Sensing
in Electroanalysis

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Electrochemical Sensing in Telemedicine (A Review)

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Abstract: Telemedicine aims to use telecommunication systems (transmitting data, documents and other information) for more rapid interventions, diagnostic and treatment decisions and medical recommendations. Electrochemical sensors could be useful to improve the practice of medicine over the distance, helping the general practitioners and the emergency doctors to apply good and rapid procedures, to monitor chronic situation for several patients (by quantification of biomarkers and specific compounds related to their medical condition).

Key words: Electrochemical sensors; Telemedicine; Review

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Introduction

Research studies in biomedical systems determine a big progress of the possibility to develop new sensors and biosensors, and to create models and to simulate the acquiring biological information at multiple scales with state-of-the-art methodologies.

The higher costs of performing of some medical tests at the point of care are recommended to the patient with clinical condition who strictly requires immediate results in order to guarantee more efficient and safer treatments. Some of these patients use successfully implantable lab-on-a-chip devices for *in vivo* continuous monitoring of specific compounds.

The development of modern information telecommunication (ITC) technology and its use in telemedicine plays an increasingly important role in facilitating access to some diagnostic services, including population living in the most remote areas, such as small cities, rural area, or less developed regions.

A telecare system consists of equipment (basically sensors and monitors) that transfers data to a communication controller, which then forwards the data to a monitoring unit where they are stored in a database for subsequent access by the user [1].

In the last 20 years, telemedicine has developed in parallel with new technology (sensors/biosensors and devices/tools/ICT systems) [2,3]. Telemonitoring is emerging as a highly promising way of managing the large numbers of patients with chronic illness [4,5]. The most sophisticated telemedicine systems offer real-time visualization of patients at home and of their physiological data [6,7].

Electroanalytical Systems

Electrochemical sensor technology, including amperometric or potentiometric biosensors, chemically modified electrodes, stripping-based metal sensors, and other tools for on-site field testing allow to measure numerous inorganic and organic compounds from the central laboratory to the specific field (environment, food industry, medicine, toxicology), and to perform them rapidly, inexpensively, and reliably [8]

Electroanalysis as a wet-chemical method has many attractive advantages, among others:

- selectivity and sensitivity (insensitive to local light conditions or contaminants),
- portable, reliable, and using inexpensive equipment
- direct accessibility — interfaced with a cell phone or internet — permitting automatic control even at distance;
- automatic data treatment.

Mutual relations of the individual benefits of electrochemical sensing are given in a scheme overleaf (see Fig.1).

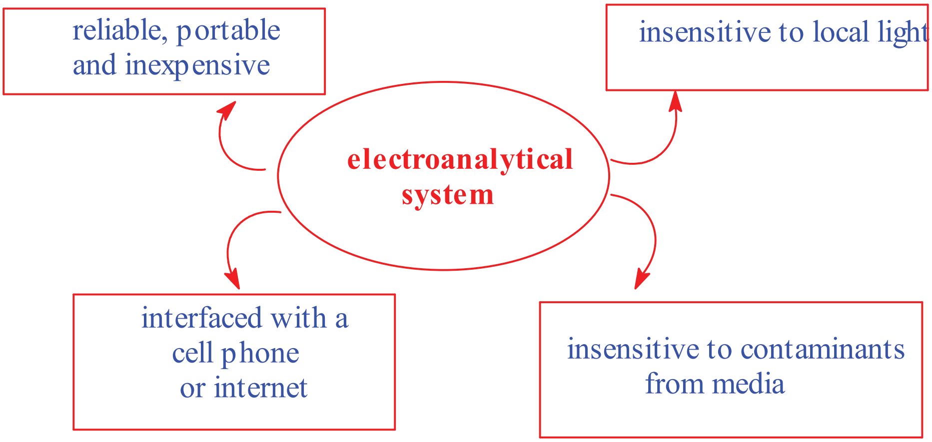

Fig. 1. *Advantages of electrochemical analysis*

Telemedicine integrates network and medical technology, generally comprising remote diagnosis, expert consultation, information service, online check-ups, remote communication, etc. The most recent developments in the field of electronics (technology), informatics and telecommunications let imagine applications in the telemedicine and home care sector which could mark a turning in the quality of the services for sanitary assistance prevention and care.

Based on cell phones, computers and network communication, as well as data delivery, it implements remote transfer, storage, query, comparison, display, and sharing of video and audio information or even medical data of a patient.

Electrochemical Sensors

Electrochemical sensors require very little power to operate. In fact, their power consumption is the lowest among all sensor types available for gas monitoring. For this reason, the sensors are widely used in portable instruments that contain multiple sensors. They are the most popular sensors in confined space applications [9].

Rapid progress in electronics and related areas has stimulated the development of contemporary technologies for fabricating the electronic sensor applicable to many diverse areas of human activity – see Fig. 2.

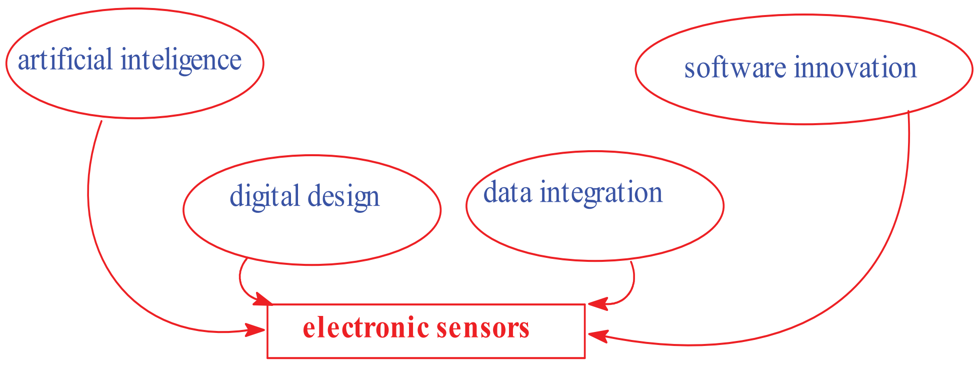

Fig. 2. *Electronics related properties of electronic sensors*

During the time, there were developed and optimized several applications of electrochemical sensors for possible use in telemedicine, which is summarized in Table I (see overleaf).

An abundance of electronic-nose applications has been developed for a variety of healthcare sectors (see Fig. 3).

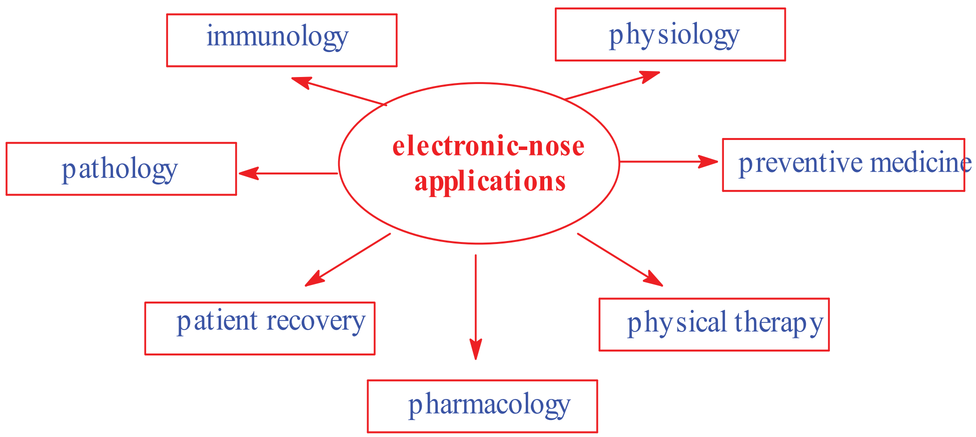

Fig. 3. *Application of electronic-nose systems in medicine*

Table I. *Application of electrochemical sensors*

No.	Electrochemical sensors	Applications	Observation	Ref.
1	Hybrid biosensor, combining principles of electrochemistry, flow injection analysis, and calorimetry	Oxidases, dehydrogenase		10
2	Carbon-based electro-chemical sensors, incl. carbon nanotubes (CNT), Diamond-Like Carbon (DLC) films, and diamond film-based sensors.	from amperometric enzyme electrodes to DNA hybridization biosensors.	development of e-nose technologies and explain why the properties of CNT sensors	11
	carbon-based sensor	specific detection of human liver diseases, such as chronic hepatitis, cirrhosis, and hepatocellular carcinoma caused by hepatitis B virus (HBV)	fast diagnosis method, using non-treated blood assay and amorphous DLC electrodes	12, 13
3	Gas sensor array with six MOS sensors and one electrochemical gas sensor	seven species of pathogens common in wound infections *in vitro*.	All seven pathogens were correctly identified and discriminated with an accuracy of 100% with this e-nose system	14
4	Devices μPEDs (microfluidic paper-based electrochemical devices)	quantify the concentrations of various analytes in aqueous solutions, including biological fluids such as urine, serum and blood - quantification of glucose in artificial urine using a chronoamperometric analysis based on glucose oxidase	μPEDs comprise micro-fluidic channels, fabricated from patterned paper (either chromatography paper or a polyester–cellulose blend), and electrodes that were screen-printed on chroma-tography paper or PE film - The detection of glucose using the device showed high sensitivity and accuracy over the full range of clinically relevant concentrations of glucose in urine (about 0.22 mM)	15
5	μPEDs	electrochemical detection of glucose, lactate, and uric acid in biological samples		16

Table I. (continued)

No.	Electrochemical sensors	Applications	Observation	Ref.
6	Novel capacitive and electrochemical sensor designs using PDMS thin films	clinical cardiovascular applications in infants and children	develop implantable, batteryless, telemetric integrated pressure and oxygen sensors	17
7	Combination of a commercial hand-held glucometer with easily fabricated Micro-Paper-based Analytical Devices (mPADs)	quantitative analysis of metabolites such as glucose, cholesterol, and lactate in human plasma or whole blood, and ethanol (or acetaldehyde) in aqueous solution	- electrochemical devices (Electrochemical mPADs or EmPADs) provide fluid handling and support sensing electrodes; - an inexpensive, commercial electrochemical reader (a glucometer) carries out electrochemical analyses and displays the results in digital format. - It can also in principle be adapted to a range of different types of assays (amperometry, chronoamperometry, cyclic voltammetry, anodic stripping voltammetry, electrochemiluminescence and others).	18
8	Electrochemical immunosensors (EIS)	multiplex measurement of cancer biomarkers (including AFP, ferritin, CEA, hCG-β, CA15-3, CA125 and CA19-9), for the quantification of levels of the colorectal cancer biomarker carcino-embryonic antigen in solution, and for the quantification of the prostate cancer biomarker AMCAR from patient urine samples.	Used amperometric devices utilizing chemical reactions to generate a current on the sensing electrode, sandwich EIS devices that use magnetic gold nanoparticles to enhance enzyme labeling, and macrocantilever devices that produce measurably sharp changes in electrical impedance	19, 20, 21

Specific biomedical e-nose applications [14,22-23] range from uses in biochemical testing, blood-compatibility evaluations, disease diagnoses, and drug delivery to monitoring of metabolic levels, organ dysfunctions, and patient conditions through telemedicine.

Conclusions

Telemedicine can improve the lives of European citizens, both patients (mobile units, hospital care, pre-hospital emergency care) and healthy people (home care), and also integrate in another high level the activities of health professionals (primary care), while tackling the challenges to healthcare systems (integrated electronic health record, telematics services) [24]. Designers, developers, and researchers might improve the utility and uptake of health-related technologies for older adults and their families by eliciting the viewpoints of clinical providers [25].

It can be stated that an optimal combination of electrochemical sensors with ICT tools contributes to the improvement of the properties of telemedicine, increasing the level of health maintenance and reducing costs.

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