10.1002/adma.202206877



Glass electronics inspire the emergence of smart functional surfaces. To evolve this concept to the next level, developing new strategies for scalable, inexpensive, and electrically conductive glass-based robust nanocomposites is crucial. Graphene is an attractive material as a conductive filler; however, integrating it firmly into a glass with no energy-intensive sintering, melting, or harsh chemicals has not been possible until now. Moreover, these methods have very limited capability for fabricating robust patterns for electronic circuits. In this work, a conductive (160 OΩ sq^{-1}) and resilient nanocomposite between glass and graphene is achieved via single-step laser-induced backward transfer (LIBT). Beyond conventional LIBT involving mass transfer, this approach simultaneously drives chemical transformations in glass including silicon compound formation and graphene oxide (GO) reduction. These processes take place together with the generation and transfer of the highest-quality laser-reduced GO (rGO) reported to date (Raman intensity ratio $I_D/I_G = 0.31$) and its integration into the glass. The rGO-LIBT nanocomposite is further functionalized with silver to achieve a highly sensitive (10^{-9} M) dual-channel plasmonic optical and electrochemical sensor. Besides the electrical circuit demonstration, an electrothermal heater is fabricated that reaches temperatures above 300 °C and continuously operates for over 48 h.

Microchemical JOURNAL

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Paracetamol detection in environmental and pharmaceutical samples using multi-walled carbon nanotubes decorated with silver nanoparticles

Saddam Weheabby [a], Zhenyn Wu [a], Ammar Al-Hamry [a], Igor A. Pašti [b], Adiraju Anurag [a], Doreen Dentel [c], Christoph Tegenkamp [c], Olfa Kanoun [a]

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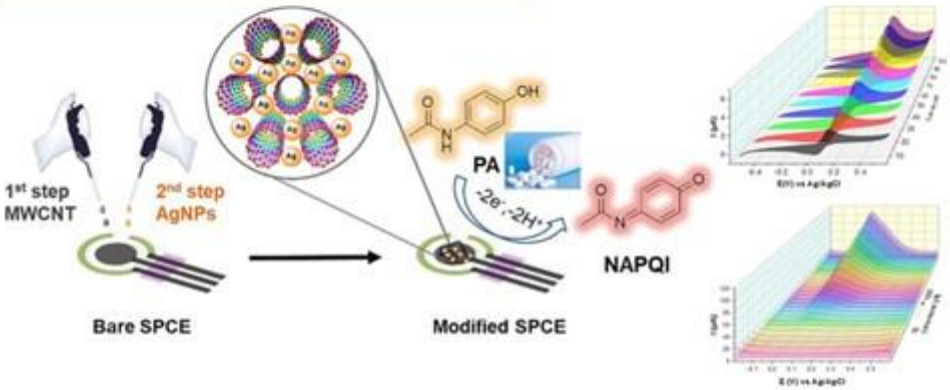

ABSTRACT

Paracetamol (PA) treats mild to moderate pain and fever with a high relative safety factor when administered properly. However, PA overuse creates harmful metabolites and serious illnesses. Thus, PA must be continually monitored and measured in environmental, pharmaceutical, and biological samples. In this work, voltammetric sensing of PA using silver nanoparticles (AgNPs) and carboxylated multi-walled carbon nanotubes (AgNPs@HOOC-MWCNT) deposited on screen-printed carbon electrode (SPCE) has been demonstrated. The AgNPs were prepared through a simple reduction method with an average particle size of 46 nm. Both AgNPs and modified electrodes were characterized by ultraviolet–visible spectroscopy, Fourier transform infrared spectroscopy, Raman spectroscopy, scanning electron microscopy, and energy-dispersive X-ray analysis. The electrochemical behaviour of PA over the modified (AgNPs@HOOC-MWCNT@SPCE) was studied using cyclic voltammetry (CV). It has been demonstrated that a relatively small quantity of AgNPs results in a considerable improvement in the active surface area of the modified electrode and an increase in the oxidation current of PA. In addition, a computational study was performed to complement the experimental work. Using square wave voltammetry (SWV) under optimal conditions (pH 7.4 and 25 °C), AgNPs@HOOC-MWCNT@SPCE sensor shows an effective sensing potential with a limit of detection of 0.24 μM in the concentration range of 0.5 to 1000 μM. The reproducibility and repeatability studies and long-term stability for 60 days were illustrated. Ultimately, the practical applications of the proposed method for determining PA in environmental and pharmaceutical samples were demonstrated with satisfactory results.

Keywords:
Silver nanoparticles
Multi-walled carbon nanotubes
Electrochemical sensors
Paracetamol

6 Smart Wearables

IEEE SENSORS JOURNAL

IEEE Sensors Council

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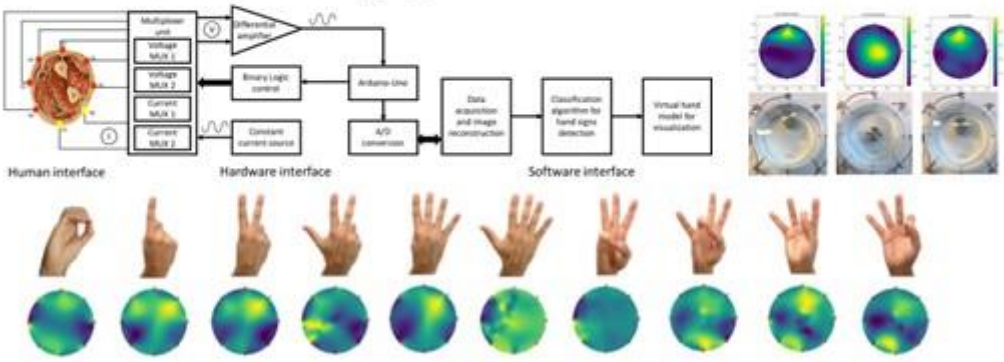
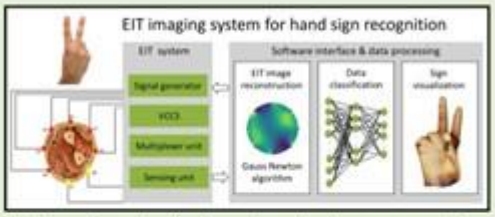
Hand Sign Recognition System Based on EIT Imaging and Robust CNN Classification

Bilel Ben Atitallah, *Member, IEEE*, Zheng Hu, Dhouha Bouchaala, Mohammed Abrar Hussain, Amir Ismail, Nabil Derbel, *Senior Member, IEEE*, and Olfa Kanoun, *Senior Member, IEEE*

IEEE Sensors Journal **2022**, 22(2), pp. 1729-1737, doi: 10.1109/JSEN.2021.3130982.



***Abstract*—Hand sign recognition is gaining importance in human-human and in human-machine communication and interaction. Electrical Impedance Tomography (EIT) is thereby very interesting as it provides information on impedance changes in depth of the section of the arm, which infers muscle contractions. This paper introduces an EIT imaging system for hand sign recognition and monitoring having a low complexity and including an electronic interface with 8 electrodes placed on the forearm, a Gauss-Newton image reconstruction algorithm, a robust CNN based hand sign classification and a virtual hand model for visualization. A database has been collected for EIT measurements in pole mode taken by eight subjects performing the American sign language numbers from 0 to 9. The overall imaging system is validated using a water tank system, where conductive objects can be changed in properties and positions. The correspondence between the reconstructed images and the expected muscle behavior for the hand signs is investigated. A robust Convolutional Neural Network (CNN) classification algorithm was implemented and optimized by implementing an Adam optimizer and conducting a dedicated study to avoid overfitting. The results obtained by CNN are compared to the results by a Support Vector Machine (SVM), and a Softmax classifier. They show a classification accuracy of 95.94%, 75.61%, and 62.9% respectively. In term of subject dependency, the system using the CNN model shows a higher performance, as the accuracy decreases only by 0.72% while increasing the number of subjects from one to eight. Finally, for visualization, a 3D virtual hand model is designed and controlled based on detected hand signs.**



***Index Terms*—Electrical impedance tomography, EIT, hand sign detection, sign language, regularized Gauss-Newton algorithm, virtual hand control, convolutional neural network, support vector machine, softmax.**

TECHNISCHES MESSEN
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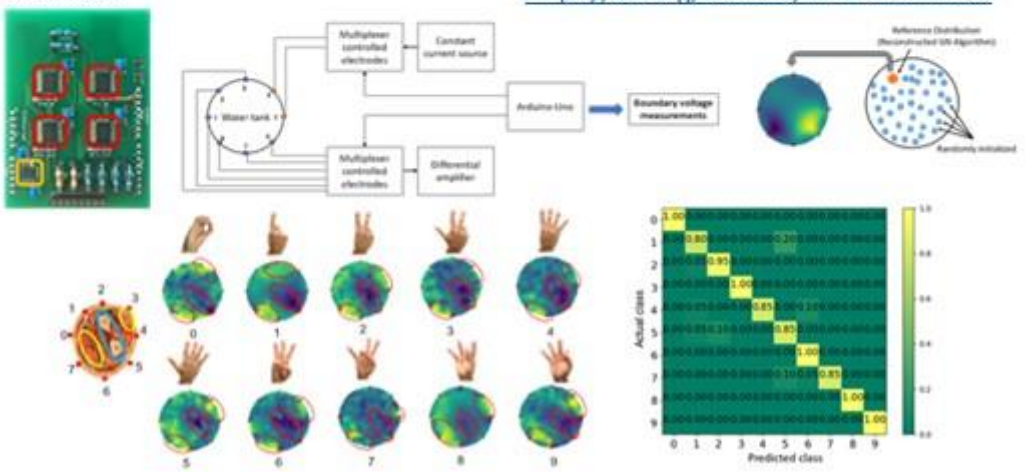
MST MEASUREMENT AND SENSOR TECHNOLOGY

A genetic algorithm for image reconstruction in electrical impedance tomography for gesture recognition

Mariem Hafsa, Bilel Ben Atitallah, Taha Ben Salah, Najoua Essoukri Ben Amara, and Olfa Kanoun*

https://doi.org/10.1515/teme-2021-0126



Abstract: Electrical impedance tomography (EIT) is an imaging method for characterizing the inner conductivity distribution of an object based on the measured boundary voltages resulting from the injection of an AC signal, followed by an image reconstruction procedure. An algorithm tries to solve an ill-posed inverse problem making it challenging to reconstruct an accurate image. To overcome this, we propose a genetic algorithm (GA) for the image reconstruction with a non-blind search method considering prior knowledge about the possible conductivity distribution in the initial search space. To validate the algorithm, experiments have been conducted in a water tank. The algorithm's performance was evaluated regarding image quality and processing time, being able to minimize the corresponding quality function to 0.0505 with 100 generations using the non-blind search and the uniform crossover/random mutation. Compared to traditional methods, the GA achieves significantly better image quality. It has been implemented as an image reconstruction algorithm for gesture recognition. EIT measurements have been conducted with six persons performing American sign numbers (0–9) resulting in 1800 reconstructed images. They were classified by a previously developed convolutional neural network (CNN), reaching a 92% accuracy, which is a very good achievement in the case of multiple subjects.

Keywords: Electrical impedance tomography, EIT, impedance spectroscopy, image reconstruction, genetic algorithm, non-blind search, parallel architecture, gesture recognition.

TECHNISCHES MESSEN
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Efficient data aggregation technique for medical wireless body sensor networks

Mbarka Belhai Mohamed*. Amel Meddeb-Makhlouf. Ahmed Fakhfakh. and Olfa Kanoun

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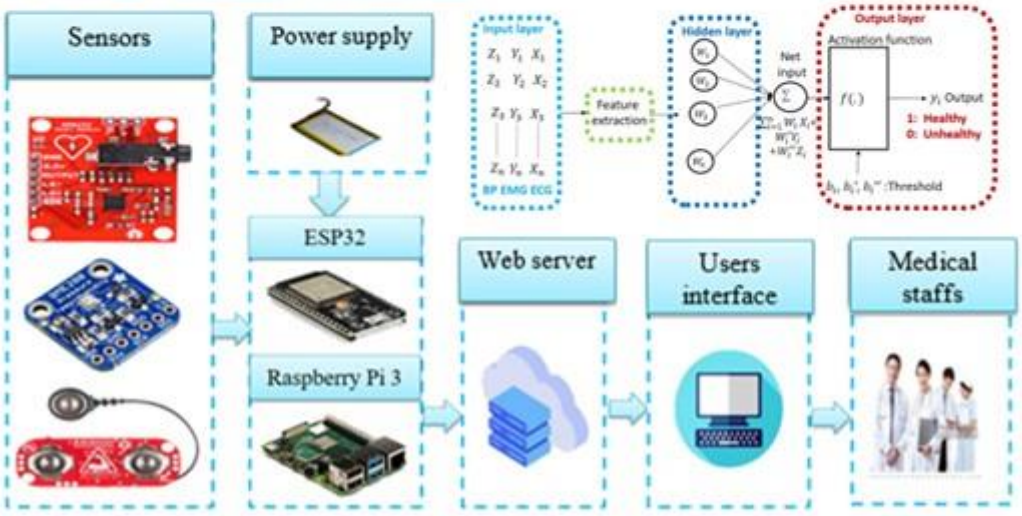

Abstract: A central issue in Wireless Body Sensor Networks (WBSNs) is the large amount of measurement data for monitoring vital parameters, which need to be continuously measured, immediately processed and timely transmitted. This requires a big storage space and computing effort leading to a high-power consumption. Reducing the amount of transmitted data contributes significantly to an extension of the sensor operation time. In this contribution, we focus exactly at this aspect. We propose a data aggregation method based on Artificial Neural Networks (ANN) combining multiple physiological signals, which are the ElectroCardioGram (ECG), ElectroMyoGram (EMG) and Blood Pressure (BP), in one signal before transmission. The simulation and implementation results reveal a reduction of energy consumption to 87.32%, ensuring a high accuracy level (80.53%) and a relatively execution time (48.47 ms).

Keywords: Accuracy, data aggregation, low energy consumption, WBSN.

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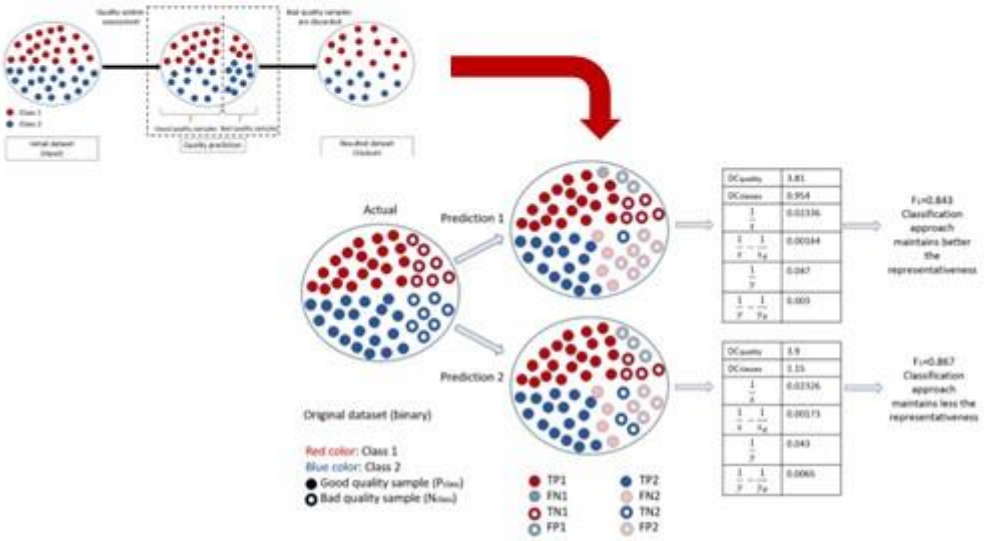
Representativeness consideration in the selection of classification algorithms for the ECG signal quality assessment

Nesrine Keskes [a,*], Sameh Fakhfakh [a,b,c], Olfa Kanoun [d], Nabil Derbel [a]



A B S T R A C T

Background and Objectives: With the progress of digitalization, electrocardiograms (ECGs) are increasingly measured by embedded and portable devices, which may lead to significant degradation of signal quality due to noise and artifacts. This leads to the necessity of signal quality assessment before ECG interpretation. Especially, if the ECG training database is not balanced between bad and good signals the classification accuracy and the data distribution on the two classes are affected. In this paper, a comparative study is elaborated between 10 re-sampling techniques for data balancing, which have been applied with the random forest classifier. Methods: Based on this study, we propose a novel metric to consider the representativeness of the original data, to guaranty the closeness of the quality assessment results to the initial classes' partition. The evaluation of the classifier's performance is based on two criteria, which are the classifier training performance and the representativeness coefficient. It is to note that this novel measure is a complementary metric for classification evaluation and the classifier performance has the first priority. We refer thereby to a multi-objective optimization (MOO) method as a tool to reconcile both criteria. Results: The hybrid balancing technique SMOTETomek fulfills both criteria in a good manner. It reaches a high training performance and maintains the data representativeness. Conclusion: It is not necessary for a classifier algorithm with the best classification performance to be able to maintain the representativeness of the data, which affirms the importance of this study. Thus the proposed new metric should be taken into consideration for the selection of the classification method when dealing with new resulted data after discarding the bad qualified signals.

Keywords:
Electrocardiogram (ECG)
Imbalanced learning
Random forest algorithm
Re-sampling technique
Representativeness coefficient
Signal quality assessment

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