Exhaustive Study on Medical Sensors

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***Abstract*—The advances in electronics allowed the development of smart miniature devices called medical sensors, that can collect physiological data from the human body and its surrounding and send it wirelessly to healthcare providers in order to help avoiding life threatening events. This article presents a general overview on the types of medical sensors, their properties, and the wireless technologies used to convey collected data. Also, this article is the first to provide a summary about the wearable sensors' brands available on the market, along with their interface and connection types [1, 2].**

***Keywords*—wearable sensors; body sensors; medical sensors.**

I. Introduction

The Wireless Sensor Networks (WSNs) are formed of small computing devices called sensor nodes that can be implanted in or placed around the human body. These intelligent sensors collect physiological data from the body and send them wirelessly to medical personnel through personal devices like PDA or smartphone, allowing continuous health monitoring of the current state of the person to make proper decisions [3, 4].

There are two applications for sensor nodes: medical and non-medical [5]. In medical applications, sensors collect physical attributes from human body like blood pressure, respiration, and temperature to detect any anomaly as early as possible and take appropriate action before it is too late. These sensors can be implanted in the human body (i.e. implanted sensors), either under the skin or in the blood stream, to detect abnormalities like cancer and cardiovascular diseases, or they can be placed on the human body (i.e. wearable sensors) to be used for disability assistance like fall detection and blinds' assistance in obstacles avoidance, and for performance assessment like soldiers' status evaluation in a battle and athletes' condition assessment during sports training, besides of anomaly detection like asthma and heart beat problems. As for non-medical applications, examples include emotion detection applications, secure authentication, entertainment applications, and non-medical emergencies through gathering data from the environment and warning people in case of disaster or danger like fire or possibility of flood.

There are numerous sensors used in medical applications. Table I summarizes the most used sensors along with their position [6]. Depending on their type, sensors are either placed on the human body (wearable), or in the surrounding, or implanted inside the human body. These sensors include the accelerometer that is used to perceive the expenditure of human energy, the artificial cochlea utilized for hearing aid, the artificial retina used for visual aid, the camera pill deployed to monitor the gastrointestinal track, the carbon dioxide sensor used to measure the content of carbon dioxide from various gas, the ECG utilized to detect heart diseases, the EEG used to detect brain anomalies, and the EMG deployed to perceive muscles and nerve cells problems. This is in addition to many other sensors measuring blood pressure, humidity, blood oxygen, pressure, respiration, and temperature.

These sensors face many challenges like self-calibration requirements to adjust the sensitivity of the sensors based on the environment where they are placed, low- maintenance requirements, compatibility and interference problems induced by integrating multiple sensors operating at different frequencies and need to communicate between each other, and limited energy resources [**16**].

The rest of the paper is organized as follows: The major properties of sensors are presented in Section II; sensor wireless communication technologies are listed in Section III, and a summary on the available sensors in the market is presented in Section IV, to conclude in Section V.

II. Major Properties of Sensors

Since sensor nodes are small wireless devices placed on, around and in the human body, and can capture various physiological parameters, they usually have the following properties [3]:

- The size of the sensor nodes is very small (not more than 1 cm^3), thus the battery size inside sensors is miniature and the energy available is often restricted. Also, sensors are requested to serve for a long period of time, and it is very hard to replace sensors' batteries specially when they are implanted inside the human body. Therefore finding ways to reduce energy consumption and to harvest additional energy is always needed in medical sensors.

- Sensor nodes are usually heterogeneous and require different data rates, bandwidth, and energy resources form the network depending on the type of data they are collecting. Table II illustrates sensors' heterogeneity based on the different data rate requirements [5, 6]. The table shows that the data rate can vary considerably from few Kbps to several Mbps.

- There are no redundant nodes. All nodes have the same level of importance and are added depending on their need in the application.

- Nodes have very limited transmit power in order to avoid interference and to address health concerns.

- Nodes should support self-organization and self-maintenance characteristics since they are usually operated by medical staff and not engineers. Once a node is added to the human body and turned on, it should be able to join the network and set up connections without any involvement.

III. Sensors' Wireless Communication Technologies

In general, there are three types of networks formed by the sensors wireless communication [7, 8]:

- In-body network communication: used for communication between wearable sensors, or between implanted sensors in the body and the receiver located outside the body.
- On-body network communication: used for communication between wearable sensors and the coordinator or sink device used to gather data and transfer sensing data to a local processing.
- External Network communication: Used for communication between the coordinator and a remote back-end server.

Table III presents the different technologies and standards used for both short range and long range communication between sensors, coordinator device and external back-end server. It shows that the radio standards used to implement in-body and on-body network communications are short-range communication standards including Industrial Scientific and Medical (ISM) band, Medical Implant Communication Service (MICS) band, Wireless Medical Telemetry Service (WMTS), Radio-Frequency Identification (RFID), Bluetooth, Zigbee, and WLAN (Wi- Fi) technologies; whereas the radio standards used to implement external network communication are medium and long-range communication standards including Cellular Networks, WiFi, GPRS, Zifbee, Wibro, and Satellite technologies.

IV. Available Sensors in the market

There are many companies specialized in wearable medical sensors designed to collect data from the human body and the surrounding environment. Table IV presents the sensors provided by some of the well-known companies in the sensor business, along with the corresponding connection type [9–17].

Table IV shows that the parameters captured by these sensors include body temperature, ECG and activity sensor, EMG, respiration, heart rate estimate, weight, force, SpO2, humidity, body position, fall alert, invasive blood pressure, barometric air pressure, and ambient light acquisition. It also shows that most sensors send the collected data via Bluetooth Low Energy (BLE). Some sensors have micro-USB interface, and many sensors are equipped with microSD card for local storage of data. In addition, many sensors are provided with external connector to connect to an external dock used to program and charge the sensor and to access the microSD card, whereas few others have digital serial interfaces.

V. Conclusion

In this article, the different types of medical sensors were presented, along with their properties and the wireless communication technologies used to send collected data. Also, the wearable medical sensors available on the market were listed along with their communication interface. The main aim of this article is to provide a clear understanding on the medical sensors, and to make it easier for the end user to select the appropriate sensor brand available on the market based on the type of data collected by the sensor and its interface and connection type.

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TABLE IV: SENSOR TYPES AND CONNECTION INTERFACE

Company	Sensor Name	Description	Interface
Movisens (Germany) [9] https://www.movisens.com	Move III Activity Sensor	Sensor for the acquisition of 3D acceleration, barometric air pressure and temperature	Micro-USB - Bluetooth Low Energy (BLE)
	LightMove 3 (Light and Activity Sensor)	Sensor for the acquisition of ambient light, 3D acceleration, barometric air pressure and temperature	Micro-USB - BLE
	EcgMove 3 (ECG and Activity Sensor)	Sensor for the acquisition of ECG, 3D acceleration, barometric air pressure and temperature	Micro-USB - BLE
	EdaMove 3 (EDA and Activity Sensor)	Sensor for the acquisition of EDA, 3D acceleration, barometric air pressure and temperature	Micro-USB - BLE
Shimmer (Ireland) [10] www.shimmersensing.com/	Shimmer3 IMU	9 DoF inertial sensing via accelerometer, gyroscope, and magnetometer, each with selectable range	Bluetooth or local storage via microSD card - Includes external connector to connect to Shimmer Dock (refer to Accessories)
	Shimmer3 ECG	Sensor for the acquisition of ECG, 3D acceleration, barometric air pressure and temperature	Micro-USB - BLE
	Shimmer3 EMG	EMG, ECG, Respiration, 9 Degree of Freedom (DoF) inertial sensing	Bluetooth Radio RN-42 - Integrated 8GB micro SD card - Includes external connector to connect to Shimmer Dock (refer to Accessories)
	Shimmer3 GSR+	GSR, PPG, heart rate (HR) estimate , 9 DoF inertial sensing	Bluetooth RN42 - Integrated 8GB microSD card slot - Includes external connector to connect to Shimmer Dock (refer to Accessories)
	Shimmer3 Bridge Amplifier	Load, Weight, Force, Torque, Pressure, 9 DoF inertial sensing	Class 2 Bluetooth Radio Roving Networks RN42 - microSD card supporting up to 32GB - Includes external connector to connect to Shimmer Dock (refer to Accessories)
	PROTO3 Deluxe Unit	Expansion boards for the Shimmer3 platform. Provides an interface between Shimmer3 and analogue output sensor, digital output sensor, serial UART or parallel bus interface. Allows application developers to add functionality to the Shimmer and to develop customized applications based on user requirement	Two 3.5mm 4-position jacks (TRRS Cables. Or through-hole connections
Accessories	Shimmer Dock	The Shimmer Dock is a multi-purpose device which can provide three primary functions: charging the Shimmer, MicroSD card access, and programming the Shimmer	The Dock includes mini USB port and connects to a PC via a USB cable

Company	Sensor Name	Description	Interface
TE Connectivity Ltd. (USA) [11] www.te.com	TE Medical Sensors	Air Bubble, Force, Humidity, Liquid Level, Piezo Film, Position, Pressure, Pulse Oximetry, Temperature Vibration. Assemblies designed to withstand the harsh environments of diagnostic equipment including ECG, EEG, TENS, temperature, SpO2 and invasive blood pressure	I2C interface - Mini USB- MicroSD card storage
MC10 (USA) [12] https://www.mc10inc.com/	BioStampRC	Access to raw kinematic and electrophysiological data 6 degrees of freedom inertial sensing with 3-axis accelerometer and gyroscope Electric biopotential	BLE
	WiSP™	Cardiac monitoring and ECG recording	BLE
Withings (USA) [13] https://www.withings.com/	Pulse Ox	Advanced tracking, every step of the way. During the day it captures steps, distance walked, elevation climbed and calories burned. At night, it monitors sleep cycles. And when asked, it measures the heart rate and blood oxygen level	BLE
	Steel HR	Continuous HR monitoring when running and in workout mode. 10+ activities tracked via automatic and learned recognition. Automatic analysis of sleep cycles, wake-ups, and sleep duration, plus silent smart alarm	BLE
	Wireless Blood Pressure Monitor	Blood Pressure and heart rate monitoring	BLE
Equivital (UK) [14] www.equivital.co.uk/	EQ02 LifeMonitor Sensor Electronics Module (SEM)	The LifeMonitor can simultaneously provide the following data : ECG, Heart rate, R-R interval, Respiratory rate, Skin temperature, Accelerometer XYZ, Body position, Motion status, Fall alert, Device alarms, Subject alerts	Class 1 Bluetooth 2.1 (100m operating range) - Connectivity: USB (2.0 compatible) - 8GB memory for up to 50 days of continuous data logging
	Equivital's Orann system for pharma	Continuous physiological - Respiratory endpoints - Ambulatory BP - Activity and sleep - Glucose monitoring	Bluetooth
Accessories and Ancillary Sensors	VitalSense Core Temp Capsule	Ingestible temperature capsule captures body temperature and transmits real time readings	Wired or wireless (Bluetooth)
	VitalSense® Dermal Patch	Patch for dermal temperature measurements. It measures skin temperature and sends data in real time to the SEM	Wired or wireless (Bluetooth)
	Nonin iPod® Sp02	Probe to measure oxygen saturation with finger clip and SEM connector	Wired or wireless (Bluetooth)
	EQ-GSR (Galvanic Skin Response Sensor)	Sensor mounted on wrist to measure galvanic skin response	Wired or wireless (Bluetooth)

Company	Sensor Name	Description	Interface
	EQ02 M-Dock	Allows simultaneous charging and 2-way data transfer communication with up to six SEM's. Five M-Docks can be chained to support 30 simultaneous connections through USB	Wired or wireless (Bluetooth)
	EQ02 SEM Lead	Allows simultaneous charging and 2-way data transfer with a single SEM	Wired
	Equivital^{TM} Bluetooth Dongle	Dongle with easy connection that enables fast communication of 2 SEMs in full disclosure and up to 6 SEMs in partial disclosure directly to a PC in real time. Up to 100m range	Bluetooth
	Equivital^{TM} Hub	The Equivital^{TM} Hub is a Bluetooth access point allowing to communicate in real time with up to 18 SEMs from a PC or LAN. Networkable via WiFi or Ethernet connection. Works with eqView professional software	Bluetooth
	Omron Blood Pressure 708BT(EU)	The Bluetooth blood pressure cuff measures subject blood pressure data, can be pre-paired with a single EQ02 SEM and can send data to store or be transmitted on from the SEM	Wired or wireless (Bluetooth)
	WristOx2 Bluetooth Oxygen Saturation (3150)	The Bluetooth, wrist worn oxygen saturation monitor measures saturation, can be pre-paired with a single EQ02 SEM and can send data to store or be transmitted on from the SEM	Wired or wireless (Bluetooth)
Somaxis (UK) [15] https://www.somaxis.com/	Cricket	EXG and IMU sensors that measure and train muscles (EMG), heart (EKG), brain (EEG), posture and movement	Bluetooth
Accessories	Chirp	iPad app controls and communicates with Cricket	Bluetooth
Vitalconnect (USA) [16] https://vitalconnect.com/	VitalPatch	Single-Lead ECG Heart Rate - Heart Rate Variability - Respiratory Rate - Skin Temperature Body - Fall Detection Activity	Bluetooth
STMicroelectronics (USA) [17] www.st.com	INEMO-M1	9 DoF inertial system: 3-axis accelerometer - 3-axis magnetometer - 3-axis gyroscope	Flexible interfaces: CAN, USART, SPI and I2C serial interfaces - full-speed USB 2.0 or BLE Module
	LPS331AP	High-resolution digital pressure sensor	SPI and I2C interfaces or BLE Module
	LIS3DH	Ultra-low-power accelerometer (motion sensor)	Digital I2C/SPI serial interface standard output or BLE Module
	HM301D	ECG acquisition system	SPI or BLE Module

TABLE I: DIFFERENT TYPES OF SENSORS

Sensors Type	Description	Position
Accelerometer	Collecting acceleration on the spatial axis of three-dimensional space.	Wearable
Artificial cochlea (hearing aid)	Transforming voice signal into electric pulse and sending them to electrodes implanted in ears, providing hearing sensation through simulating aural nerves.	Implanted
Artificial retina (visual aid)	Capturing pictures by external camera and converting them to electric pulse signals to be used to provide visual sensation through simulating optic nerves.	Implanted
Blood-pressure sensor	Finding the maximum systolic pressure and the minimum diastolic pressure.	Wearable
Gastrointestinal sensor (camera pill)	Identifying gastrointestinal tract via wireless capsule endoscope technique.	Implanted
Carbon dioxide sensor	Using infrared technique to measure the content of carbon dioxide from diverse gas	Wearable
ECG/EEG/EMG sensor	Placing two electrodes on the body skin and measuring the voltage difference between them.	Wearable
Humidity sensor	Using changes in capacitance and resistivity caused by humidity variations to measure humidity.	Wearable
Blood oxygen saturation sensor	Computing the ratio of absorption of infrared and red light passing through a thin part of human body to measure blood oxygen saturation.	Wearable
Pressure sensor	Using piezoelectric effect of dielectric medium to measure the value of pressure.	Wearable/ Surrounding
Respiration sensor	Perceiving the expansion and contraction of chest or abdomen to assess the respiration.	Wearable
Temperature sensor	Using the variations in the physical properties of materials to measure temperature.	Wearable
Visual sensor	Assessing different parameters like length, area, and location.	Wearable/ Surrounding

TABLE II: SENSORS DATA RATES REQUIREMENTS

Sensor Type	Data Rate
ECG (12 Leads)	288 Kbps
ECG (6 Leads)	71 Kbps
EMG	320 Kbps
EEG (12 Leads)	43.2 Kbps
Blood saturation	16 bps
Glucose level	1.6 Kbps
Temperature	120 bps
Motion	35 Kbps
Artificial retina	50-700 Kbps
Audio	1 Mbps
Voice	50-100 Kbps
Endoscope Capsule	2 Mbps

TABLE III: RADIO COMMUNICATION STANDARDS

Communication Type	**In-Body**	**On-Body**	**External Network**
Description	Between sensor nodes	Between sensor nodes and coordinator	Between coordinator and external server
Communication range	Short range	Short range	Medium to long range
Radio communication standard	Low- frequency inductive coupling, ISM, MICS	WMTS, RFID, Bluetooth, Zigbee, WLAN (Wi- Fi)	Cellular Networks (CDMA/ HSDPA/ GPRS/ EDGE/ (UMTS), WiFi, GPRS, Zifbee, Wibro, satellite
Data format	Raw signal	Raw signal	XML, CSV, JSON, etc.