Real-time Contactless Bio-Sensors and Systems for Smart Healthcare using IoT and E-Health Applications

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Abstract: - The population surge and geographical mass transit for survival and healthcare is increasing exponentially since the 1900 and climate change has made it inevitable. These geographical dynamics have mandated the requirement of contactless or non-invasive scalable and smart healthcare methods and techniques across the globe. The recent pandemic has obliged contactless sensing technologies in all the bio-sensing domains. In this work, the contactless bio-capacitive electrode for cardiological condition assessment has been addressed for researchers, technologists, scientists, and clinical professionals to understand the gradual innovation and enrichment in contactless bio-sensing techniques, methods, and materials, devices, and systems is exponentially increasing over the last seven decades. This work is a comprehension of major contributions in contactless capacitive bio-sensors and systems developed from 1950 to 2020. An overall of 500 articles in contactless capacitive bio-sensors and systems domain from top journals were selected for study; out of which 100 have been referred in this work. Starting from bio-capacitive electrodes to IoT-based indigenous contactless smart nodes have been introduced in this article.

Keywords: - bio-sensors, CoVID19, EEG, ECG, MRI, PET, IoT, eHealth.

Received: May 21, 2021. Revised: March 10, 2022. Accepted: April 11, 2022. Published: May 7, 2022.

1 Introduction

The term "biosensor" refers to a bio-electronic or electro-chemical instrument that can sense and measure life activities through some biological sensing element and may have a variety of other applications covered in that body of knowledge in [1, 2] by M. Cremer et al (1906) and Soren Peder Lauritz Sorensen (1909) and onwards by Griffin and Nelson (1909-4922) in [3]. In 1962, the first biosensor system was invented by Clark and Lyons to measure glucose in biological samples that utilized the strategy of electrochemical detection of oxygen or hydrogen peroxide [3] and a sequence of experiments documented by Clarke et al [4] and Joseph et al in [5] and a comprehensive chronological verdict [6]. The ubiquity of impedance is mainly leveraged to realize the bio-transducers eloquent from the works [7, 8]. Formally, contactless impedance sensors being passive requires an external field excitation source to inject some energy into the observation specimen [9] explained by Birgette et al (1950). The feedback of this energy can have many numerical relationships with the induced signal termed a working response (capacitive coupling) [10]. For decades, capacitive impedance sensors have been well consolidated in the industry; thanks to their versatility and two key properties: they are (1) noninvasive and (2) contactless [11-15].

In this work, we will exclusively discuss bio-capacitive sensing. Different names are used to realize the unique types of EEG capacitive electrodes and contactless bio-capacitive systems. This practice leads to transparency and resolution of conceptual complexities in recognizing the similarities and differences between contactless capacitive sensing systems and the contributions of new techniques. The contributions of this paper are chrono-logically comprehending:

1. A scientific coherence to clarify and classify contactless capacitive electrodes, their fabrication, and assemblies.
2. A guideline for CCEB generations based on their signal conditioning and data acquisition.
3. A detailed survey of past work and recommendations for EEG/ECG system design.
4. EEG health platforms utilizing bio-capacitive sensors. The overall study carried out in this research is presented in figure 1.

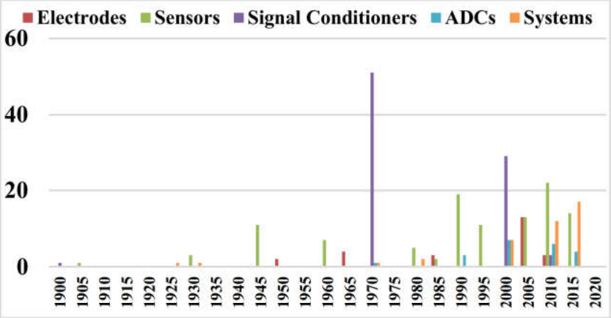
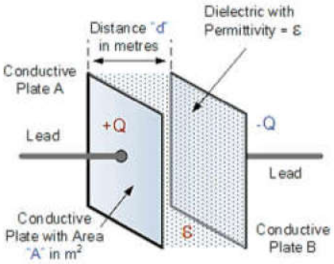


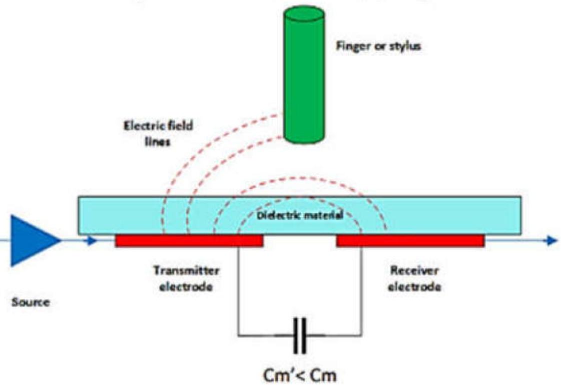
Fig 1. A Chronological Walkthrough of Capacitive Bio-Sensors and Systems [1-100]

2 Origin to Application of Capacitive Sensing Electrodes

Different types of capacitive electrodes or terminals can be used to assess the physical properties [16] such as touch capacitive [17-19], proximity capacitive [18], or shape variation by measuring the capacitive impedance between two or more conductors [19]. These conductors, which are termed as electrodes, are solid metal parts as a material [20, 21], but they can also be made from other conductive materials including foils, various transparent films (e.g., indium tin oxide, InTO) [22, 23], plastics, rubber, textiles, inks, and paints. In other cases, electrodes include the human body or objects in the environment [24, 25] by Chan et al and Elif et al. The first a foremost fundamental model of capacitive sensing is presented in figure 2.



a. Capacitive Plates (Electrodes) [3-11];



b. Capacitive Sensing Electrodes [8-30]
Fig 2. Capacitor Plates and Capacitive Electrodes Sensing

Figure 2 (a) presents the working principle of a generic parallel plate capacitor and figure 2b realizes a capacitive electrode concept for sensing applications based on a transmit electrode, a receive electrode [26-28]. The dielectric variation leads to a change in capacitance C due to displacement current I during some time interval Δt. The capacitive electrodes sensing mechanism is entirely electrical, low power, and requires low-cost electronics with static parts or mechanical intermediaries [26-31].

3 Capacitive Electrodes Sensing Approaches and Operating Modes

Fundamentally, there are only two capacitive electrode sensing approaches; a) active sensing: active sensing systems mandatorily generate an electric field [34-145] and b) passive sensing: passive sensing systems depend on the existing electric field [33-51]. Furthermore, there are four operative modes for each approach; a) Isometric, b) receive, c) transmit, and d) loading [33-124].

Comprehensive research by Zimmerman et al in active capacitive sensing realized that there is a specific signal generated from the transmit electrode to receive electrode and in between exists dielectric or human body dielectric to vary the signal strength [38-55]. The majority of research in the past has been conducted in touch sensing [7-54]. An emerging area in capacitive sensing is passive capacitive sensing in which there are opportunist existing or external electric fields sensing [39, 40]. In simpler words, active sensing is about generating or transmitting electric flux, whereas passive is capturing or receiving the flux inference [42, 45]. Let us briefly discuss operating modes for capacitive sensing approaches.

3.1 Isometric Mode (Mutual Coupling)

Identical or isometric coupling by 1:1 TX/RX is a combination of transmitting and receive mode occurs. In this case, a variable dielectric is introduced like the human body as exhibited in the figure below [34-37].

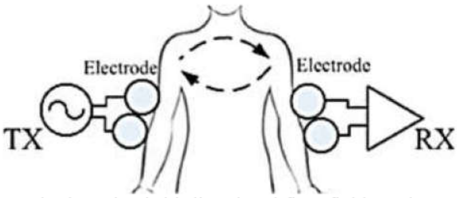
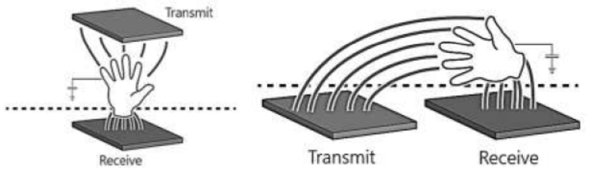


Fig 3. Human body active is bi-directional flow field conductor [35, 36]

3.2 Receive Mode

The receive mode is made possible by making the body as an extension of the receiver electrode to access surrounding electric fields. In this case, a human body acts as a multi-channel receiver for multi-variable sensing as exhibited in the figure below [41-43].

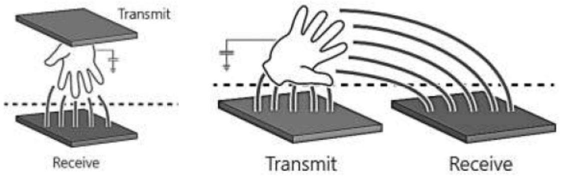


a. Passive Receiver b. Active Receiver

Fig 3. Human body acting as a collaborative flux receiver [41, 43]

3.3 Transmit Mode

The transmit mode is made possible by making the body an extension of the transmit electrode to improvise the nearest transmitter created electric fields.



a. Passive transmitter b. Active transmitter

Fig 3. Human body acting as a collaborative flux transmitter [44]

In this case, the human body acts as a multi-impedance transmitter for multi-variable sensing receivers as exhibited in the figure below [44].

3.1 Loading Mode

In loading mode, an offset current flow through the body to the ground through the capacitively-loaded electrode. A single electrode is utilized as a transmitter and receiver of flux as exhibited in the figure below [45-49].

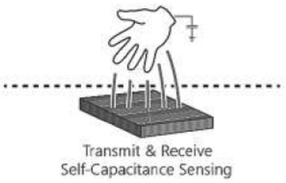


Fig 3. Single capacitive electrode being used as TX/RX [43-47]

Different types of capacitive electrodes or terminals can be used to assess the physical properties [50, 51] such as touch capacitive.

2 Contactless Capacitive Electrode Biosensors (CCEBs)

In 1907, the first bio-sensors were registered by Cremer, i.e. a string electrometer to approximate the epithelial movement in heart of a frog [5, 18, 62]. The heart of the frog was placed between the plates of a capacitor, and as it vibrated with each beat a change in capacitance was observed. Later, in 1920, Leon Theremin demonstrated a gesture-controlled electronic ´musical instrument known as the Theremin [18, 19], consisting of bi-capacitive tuned resonant circuits controlling pitch and volume [53]. While capacitive sensing grew to be an important tool for many engineering applications, such as sensing distance, acceleration, force, pressure, etc. [54-59]. Since the invention of the glucometer in 1962 as the first commercially available biosensor by Clark and Lyons [61-63], several techniques and strategies became ambient. The major types of biosensors that emerged and made their ground in different measurement conditions were [65-75]:

1. Electrochemical biosensors (by Clark and Lyons (1962) [4, 5], Wang et al. (2014) [63], Erden and Kilic (2013) [64] and Kim et al. (2015) [65], Pundir and Chauhan (2012), and Marrazza (2014)).
2. Optical/visual biosensors by Schneider and Clark (2013) [64, 66], Khimji et al. (2013), Peng et al. (2014) and Shen et al. (2014) [64, 65, 67].
3. Silica, quartz/crystal and glass biosensors (by Ogi (2013)) [64, 66-68].
4. Nanomaterials-based biosensors (by Ko et al. (2013), Senveli and Tigli (2013), Valentini et al. (2013), Li et al. (2011), Kwon and Bard (2012), Zhou et al. (2012), Guo (2013), Hutter and Maysinger (2013), Lamprecht et al. (2014) and Sang et al. (2015)) [64, 66-72].
5. Genetically encoded or synthetic fluorescent biosensors (by Kunzelmann et al. (2014), Randriamampita and Lellouch (2014), Oldach and Zhang (2014), and Wang et al. (2015)) [66, 68-71].
6. Microbial biosensors through synthetic biology and genetic/protein engineering (by Sun et al. (2015) and Gutierrez et al. (2015)) [72-74].

This discussion will follow one type of capacitive bio-sensors (the first type of bio-sensors), further trimmed down to branch contactless capacitive electrodes based bio-sensors [75].

2.1 Unified Structure and Topologies of CCEBs

The basic architecture or structure of a contactless capacitive electrode bio-sensor (CCEB) and its evolution or optimization is comprehended in figure 11 given below [75-78].

Figure 4 shows four generations of CCEBs [75-88]. The blue rectangle presents the earliest vision and breed of CCEBs dedicated to EEG and ECG [75, 76].

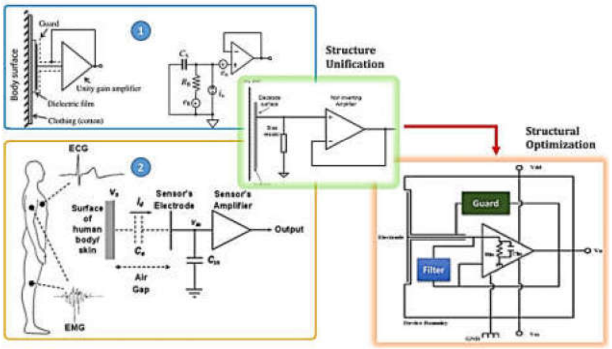


Fig 4. Unified Structure and Chronological Evolution of Contactless Bio-Sensor [75-78]

The orange rectangle is a realization of a single sensor for EMG and ECG [18, 77-80] [18, 78-81] and the green one is a single structure [81] put forth to be worked at and improved for all future designs and bio-instrumentation practices. Further improvement created huge gaps in filter design and guard or shielding optimization for CCEBs [82].

2.2 Key Performance Indicators in CCEBs

The key performance indicators (KPIs) in contactless capacitive bio-sensors are [7, 84-101]:

1. Electrostatic transients of electrode shape on the signal measured (discovered by Bri-to-Neto et al in coupled contactless conductivity study (2005) [83], da Silva et al in oscillometric detector design (1998) [78], Francisco et al in the design of compact and high-resolution version of a capacitively coupled contactless conductivity detector (2009)[86], Opekar et al in formulating a simple contactless conductivity detector em-ploying a medium wave radio integrated circuit for the signal treatment (2010) [87], Tuma et al in work of contactless conductometric detector with exchangeable capillary (2001) [88], Novotny et al in the study of effects of the electrode system geometry on the properties of contactless conductivity detectors for capillary (2005) [84], Ziemann et al for contactless conductivity detection for capillary electrophoresis (1998) [77, 88], Pumera et al used contactless conductivity detector for microchip capillary (2002) [89].
2. Field-effect of the width of the electrode (researched by Wang et al in contactless chip-based capillary conductivity microsystem for fast measurements of low-explosive ionic components (2002) [90], hardware improvement and optimization of input signal amplitude and frequency study by da Silva et al (2002) [91], like-wise Mayrhofer et al (1999) [92], Tuma et al (2002), and Kuban et al (2005) discovered contactless conductivity detection of ions in narrow inner diameter capillaries [93].
3. Displacement or offset between electrodes in research by Novotny et al for the effects of the electrode system geometry on the properties of contactless conductivity detectors (2005) [94].
4. Volume and chemistry of dielectric worked in different ways by 96.José Geraldo et al [95]and Zahiyoa et al [96] for high-voltage capacitively coupled contactless conductivity detection for microchip capillary (2002), Mika et al and Opika et al inflow study using thin-layer contactless conductivity cell (2009) [90, 97], Mark et al for comparison of the performance characteristics of two tubular contactless conductivity detectors with different dimensions and application in conjunction with HPLC (2009) [98, 99].
5. Transition in input voltage in conductivity detection and assessment studies by Tan-yanyiwa et al (2002) [100], Hohercakova et al (2005) [99], and Pavlicek et al (2011) [101].
6. Detector noise and signal deformation were inferred by high-voltage studies by Tanyanyiwa et al (2003), Hohercakova et al (2005), and Emaminejad (2012) [102].

7. Signal conditioners input scaling and reference voltage offset for detection [101-105]. The basic architecture or structure of a contactless capacitive electrode bio-sensor (CCEB) and its evolution or optimization is comprehended in figure 11 [75-78]

3 ECG/EEG Systems Architectures and Topologies Implemented using CCEBs

During the first 100 years of EEG CCEBs, a plethora of working models emerged and hold a foundation stone for future developments in this domain. In this section, major contributions will be reviewed and discussed. The improvement from the basic architecture or structure of a CCEB node to the Internet of Everything (IoE) will be revisited in the following sections:

3.1 Wireless Implementations of ECG/EEG Systems using CCEBs

Research niche in wireless CCEBs in ECG/EEG systems resulted in two major and notice-able topologies: a) multiple Wearable EEG/ECG electrode section nodes telemetry segregated at radio interface [144, 150-152]; b) multiple patch electrodes decision edges for EEG/ECGs [121, 122, 144]. Both topologies are presented in fig 16. The common architecture or structure of a contactless capacitive electrode bio-sensor (CCEB) and its evolution or optimization is comprehended in the figure below. It is commonly used by the key contributors Crippa et al (2002) [150], Wang et al (2012) [144], Northdrop el al (2003) [151], and Michael et al (2018) [152] using microcontrollers and SoC interfacing modules with AFEs at the input.

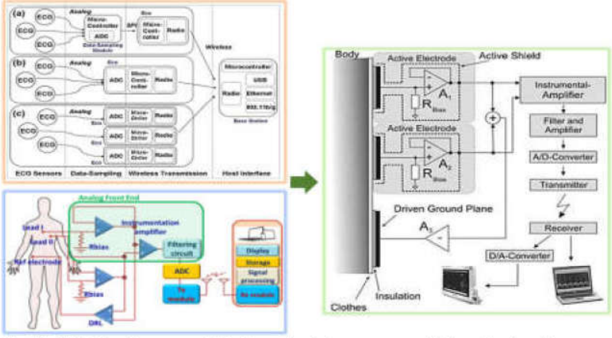


Fig 5. CCEBs Systems Wireless Architectures and Topologies from 2006 to 2007 [36, 121-127, 144, 150-152]

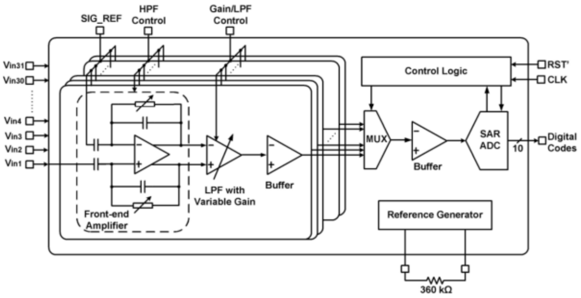
In fig 5, the parallel EEG/ECG CCEBs topology “Eco” for wearable EEG application by Chulsung Park et al (2006) [121] is presented in the pink color block, i.e. three unique EEG node architectures are pooling data to the radio transmitters that are sending it to the edge collector base-station. Eco used Nordic VLSI’s nRF24E1 (2.4 GHz RF transceiver) interfaced to DW8051. The base stations employed a GFSK modulation scheme with 125 frequency channels that were 1 MHz apart. The transmission output power is also soft-ware-configurable for four different levels using RainSun chip antenna (AN9520). This topology is significant in handling critically redundant situations. An improved version of CCEBs EEG node can be observed in the blue block in fig 16 by Sumit Majumder et al (2018) [122] with power consumption (19 µW) by subthreshold DSP and RF transmission power of 397 µW.

3.2 Future ECG/EEG Systems

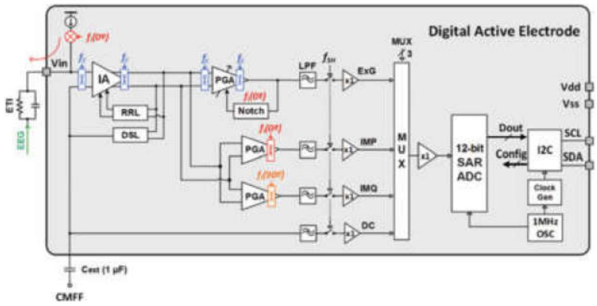
The research in CCEBs is harnessing towards the remote calibration and optimization of the existing EEG/ECG systems though serial on the go (OTG) interfaces using smartphones and update on the air (OTA) using web interface [144-162]. Five key areas in this effort were found in the literature as:

1. Remote Gain using Trans-conductance operational amplifiers, Filter Tuning, and Improved Signal Conditioners for CCEBs with OTA Parameterization (fig 17) [36, 123-128].
2. Patient State CCEBs CMOS ICs for Sensor Calibration OTG for EEG Systems (fig 18).
3. Single Board Computer Stand-Alone (with Multi-parametric System-on-Chip (SoC) EEG/ECG Nodes) Systems (fig 19).
4. Networked Adaptive Neuro-Fuzzy Inference Engine (ANFIE) EEG/ECG Decision Support Systems (fig 20).

In 1969, the shift-registers technique was first used by Lopez et al [36] by interfacing the core CCEBs block by the current mode single-frequency modulation channel of an IRIG instrumentation tape recorder. In 2007, a gel-free, non-contact EEG/ECG sensor with an onboard electrode that capacitively coupled to the skin was proposed by Thomson J. Sullivan et al [124] with configurable and programmable CCEBs interfaces in a 1-inch diameter enclosure. The measured input-referred noise, over the 1-100Hz-frequency range, is 2µVrms at 0.2mm sensor distance, and 17µVrms at 3.2mm distance using active shield-ing of the high-impedance input significantly that reducing noise pickup, and reduced variations in gain as a function of gap distance. In 2009, Jin Tao Li et al proposed a cur-rent-mode instrumentation amplifier (CMIA) topology using the CMOS 0.35 µm technology. The CMIA consumed 20.22 µW for a 3 V DC power supply and had a continuous adjustable gain-bandwidth product (GBW)-independent voltage gain via the single resistor. Its CMRR was higher than 120dB up to 1 Hz and more than 80 dB up to 100 Hz as plus to [125]. In 2014, Mahmoud, S. A. et al [126] proposed a six order cascaded power line notch filter for ECG detection systems with noise shaping based on 0.25 µm technology operating under ±0.8 V voltage supply 6th order notch filter provided a notch depth of 65 dB (43 dB for 4th order), input-referred voltage noise spectral density with noise shaping of 9 µVrms/√Hz at the pass-band frequencies and 9 mVrms/√Hz at the notch (zero) frequency and demonstrated the ability of the filter to be used for EEG/ECG signals filtering within the bandwidth of 150 Hz.



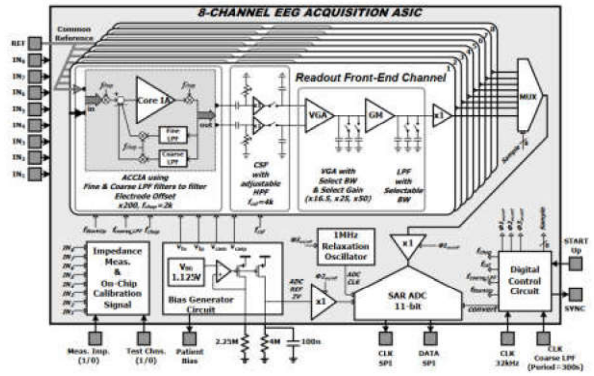
a) Accumulation of Contributions [36, 124-131] with programmability leading to CMOS in EEGs



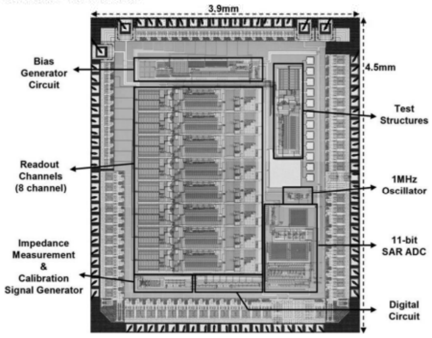
b) The architecture of a digital active electrode (DAE) chip.

Fig 6. A journey from Parametric EEGs modules to Programmable and Dedicated DAE ICs [36, 124-132, 134-138, 148]

The contributions in two niches by [36, 124-128, 130] work segregated into a partially con-figurable and programmable CMOS IC with addressable AFEs, switchable amplifications multiplexed to SAR with a static R as presented in fig 6 (a) by T. Denison et al [131] and evolved into the next generation active electrode CCEBs based on dedicated EEG/ECG DAE ICs proposed by Jiawei Xu et in 2015 [132]. In Jiawei Xu et al work, an IC was de-signed and developed that performed real-time EEG signal processing using 12-bit ADC with 15 electrodes interfaces, achieving state-of-the-art performance: 60 nV/sqrt (Hz) at input-referred noise (IRN), an improved CMRR of an AE pair from 40 dB to 102 dB and electrode-offset tolerance 350 mV for the block diagram exhibited in fig 6 (b).



a) Accumulation of Contributions [36, 124-131] with programmability leading to CMOS in EEGs



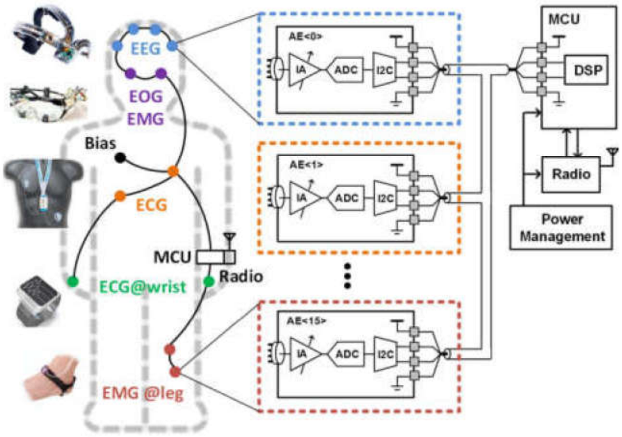
b) The architecture of a digital active electrode (DAE) chip.

Fig 7. A journey from Parametric EEGs modules to Programmable and Dedicated DAE ICs [36, 124-132, 134-138, 148]

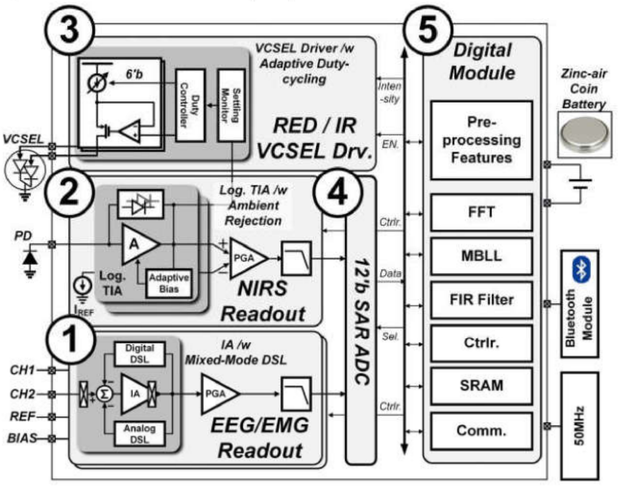
The 200 µW 8-channel EEG acquisition ASIC for ambulatory EEG systems [148] by Refet Firat et al (2008) is considered a masterpiece of ULSI in mobile EEGs presented in fig 7(a).

The major contribution [148] was the novel AC coupled chopper-stabilized instrumentation amplifier (ACCIA) implementation with coarse-fine servo-loop achieving 120 dB CMRR at 2.3 muA, noise-efficiency factor (NEF) of 4.3 for an ASIC implemented in 0.5 mum CMOS process, and the total current consumption 66 muA from 3 V power supply.

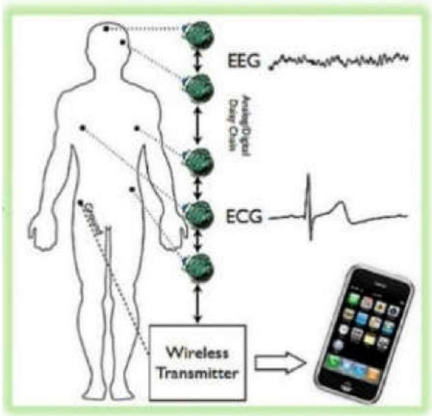
The dawn of networked or body area network (BAN) of EEG CCEBs was observed since 2010 including SBCs, IoT-edge, and endpoint servers [134-138, 153-162]. In 2010, the WBAN pioneered by Yu M. Chi et al [134] contributed as a novel system with 46 dB of gain over a .7-100Hz bandwidth with a noise level of 3.8µV RMS for high quality nervous (brain) and heart (cardio) measurements, stored and processed remotely presented in fig 7 (b).



a) Wired CCEBs EEG BAN [132] for DAEs



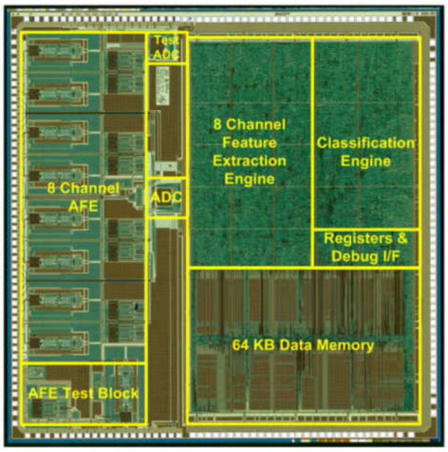
b) Specialized CCEBs EEG SoCs for Future Generation WBAN EEGs [135]



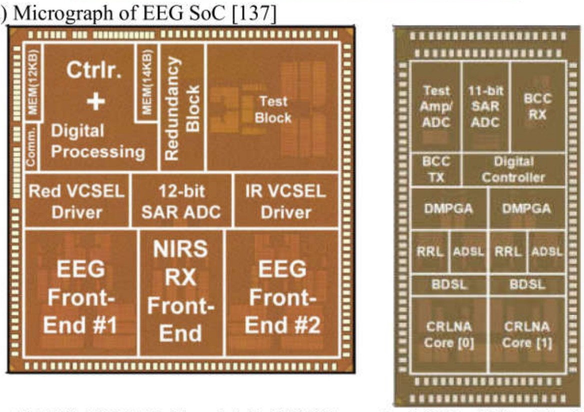
c) Ubiquitous WBAN EEG/ECG [136]

Fig 8. A journey from Parametric EEGs modules to Programmable and Dedicated DAE ICs [36, 124-132, 134-138, 148]

The Aachen SmartChair [135] by A. Aleksandrowicz et al (2017) was a landmark (fig 8 b) in body area networks with mobility and real-time validation of a classical ECG with conductive electrodes and an oxygen saturation signal (SpO2) were obtained simultaneously as presented in fig 9(a) in the green block. The mentioned work opened the floor for many to come.



a) Micrograph of EEG SoC [137]

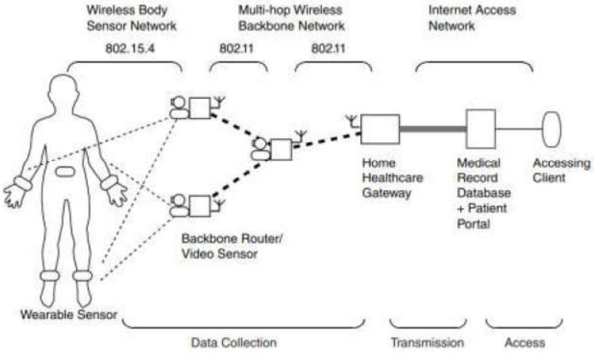


b) EEG-NIRS Multimodal SoC [138]

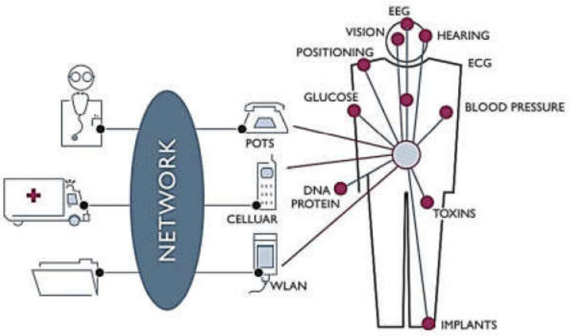
c) 0.8-V 82.9-µW SoC with 8.8 PEF EEG WBAN Transceiver [153]

Fig 9. Machine Learning-based SoCs/ASICs for EEG based on CCEBs

In 2013, Jerald Yoo pioneered the scalability in EEG SoC (fig 9 (b)) dedicated to seizure classification and recording processor [138]. An 8-channel AFE with Chopper-Stabilized Capacitive Coupled Instrumentation Amplifier (CCC-IA) to show NEF of 5.1 and noise RTI of 0.91 for 0.5–100 Hz bandwidth scalable EEG acquisition SoC with a ma-chine-learning seizure classification processor and a 64 KB SRAM. The EEG-SoC employed the Distributed Quad-LUT filter architecture to minimize the area while sup-port-vector machine as a classifier, with a GBW controller that gave real-time gain and bandwidth feedback to AFE to maintain accuracy. The CCC-IA SoC for EEGs was implemented in 0.18 1P6M CMOS process with an accuracy of 84.4% in eye blink classification test, at 2.03 /classification energy efficiency. The 64 KB on-chip memory had stored up to 120 seconds of raw EEG data. Recently, a successful clinical trial was demonstrated by a multimodal EEG-NIRS proposed by Unsoo Ha et al (2019) [153]. The multimodal EEG and near-infrared spectroscopy (NIRS) canceled out the ±300-mV electrode-dc offset for dried gel condition with 3.59 noise-efficiency factor by achieving a dynamic range of 60-dB crafted on a chip 16-mm2 (4 mm × 4 mm) SoC fabricated (65-nm) CMOS presented in fig 20 (b) and incorporated into a 3.5 cm × 26 cm head patch. Later a comprehensive contribution in EEG was documented by Jaehyuk Lee et al (2019) for an in-ear brain-computer interface (BCI) controller [154] implemented with a dedicated system-on-chip (SoC) for electroencephalography (EEG) readout and body channel communication (BCC) transceiver (TRX). The 8-mm2 chip fabricated with 65-nm CMOS packaged with a current reusing low-noise amplifier (CRLNA), bootstrapping dc servo loop (BDSL) and dual-mode programmable gain amplifier (DMPGA) that reduced TRX power consumption by the Chopper-Stabilized Capacitive Coupled Instrumentation Amplifier to show NEF of 5.1 and noise RTI of 0.91 for 0.5–100 Hz bandwidth and IC consumed 82.9 µW.



a) CareNet WBAN [161]



b) Human++ [162].

Fig 10. State of the Art WBAN EEG IoT Platforms with ML capabilities [156-161] [164-169]

In fig 10(a), Shanshan Jiang et al documented CareNet [161] as an integrated WBAN platform and WSN environment to facilitate remote care in EEG applications using TinyOS and NesC presented in fig 22 (a). Various SDN techniques were demonstrated along with the reliable and privacy-aware patient data collection using SSL, transmission, and access over the cloud using IPV4. The most comprehensive EEG WBAN implementation and contribution were registered by Bert Gyselinckx et al as HUMAN++ project (fig 10(b)) utilizing the full spectrum of capabilities in achieving highly miniaturized and autonomous transducer systems by employing 3D System-in-a-Package (SIP), wireless ultra-low-power communications with ball-grid-array (BGA), 3D integration technologies, MEMS energy scavenging techniques using TEGs with 200 cm2K/W per cm^2 and low-power design techniques.

4 Conclusion

The key contributions in the study of contactless bio-capacitive electrodes used for bio-sensors measurement, assessment, sensors, systems, and their life-cycle were chronologically elaborated in this work in a systematic portrait with state-of-the-art contributions by re-searchers around the world. This research served its purpose in key factors and criterion in contactless bio-capacitive sensors a) the effective impedance assessment techniques at skin, scalp and cloth level defined the credibility and accuracy of bio-metrics status; b) the electrodes selection and optimizable signal processing components contributed to achieve the desired measurements; c) the tactical and strategic orientation of capacitive plates assemblies and arrays were used to meet critical application challenges; d) the state-of-the-art sensors on chip options assisted in meeting the cutting edge market needs; e) the fabrication technologies and methods streamlined the properties, specifications and capabilities of bio-capacitive plates; f) the gradual improvement in testing methods of bio-capacitive plates harnessed enhanced calibration methods using ICs, ASICs and SoCs; g) the multi-parametric and dedicated sensor testing and calibration systems gave better in-sights of operational, measurement, and transient anomalies using programmable signal conditioners, ADCs, trans-impedance operational amplifiers, programmable gain amplifiers, analog front end; h) the application of machine learning based signal processing techniques and approaches was state-of-the-art evaluation method that served as a horizon in accuracy and credibility of bio-metric measurements; i) the selection of appropriate key performance indicators assisted in the quality of WBAN EEG topologies.

References:

[1] M. Cremer, Über die Ursache der elektromotorischen Eigenschaften der Gewebe. *zugleich ein Beitrag zur Lehre von den polyphasischen Elektrolytketten: R. Oldenbourg*, 1906.

[2] S. Sorensen, Etudes enzymatiques. II. Sur le mesure et l'importance de la concentration des ions hydrogène dans les reactions enzymatiques. *Compt. rendu Lab. Carlsberg*, viii, vol. 1, 1909.

[3] E. G. Griffin and J. Nelson, THE INFLUENCE OF CERTAIN SUBSTANCES ON THE ACTIVITY OF INVERTASE. Journal of the American Chemical Society, vol. 38, pp. 722-730, 1916.

[4] J. Wang, Electrochemical glucose biosensors. *Chemical reviews*, vol. 108, pp. 814-825, 2008.

[5] S. Clarke and J. Foster, A history of blood glucose meters and their role in self-monitoring of diabetes mellitus. *British journal of biomedical science*, vol. 69, pp. 83-93, 2012.

[6] J. Wang, Glucose biosensors: 40 years of advances and challenges. *Electroanalysis: An International Journal Devoted to Fundamental and Practical Aspects of Electroanalysis*, vol. 13, pp. 983-988, 2001.

[7] B. Nikhil, J. Pawan, F. Nello, and E. Pedro, Introduction to biosensors, *Essays in Biochemistry*, vol. 60, pp. 1-8, 2016.

[8] S. Kasturi, Y. Eom, S. R. Torati, and C. Kim, Highly sensitive electrochemical biosensor based on naturally reduced rGO/Au nanocomposite for the detection of miRNA-122 biomarker, *Journal of Industrial and*

Engineering Chemistry, vol. 93, pp. 186-195, 1920.

[9] R. J. Murtagh, X-ray triggering by automatic sensing, 1967.

[10] B. Freiesleben De Blasio and J. Wegener, Impedance Spectroscopy, *Encyclopedia of Medical Devices and Instrumentation*, 2006.

[11] W. Ko, B.-X. Shao, C. Fung, W.-J. Shen, and G.-J. Yeh, Capacitive pressure transducers with integrated circuits, *Sensors and Actuators*, vol. 4, pp. 403-411, 1983.

[12] K. Jaehwan, K. Joo-hyung, and S. B. Sup, Disposable and Flexible Chemical Sensors and Biosensors Made with Renewable Materials: *World Scientific*, 2017.

[13] C. Nylander, Chemical and biological sensors, *Journal of Physics E: Scientific Instruments*, vol. 18, p. 736, 1985.

[14] W. Ko, Sensors and actuators for prosthetic systems, in *COMPEURO 89 Proceedings VLSI and Computer Peripherals*, 1989, pp. 3/158-3/163.

[15] J. Healer, Review of biological mechanisms for application to instrument design, 1967.

[16] S. N. Asl, F. Ludwig, and M. Schilling, Noise properties of textile, capacitive EEG electrodes, *Current Directions in Biomedical Engineering*, vol. 1, pp. 34-37, 2015.

[17] A. J. Portelli and S. J. Nasuto, Design and development of non-contact bio-potential electrodes for pervasive health monitoring applications, *Biosensors*, vol. 7, p. 2, 2017.

[18] R. Wijesiriwardana, K. Mitcham, W. Hurley, and T. Dias, Capacitive fiber-meshed transducers for touch and proximity-sensing applications, *IEEE Sensors Journal*, vol. 5, pp. 989-994, 2005.

[19] E. Ghafar-Zadeh and M. Sawan, Capacitive Bio-interfaces, in CMOS Capacitive Sensors for Lab-on-Chip Applications, ed: *Springer*, 2010, pp. 35-50.

[20] K. Vlach, J. Kijonka, F. Jurek, P. Vavra, and P. Zonca, Capacitive biopotential electrode with a ceramic dielectric layer, *Sensors and Actuators B: Chemical*, vol. 245, pp. 988-995, 2017.

[21] D. L. Mathine, D. Z. Fang, D. J. O'Connell, J. Bahl, M. Scholz, and R. B. Runyan, Indium tin oxide electrodes for cell-based biosensors, in 2005 3rd *IEEE/EMBS Special Topic Conference on Microtechnology in Medicine and Biology*, 2005, pp. 180-183.

[22] C.-H. Hong, J.-H. Shin, B.-K. Ju, K.-H. Kim, N.-M. Park, B.-S. Kim, et al., Index-matched indium tin oxide electrodes for capacitive touch screen panel applications, *Journal of nanoscience and nanotechnology*, vol. 13, pp. 7756-7759, 2013.

[23] E. B. Aydın and M. K. Sezgintürk, Indium tin oxide (ITO): A promising material in biosensing technology, *TrAC Trends in Analytical Chemistry*, vol. 97, pp. 309-315, 2017.

[24] I. Korhonen, J. Parkka, and M. Van Gils, Health monitoring in the home of the future, *IEEE Engineering in medicine and biology magazine*, vol. 22, pp. 66-73, 2003.

[25] R. Vishal and B. Poonkathirvelan, Capacitive Bio-Sensing, *ISOCC*, pp. 87-91, 2009.

[26] M. Ishijima, Monitoring of electrocardiograms in bed without utilizing body surface electrodes, *IEEE transactions on biomedical engineering*, vol. 40, pp. 593-594, 1993.

[27] S. Yiming and G. Li, Study on correlations of impedance pneumograph and siprometer, *Chinese journal of anesthesiolog*, vol. 18, pp. 278-281, 1995.

[28] J. H. Kim, S. M. Lee, and S.-H. Lee, Capacitive monitoring of bio and neuro signals, *Biomedical Engineering Letters*, vol. 4, pp. 142-148, 2014.

[29] S. S. Lobodzinski and M. M. Laks, Comfortable textile-based electrocardiogram systems for very long-term monitoring, *Cardiology journal*, vol. 15, pp. 477-480, 2008.

[30] D.-H. Zhu, L. Wang, and Y.-T. Zhang, A non-contact ECG measurement system for pervasive heart rate detection, in *2008 International Conference on Information Technology and Applications in Biomedicine*, 2008, pp. 518-519.

[31] D. Prutchi and M. Norris, Design and development of medical electronic instrumentation: a practical perspective of the design, construction, and test of medical devices*: John Wiley & Sons*, 2005.

[32] A. Usakli and N. Gencer, USB-Based 256-Channel Electroencephalographic Data Acquisition System for Electrical Source Imaging of the Human Brain, *Instrumentation Science and Technology*, vol. 35, pp. 255-273, 2007.

[33] O. J. Prohaska, F. Olcaytug, P. Pfundner, and H. Dragaun, Thin-film multiple electrode probes: Possibilities and limitations, *IEEE transactions on biomedical engineering*, pp. 223-229, 1986.

[34] N. Cho, J. Yoo, S.-J. Song, J. Lee, S. Jeon, and H.-J. Yoo, The human body characteristics as a signal transmission medium for intrabody communication, *IEEE transactions on microwave theory and techniques*, vol. 55, pp. 1080-1086, 2007.

[35] H. J. Baek, H. J. Lee, Y. G. Lim, and K. S. Park, Conductive polymer foam surface improves the performance of a capacitive EEG electrode, *IEEE transactions on biomedical engineering*, vol. 59, pp. 3422-3431, 2012.

[36] A. Lopez and P. C. Richardson, Capacitive electrocardiographic and bioelectric electrodes, *IEEE Transactions on Biomedical Engineering*, pp. 99-99, 1969.

[37] C. Wehrmann, M. Langer, and M. Schilling, Motion artefact detection in capacitively coupled EEG recording, *Biomedical Engineering/Biomedizinische Technik*, vol. 58, 2013.

[38] A. Clippingdale, R. Prance, T. Clark, and C. Watkins, Ultrahigh impedance capacitively coupled heart imaging array, *Review of scientific instruments*, vol. 65, pp. 269-270, 1994.

[39] J. G. Webster, Medical instrumentation: application and design: John Wiley & Sons, 2009.

[40] T. G. Zimmerman, J. R. Smith, J. A. Paradiso, D. Allport, and N. Gershenfeld, Applying electric field sensing to human-computer interfaces, in Proceedings of the *SIGCHI conference on Human factors in computing systems*, 1995, pp. 280-287.

[41] G. Cohn, S. Gupta, T.-J. Lee, D. Morris, J. R. Smith, M. S. Reynolds, et al., An ultra-low-power human body motion sensor using static electric field sensing, in Proceedings of the 2012 *ACM Conference on Ubiquitous Computing*, 2012, pp. 99-102.

[42] T. Grosse-Puppendahl, X. Dellangnol, C. Hatzfeld, B. Fu, M. Kupnik, A. Kuijper, et al., Platypus: Indoor localization and identification through sensing of electric potential changes in human bodies, in Proceedings of the 14th *Annual International Conference on Mobile Systems, Applications, and Services*, 2016, pp. 17-30.

[43] H. Prance, P. Watson, R. Prance, and S. Beardsmore-Rust, Position and movement sensing at metre standoff distances using ambient electric field, *Measurement Science and Technology*, vol. 23, p. 115101, 2012.

[44] Daniel Zehe et al, SEMSim Cloud Service: Large-scale urban systems simulation in the cloud. *Simulation Modelling Practice and Theory*, September 2015.

[45] Stella Vetova, Big Data Integration and Processing Model. *WSEAS Transactions on Computers*, vol. 20, pp. 82-87, 2021

[46] Farid Touati, Hasan Tariq, Damiano Crescini, Adel Ben Mnaouer, (2018). Development of Prototype for IoT and IoE Scalable Infrastructures, Architectures and Platforms. *Ubiquitous Networking. UNet 2018*. *Lecture Notes in Computer Science*, vol 11277. Springer, Cham.

[47] Zaheer Khan et al, An architecture for integrated intelligence in urban management using cloud computing. *Journal of Cloud Computing: Advances, Systems and Applications*, 2012.

[48] Abdullah A. Wardak, Interfacing C and TMS320C6713 Assembly Language (Part II). *WSEAS Transactions on Computers*, vol. 20, pp. 74-81, 2021.

[49] Hasan Tariq, Farid Touati, M. Al-Hitmi, Adel Ben Mnaouer and Damiano Crescini, A Real-time Early Warning Seismic Event Detection Algorithm using Smart Geo-spatial Bi-axial Inclinometer Nodes for Industry 4.0 Applications. *Applied Sciences,* 2019.

[50] Wang Jianhong, Ricardo A. Ramirez-Mendoza, Application of Interval Predictor Model Into Model Predictive Control. *WSEAS Transactions on Systems*, vol. 20, pp. 331-343, 2021.

[51] Hasan Tariq, Farid Touati, M. Al-Hitmi, Adel Ben Mnaouer and Damiano Crescini, Design and Implementation of Information Centered Protocol for Long Haul SHM Monitoring. *IEEE International Conference on Design & Test of Integrated Micro & Nano-Systems*, 2019.

[52] Luca Tamburini et al, Electronic and ICT Solutions for Smart Buildings and Urban Areas. *Renewable and Alternative Energy: Concepts, Methodologies, Tools, and Applications*, 2017.

[53] Hasan Tariq, Farid Touati, Mohammed Abdulla E Al-Hitmi, Anas Tahir, Damiano Crescini, and Adel Ben Manouer, Structural Health Monitoring and Installation Scheme Deployment using Utility Computing Model. *2nd European Conference on Electrical Engineering and Computer Science*, 2018.

[54] Eman Emad, Omar Alaa, Mohamed Hossam, Mohamed Ashraf, Mohamed A. Shamseldin, Design and Implementation of a Low-Cost Microcontroller-Based an Industrial Delta Robot. *WSEAS Transactions on Computers*, vol. 20, pp. 289-300, 2021

[55] Hasan Tariq, Farid Touati, Mohammed A. E. Al-Hitmi, Damiano Crescini, Adel Ben Manouer, Design and Implementation of Programmable Multi-parametric 4-degrees of Freedom Seismic Waves Ground Motion Simulation IoT Platform. *15th International Wireless Communications & Mobile Computing Conference,* 2019.

[56] Luigi Maxmillian Caligiuri, Antonio Manzalini, Quantum Hypercomputing and Communications: Overview and Future Applications. *WSEAS Transactions on Computers*, vol. 20, pp. 247-257, 2021.

[57] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammed Abdulla E Al-Hitmi, Damiano Crescini, Adel Ben Mnaouer, An Autonomous Multi-variable Outdoor Air Quality Mapping Wireless Sensors IoT Node for Qatar. *IEEE International Wireless Communications & Mobile Computing Conference,* 2020.

[58] Merve Nur Cakir, Mehwish Saleemi, Karl-Heinz Zimmermann, Dynamic Programming in Topological Spaces. *WSEAS Transactions on Computers*, vol. 20, pp. 88-91, 2021

[59] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammed Abdulla E Al-Hitmi, Damiano Crescini, Adel Ben Manouer, Design and Implementation of Multi-Protocol Data Networks Interface Detector in Heterogeneous IoTs. *IEEE International Conference on Informatics, IoT, and Enabling Technologies,* 2020.

[60] Kellee Farris, Subhashini Ganapathy, Mary Fendley, Presenting Trends in Petrochemical Process Control Systems. *WSEAS Transactions on Computers*, 2224-2872, Volume 19, Art. #24, pp. 194-200, 2020.

[61] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammed Abdulla E Al-Hitmi, Damiano Crescini, Adel Ben Manouer, A Real-time Gradient Aware Multi-Variable Handheld Urban Scale Air Quality Mapping IoT System. *IEEE International Conference on Design & Test of Integrated Micro & Nano-Systems,* 2020.

[62] Aydin Teymourifar, Ana Maria Rodrigues, Jose Soeiro Ferreira, Geographically Separating Sectors in Multi-Objective Location-Routing Problems. *WSEAS Transactions on Computers*, Volume 19, 2020, Art. #13, pp. 98-102, 2020.

[63] Hasan Tariq, Farid Touati, Mohammed A. E. Al-Hitmi, Damiano Crescini, Adel Ben Manouer, Design and Implementation of Cadastral Geo-spatial IoT Network Gateway Analyzer for Urban Scale Infrastructure Health Monitoring. *10th Annual Computing and Communication Workshop and Conference,* 2020.

[64] Stanislav Bovchaliuk, Sergii Tymchuk, Sergii Shendryk, Vira Shendryk, The Fuzzy Control Automation Architecture of Parallel Action for the Intelligent Smart Grid Networks. *WSEAS Transactions on Computers*, Volume 19, 2020, Art. #3, pp. 21-25, 2020.

[65] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammad Abdullah Al Hitmi, Damiano Crescini, Adel Ben Mnaouer, Real-time Gradient-Aware Indigenous AQI Estimation IoT Platform. *Advances in Science, Technology and Engineering Systems Journal Vol. 5, No. 6, 1666-1673,* 2020.

[66] Muneer Bani Yassein, Omar Alzoubi, Saif Rawasheh, Farah Shatnawi, Ismail Hmeidi. Features, Challenges and Issues of Fog Computing: A Comprehensive Review. *WSEAS Transactions on Computers*, Volume 19, 2020, Art. #12, pp. 86-97, 2020.

[67] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammed Abdulla E Al-Hitmi, Damiano Crescini, Adel Ben Manouer, Design and Implementation of a Multi-Parametric Geo-Seismic Realization Engine for Programmable Mechatronic IoT Geo-Mechanics Simulators. *International Journal of Geology,* 2019.

[68] Roumen Trifonov, Slavcho Manolov, Georgi Tsochev, Galya Pavlova, Automation of Cyber Security Incident Handling through Artificial Intelligence Methods. *WSEAS*

Transactions on Computers, Volume 18, 2019, Art. #35, pp. 274-280, 2020.

[69] Hasan Tariq, Abderrazak Abdaoui, Farid Touati, Mohammed Abdulla E Al-Hitmi, Damiano Crescini, Adel Ben Manouer, IoT/Edge Structural Health Monitoring System as a Life-Cycle Management tool for SDG-11 using Utility Computing Platform. *WSEAS TRANSACTIONS on COMPUTERS, 2019*.

[70] C. A. Pickering, "Human vehicle interaction based on electric field sensing," in Advanced Microsystems for Automotive Applications 2008, ed: Springer, 2008, pp. 141-154.

[71] T. G. Zimmerman, "Personal area networks: near-field intrabody communication," IBM systems Journal, vol. 35, pp. 609-617, 1996.

[72] H. M. Elfekey and H. A. Bastawrous, "Design and implementation of a new thin cost effective ac hum based touch sensing keyboard," in 2013 IEEE International Conference on Consumer Electronics (ICCE), 2013, pp. 602-605.

[73] N.-W. Gong, J. Steimle, S. Olberding, S. Hodges, N. E. Gillian, Y. Kawahara, et al., "PrintSense: a versatile sensing technique to support multimodal flexible surface interaction," in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2014, pp. 1407-1410.

[74] Y. Wang, C. Yu, L. Du, J. Huang, and Y. Shi, "BodyRC: Exploring interaction modalities using human body as lossy signal transmission medium," in 2014 IEEE 11th Intl Conf on Ubiquitous Intelligence and Computing and 2014 IEEE 11th Intl Conf on Autonomic and Trusted Computing and 2014 IEEE 14th Intl Conf on Scalable Computing and Communications and Its Associated Workshops, 2014, pp. 260-267.

[75] J. Cheng and P. Lukowicz, "Towards wearable capacitive sensing of physiological parameters," in 2008 Second International Conference on Pervasive Computing Technologies for Healthcare, 2008, pp. 272-273.

[76] Y. Kim, S. Lee, I. Hwang, H. Ro, Y. Lee, M. Moon, et al., "High5: promoting interpersonal hand-to-hand touch for vibrant workplace with electrodermal sensor watches," in Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, 2014, pp. 15-19.

[77] S. M. Lee, H. J. Byeon, B. H. Kim, J. Lee, J. Y. Jeong, J. H. Lee, et al., "Flexible and implantable capacitive microelectrode for bio-potential acquisition," BioChip Journal, vol. 11, pp. 153-163, 2017.

[78] K. H.-L. Chau and R. E. Sulouff Jr, "Technology for the high-volume manufacturing of integrated surface-micromachined accelerometer products," Microelectronics Journal, vol. 29, pp. 579-586, 1998.

[79] Infineon, "Sensor Solutions for Automotive, Industrial and Consumer Applications," sensors2015.

[80] J. Smith, S. Montague, J. Sniegowski, J. Murray, and P. McWhorter, "Embedded micromechanical devices for the monolithic integration of MEMS with CMOS," in Proceedings of International Electron Devices Meeting, 1995, pp. 609-612.

[81] L. J. Hornbeck, "The DMD TM projection display chip: a MEMS-based technology," Mrs Bulletin, vol. 26, pp. 325-327, 2001.

[82] H. Baltes, O. Brand, G. K. Fedder, C. Hierold, J. G. Korvink, and O. Tabata, "CMOS-MEMS: Advanced Micro and Nanosystems (Advanced Micro and Nanosystems)," 2005.

[83] C. Hierold, "Intelligent CMOS sensors," in Proceedings IEEE Thirteenth Annual International Conference on Micro Electro Mechanical Systems (Cat. No. 00CH36308), 2000, pp. 1-6.

[84] J. P. Sáenz, "An Introduction to micro electro mechanical systems (MEMS)," Buran, pp. 13-18, 2005.

[85] W.-C. Tian, J. Weigold, and S. Pang, "Comparison of Cl 2 and F-based dry etching for high aspect ratio Si microstructures etched with an inductively coupled plasma source," Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena, vol. 18, pp. 1890-1896, 2000.

[86] D. Vincenzi, M. A. Butturi, V. Guidi, M. C. Carotta, G. Martinelli, V. Guarnieri, et al., "Development of a low-power thick-film gas sensor deposited by screen-printing technique onto a micromachined hotplate," Sensors and Actuators B: Chemical, vol. 77, pp. 95-99, 2001.

[87] N.-T. Nguyen, "5 Fabrication Issues of Biomedical Micro Devices," in BioMEMS

and Biomedical Nanotechnology, ed: Springer, 2006, pp. 93-115.

[88] A. Romani, N. Manaresi, L. Marzocchi, G. Medoro, A. Leonardi, L. Altomare, et al., "Capacitive sensor array for localization of bioparticles in CMOS lab-on-a-chip," in 2004 IEEE International Solid-State Circuits Conference (IEEE Cat. No. 04CH37519), 2004, pp. 224-225.

[89] C. Stagni, C. Guiducci, L. Benini, B. Riccò, S. Carrara, B. Samorí, et al., "CMOS DNA sensor array with integrated A/D conversion based on label-free capacitance measurement," IEEE Journal of Solid-State Circuits, vol. 41, pp. 2956-2964, 2006.

[90] P. M. Levine, P. Gong, R. Levicky, and K. L. Shepard, "Active CMOS sensor array for electrochemical biomolecular detection," IEEE Journal of Solid-State Circuits, vol. 43, pp. 1859-1871, 2008.

[91] M. Barbaro, A. Bonfiglio, L. Raffo, A. Alessandrini, P. Facci, and I. Barák, "Fully electronic DNA hybridization detection by a standard CMOS biochip," Sensors and Actuators B: Chemical, vol. 118, pp. 41-46, 2006.

[92] L. Xu, H. Yu, M. S. Akhras, S.-J. Han, S. Osterfeld, R. L. White, et al., "Giant magnetoresistive biochip for DNA detection and HPV genotyping," Biosensors and Bioelectronics, vol. 24, pp. 99-103, 2008.

[93] S. Zhang, J. Ding, Y. Liu, J. Kong, and O. Hofstetter, "Development of a highly enantioselective capacitive immunosensor for the detection of α-amino acids," Analytical chemistry, vol. 78, pp. 7592-7596, 2006.

[94] A. F. Flannery, N. J. Mourlas, C. W. Storment, S. Tsai, S. H. Tan, J. Heck, et al., "PECVD silicon carbide as a chemically resistant material for micromachined transducers," Sensors and Actuators A: Physical, vol. 70, pp. 48-55, 1998.

[95] H. Tsuchiya, T. Shirai, H. Nishida, H. Murakami, T. Kabata, N. Yamamoto, et al., "Innovative antimicrobial coating of titanium implants with iodine," Journal of Orthopaedic Science, vol. 17, pp. 595-604, 2012.

[96] J. Hardes, C. Von Eiff, A. Streitbuerger, M. Balke, T. Budny, M. P. Henrichs, et al., "Reduction of periprosthetic infection with silver-coated megaprostheses in patients with bone sarcoma," Journal of surgical oncology, vol. 101, pp. 389-395, 2010.

[97] M. Zanocco, F. Boschetto, W. Zhu, E. Marin, B. J. McEntire, B. S. Bal, et al., "3D-additive deposition of an antibacterial and osteogenic silicon nitride coating on orthopaedic titanium substrate," Journal of the Mechanical Behavior of Biomedical Materials, vol. 103, p. 103557, 2020.

[98] N. A. Reger, W. S. Meng, and E. S. Gawalt, "Antimicrobial activity of nitric oxide-releasing Ti-6Al-4V metal oxide," Journal of functional biomaterials, vol. 8, p. 20, 2017.

[99] R. S. Lima, M. H. Piazzetta, A. L. Gobbi, U. P. Rodrigues-Filho, P. A. Nascente, W. K. Coltro, et al., "Contactless conductivity biosensor in microchip containing folic acid as bioreceptor," Lab on a Chip, vol. 12, pp. 1963-1966, 2012.

[100] G. Fercher, A. Haller, W. Smetana, and M. J. Vellekoop, "End-to-end differential contactless conductivity sensor for microchip capillary electrophoresis," Analytical chemistry, vol. 82, pp. 3270-3275, 2010.

[101] C. L. Manzanares Palenzuela, F. Novotný, P. Krupička, Z. k. Sofer, and M. Pumera, "3D-printed graphene/polylactic acid electrodes promise high sensitivity in electroanalysis," Analytical chemistry, vol. 90, pp. 5753-5757, 2018.

[102] V. Katseli, A. Economou, and C. Kokkinos, "Single-step fabrication of an integrated 3D-printed device for electrochemical sensing applications," Electrochemistry Communications, vol. 103, pp. 100-103, 2019.

[103] J. G. A. Brito-Neto, J. A. Fracassi da Silva, L. Blanes, and C. L. do Lago, "Understanding capacitively coupled contactless conductivity detection in capillary and microchip electrophoresis. Part 1. Fundamentals," Electroanalysis: An International Journal Devoted to Fundamental and Practical Aspects of Electroanalysis, vol. 17, pp. 1198-1206, 2005.

[104] Z. Huang, J. Long, W. Xu, H. Ji, B. Wang, and H. Li, "Design of capacitively coupled contactless conductivity detection sensor," Flow Measurement and Instrumentation, vol. 27, pp. 67-70, 2012.

[105] J. Mika, F. Opekar, P. Coufal, and K. Štulík, "A thin-layer contactless conductivity cell for detection in flowing liquids," Analytica chimica acta, vol. 650, pp. 189-194, 2009.

[106] J. J. P. Mark, P. Coufal, F. Opekar, and F.-M. Matysik, "Comparison of the performance characteristics of two tubular contactless conductivity detectors with different dimensions and application in conjunction with HPLC," Analytical and bioanalytical chemistry, vol. 401, p. 1669, 2011.

[107] B. Fowler, M. D. Godfrey, and S. Mims, "Reset noise reduction in capacitive sensors," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 53, pp. 1658-1669, 2006.

[108] P. Kubáň and P. C. Hauser, "Contactless conductivity detection for analytical techniques: Developments from 2016 to 2018," Electrophoresis, vol. 40, pp. 124-139, 2019.

[109] M. Carminati, "Advances in high-resolution microscale impedance sensors," Journal of Sensors, vol. 2017, 2017.

[110] Z. Cheng, N. Choi, R. Wang, S. Lee, K. C. Moon, S.-Y. Yoon, et al., "Simultaneous detection of dual prostate specific antigens using surface-enhanced Raman scattering-based immunoassay for accurate diagnosis of prostate cancer," Acs Nano, vol. 11, pp. 4926-4933, 2017.

[111] Y. Wu, X. Liu, Q. Wu, J. Yi, and G. Zhang, "Carbon nanodots-based fluorescent turn-on sensor array for biothiols," Analytical Chemistry, vol. 89, pp. 7084-7089, 2017.

[112] C. D. Binnie, A. J. Rowan, and T. Gutter, A manual of electroencephalographic technology: CUP Archive, 1982.

[113] S. Emaminejad, M. Javanmard, R. W. Dutton, and R. W. Davis, "Microfluidic diagnostic tool for the developing world: Contactless impedance flow cytometry," Lab on a Chip, vol. 12, pp. 4499-4507, 2012.

[114] L. Losonczi, L. F. Márton, T. S. Brassai, and L. Farkas, "Embedded EEG signal acquisition systems," Procedia Technology, vol. 12, pp. 141-147, 2014.

[115] H. J. Scheer, T. Sander, and L. Trahms, "The influence of amplifier, interface and biological noise on signal quality in high-resolution EEG recordings," Physiological measurement, vol. 27, p. 109, 2005.

[116] M. Teplan, "Fundamentals of EEG measurement," Measurement science review, vol. 2, pp. 1-11, 2002.

[117] R. F. Yazicioglu, C. Van Hoof, and R. Puers, Biopotential readout circuits for portable acquisition systems: Springer Science & Business Media, 2008.

[118] S. J. Luck and E. S. Kappenman, The Oxford handbook of event-related potential components: Oxford university press, 2011.

[119] J. D. Bronzino, Biomedical Engineering Handbook 2 vol. 2: Springer Science & Business Media, 2000.

[120] M. Unser, "Sampling-50 years after Shannon," Proceedings of the IEEE, vol. 88, pp. 569-587, 2000.

[121] I. Ulbert, E. Halgren, G. Heit, and G. Karmos, "Multiple microelectrode-recording system for human intracortical applications," Journal of neuroscience methods, vol. 106, pp. 69-79, 2001.

[122] H. W. Ott and H. W. Ott, Noise reduction techniques in electronic systems vol. 442: Wiley New York, 1988.

[123] T. K. Bera, S. Choudhary, T. Maiti, and S. P. Barnwal, "A Low-Cost Electroencephalography (EEG) Instrumentation for Epileptic Seizure Detection," in Journal of Physics: Conference Series, 2020, p. 012038.

[124] S. W. Smith, "The scientist and engineer's guide to digital signal processing," 1997.

[125] K. Blinowska and P. Durka, "Electroencephalography (eeg)," Wiley encyclopedia of biomedical engineering, 2006.

[126] A. B. Usakli and N. G. Gencer, "Performance tests of a novel electroencephalographic data-acquisition system," in Proceedings of the 5th IASTED International Conference on Biomedical Engineering (BioMED'07), 2007, pp. 253-257.

[127] R. B. Northrop, Introduction to instrumentation and measurements: CRC press, 2005.

[128] E. S. Bucher and R. M. Wightman, "Electrochemical analysis of neurotransmitters," Annual review of analytical chemistry, vol. 8, pp. 239-261, 2015.

[129] C. Park, P. H. Chou, Y. Bai, R. Matthews, and A. Hibbs, "An ultra-wearable, wireless, low power ECG monitoring system," in 2006 IEEE biomedical circuits and systems conference, 2006, pp. 241-244.

[130] S. Majumder, L. Chen, O. Marinov, C.-H. Chen, T. Mondal, and M. J. Deen,

"Noncontact wearable wireless ECG systems for long-term monitoring," IEEE reviews in biomedical engineering, vol. 11, pp. 306-321, 2018.

[131] A. A. Alhammadi and S. A. Mahmoud, "Fully differential fifth-order dual-notch powerline interference filter oriented to EEG detection system with low pass feature," Microelectronics Journal, vol. 56, pp. 122-133, 2016.

[132] T. J. Sullivan, S. R. Deiss, and G. Cauwenberghs, "A low-noise, non-contact EEG/ECG sensor," in 2007 IEEE Biomedical Circuits and Systems Conference, 2007, pp. 154-157.

[133] J. T. Li, S. H. Pun, M. I. Vai, P. U. Mak, P. I. Mak, and F. Wan, "Design of current mode instrumentation amplifier for portable biosignal acquisition system," in 2009 IEEE Biomedical Circuits and Systems Conference, 2009, pp. 9-12.

[134] S. A. Mahmoud, A. Bamakhramah, and S. A. Al-Tunaiji, "Six order cascaded power line notch filter for ECG detection systems with noise shaping," Circuits, Systems, and Signal Processing, vol. 33, pp. 2385-2400, 2014.

[135] W.-C. Heerens, "Application of capacitance techniques in sensor design," Journal of physics E: Scientific instruments, vol. 19, p. 897, 1986.

[136] J. R. Evans and A. Abarbanel, Introduction to quantitative EEG and neurofeedback: Elsevier, 1999.

[137] G. Gargiulo, P. Bifulco, R. A. Calvo, M. Cesarelli, C. Jin, and A. Van Schaik, "A mobile EEG system with dry electrodes," in 2008 IEEE Biomedical Circuits and Systems Conference, 2008, pp. 273-276.

[138] Y. M. Chi, Y.-T. Wang, Y. Wang, C. Maier, T.-P. Jung, and G. Cauwenberghs, "Dry and noncontact EEG sensors for mobile brain–computer interfaces," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 20, pp. 228-235, 2011.

[139] T. Denison, K. Consoer, A. Kelly, A. Hachenburg, and W. Santa, "A 2.2/spl mu/W 94nV//spl radic/Hz, Chopper-Stabilized Instrumentation Amplifier for EEG Detection in Chronic Implants," in 2007 IEEE International Solid-State Circuits Conference. Digest of Technical Papers, 2007, pp. 162-594.

[140] J. Xu, B. Büsze, C. Van Hoof, K. A. Makinwa, and R. F. Yazicioglu, "A 15-channel digital active electrode system for multi-parameter biopotential measurement," IEEE Journal of Solid-State Circuits, vol. 50, pp. 2090-2100, 2015.

[141] R. F. Yazicioglu, P. Merken, R. Puers, and C. Van Hoof, "A 200$\mu $ W Eight-Channel EEG Acquisition ASIC for Ambulatory EEG Systems," IEEE Journal of Solid-State Circuits, vol. 43, pp. 3025-3038, 2008.

[142] Y. M. Chi and G. Cauwenberghs, "Wireless non-contact EEG/ECG electrodes for body sensor networks," in 2010 International Conference on Body Sensor Networks, 2010, pp. 297-301.

[143] A. Aleksandrowicz and S. Leonhardt, "Wireless and non-contact ECG measurement system–the “Aachen SmartChair”," Acta Polytechnica, vol. 47, 2007.

[144] M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. P. Zaveri, "Neuro-detect: a machine learning-based fast and accurate seizure detection system in the IoMT," IEEE Transactions on Consumer Electronics, vol. 65, pp. 359-368, 2019.

[145] S.-A. Huang, K.-C. Chang, H.-H. Liou, and C.-H. Yang, "A 1.9-mW SVM Processor With On-Chip Active Learning for Epileptic Seizure Control," IEEE Journal of Solid-State Circuits, vol. 55, pp. 452-464, 2019.

[146] J. Yoo, L. Yan, D. El-Damak, M. A. B. Altaf, A. H. Shoeb, and A. P. Chandrakasan, "An 8-channel scalable EEG acquisition SoC with patient-specific seizure classification and recording processor," IEEE journal of solid-state circuits, vol. 48, pp. 214-228, 2012.

[147] A. Breitenbach, "A method for determining the signal-to-noise ratio of sensors by spectral analysis," in IEEE Instrumentation and Measurement Technology Conference Sensing, Processing, Networking. IMTC Proceedings, 1997, pp. 457-462.

[148] J. Fraden, Handbook of modern sensors: physics, designs, and applications: Springer Science & Business Media, 2004.

[149] A. B. Usakli, "Improvement of EEG signal acquisition: An electrical aspect for state of the art of front end," Computational intelligence and neuroscience, vol. 2010, 2010.

[150] T.-Y. Wei, D.-W. Chang, Y.-D. Liu, C.-W. Liu, C.-P. Young, S.-F. Liang, et al., "Portable

wireless neurofeedback system of EEG alpha rhythm enhances memory," Biomedical engineering online, vol. 16, pp. 1-18, 2017.

[151] M. Tohidi, J. K. Madsen, and F. Moradi, "Low-power high-input-impedance EEG signal acquisition SoC with fully integrated IA and signal-specific ADC for wearable applications," Ieee Transactions on Biomedical Circuits and Systems, vol. 13, pp. 1437-1450, 2019.

[152] H. Wang and P. P. Mercier, "A current-mode capacitively-coupled chopper instrumentation amplifier for biopotential recording with resistive or capacitive electrodes," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 65, pp. 699-703, 2017.

[153] J. Zheng, W.-H. Ki, and C.-Y. Tsui, "A fully integrated analog front end for biopotential signal sensing," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 65, pp. 3800-3809, 2018.

[154] R. R. Sharma, P. Varshney, R. B. Pachori, and S. K. Vishvakarma, "Automated system for epileptic EEG detection using iterative filtering," IEEE Sensors Letters, vol. 2, pp. 1-4, 2018.

[155] M. A. Yokus and J. S. Jur, "Fabric-based wearable dry electrodes for body surface biopotential recording," IEEE Transactions on Biomedical Engineering, vol. 63, pp. 423-430, 2015.

[156] R. Yazicioglu, P. Merken, R. Puers, and C. Hoof, "A 200 W eight-channel acquisition ASIC for ambulatory EEG systems," in IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers, 2007, pp. 164-165.

[157] S. O'Driscoll, K. V. Shenoy, and T. H. Meng, "Adaptive resolution ADC array for an implantable neural sensor," IEEE Transactions on Biomedical Circuits and Systems, vol. 5, pp. 120-130, 2011.

[158] P. Crippa, C. Turchetti, and M. Conti, "A statistical methodology for the design of high-performance CMOS current-steering digital-to-analog converters," IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 21, pp. 377-394, 2002.

[159] R. B. Northrop, Analysis and application of analog electronic circuits to biomedical instrumentation: CRC press, 2012.

[160] M. Trakimas, R. D'Angelo, S. Aeron, T. Hancock, and S. Sonkusale, "A compressed sensing analog-to-information converter with edge-triggered SAR ADC core," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 60, pp. 1135-1148, 2013.

[161] U. Ha, J. Lee, M. Kim, T. Roh, S. Choi, and H.-J. Yoo, "An EEG-NIRS multimodal SoC for accurate anesthesia depth monitoring," IEEE Journal of Solid-State Circuits, vol. 53, pp. 1830-1843, 2018.

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Author Contributions: Please, indicate the role and the contribution of each author:
Example
Hasan Tariq performed the conceptual study, research methods, and case study (sections 1-3).
Shafaq Sultan has organized the manuscript and formatting and done the write-up (sections 4-5).

Sources of funding for research presented in a scientific article or scientific article itself

Self-Funded.

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