UNIVERSITATEA POLITEHNICA
DIN BUCUREŞTI

Şcoala Doctorală de Electronică, Telecomunicații
şi Tehnologia Informației

Decizie nr. 805 din 21-02-2022

Doctoral Thesis Abstract

Eng. Raluca Maria AILENI

Contribuţii teoretice şi experimentale la monitorizarea parametrilor vitali folosind sisteme de control inteligent bazate pe senzori integraţi în structuri textile şi servicii cloud computing
Theoretical and experimental contributions to monitoring of vital parameters using intelligent control systems based on sensors integrated in textile structures and cloud computing services

---

Doctoral Committee

Prof. Dr. Ing. Bogdan IONESCU Univ. Politehnica din Bucureşti	President
Prof. Dr. Ing. Rodica STRUNGARU Univ. Politehnica din Bucureşti	PhD Supervisor
Prof. Dr. Ing. Adriana FLORESCU Univ. Politehnica din Bucureşti	PhD Supervisor
Conf. Dr. Ing. Alina SULTANA Univ. Politehnica din Bucureşti	Reviewer
Conf. Dr. Ing. Alin DĂNIŞOR Universitatea Maritimă din Constanţa	Reviewer
Conf. dr. ing. Ovidiu URSARU Universitatea Tehnică "Gheorghe Asachi" din Iaşi	Reviewer

BUCHAREST 2022

Table of Contents

Chapter 1

Introduction

1.1 Presentation of the Field of the Doctoral Thesis

The doctoral thesis entitled "Theoretical and experimental contributions to monitoring of vital parameters using intelligent control systems based on sensors integrated into textile structures and cloud computing services" has the objective to study the theoretical and experimental aspects concerning vital parameters monitoring by intelligent control systems based Cloud data storage and sensors integrated into textile structures. Monitoring the biomedical parameters (temperature, humidity, pulse and respiratory rhythm) consists of electrical signals acquisition using flexible conductive electrodes made of textile materials and integrating the small electronics components into textile structures for remote monitoring of the patients at home. Medical monitoring at the patient's home or abroad uses small electronic devices that can be worn and are comfortable (wearable devices).

The developments in electronics, miniaturization and the trend to adopt wearable technologies with software applications interconnected everywhere (pervasive computing) and being interconnected in the internet of things or medical internet of things (IoT, MIoT) lead to progress in the field of wearable devices for medical applications or biomedical monitoring of the persons involved in sportive activities.

In the case of patients suffering from chronic diseases (diabetes, cardiovascular diseases or neurological), continuous monitoring outside of the hospital is a positive aspect because using such applications, the doctor can monitor the biomedical parameters of the patient and can react rapidly in the case of a crisis.

1.2 Scope of the Doctoral Thesis

The goal of the doctoral thesis is to perform an analysis of the possibilities of using the textile electrodes or sensors integrated into textile structures for biomedical parameters monitoring and to investigate the possibility of using biomedical data for intelligent monitoring systems (support systems based on decisions, systems based on data fusion and predictive analysis based on neural networks). The main research directions approached in order to achieve the goal consisted in: developing textile electrodes that can be integrated into monitoring systems, proposing the architectures for intelligent systems, developing a software application for biomedical signals acquisition and storage in database vitalsense, evaluating the report reflectance/transmittance by spectrophotometric methods, processing and predictive analysis of the signals by multivariate techniques and neural networks. The doctoral thesis has designed and developed textile electrodes based on conductive yarns and used in monitoring human body humidity, breathing rhythm, and heart electrical activity. The materials used have been morphological, physicomechanical and electrical characterized to highlight the potential to be used as electrodes in different systems for biomedical monitoring. Evaluating the possibility of integrating pulse monitoring sensors into textile structures was investigated by spectrophotometry the reflectance/transmittance of the radiation having different wavelengths in different human body areas. The EEG signals have been processed and analyzed using artificial neural networks and correlations with other biomedical parameters. The acquisition data's correlative, multivariate and predictive analyses were developed for intelligent systems.

1.3 Content of the Doctoral Thesis

The research developed in the framework of the doctoral program is presented in this thesis during the ten chapters.

CHAPTER 1 presents a short description of the monitoring systems based on sensors integrated into the textiles domain and continues with a description of the doctoral thesis goal and the objectives proposed for its fulfillment.

CHAPTER 2 is dedicated to presenting textile materials with electroconductive properties and investigating the surface morphology of selected materials using optical and scanning electron microscopy.

CHAPTER 3 presents a succinct analysis of the wearable devices based on sensors integrated into textile products used for medical monitoring. In addition, adequate methods for data transmission and information processing are presented using artificial intelligence methods and methods to optimize the distribution of the electroconductive components in the wearable structures.

CHAPTER 4 contains the theoretical and practical aspects related to temperature and humidity thermoregulation physiopathology, human body temperature and humidity evaluation at the skin level, and temperature and humidity monitoring using sensors integrated into textile structures.

CHAPTER 5 presents theoretical and experimental aspects concerning the wearable systems for respiratory rhythm investigation by textile sensors. It presents an experimental model of a monitoring system, which uses electro-resistive components and is integrated into a textile structure used to monitor respiratory rhythm and data processing. Furthermore, all textile structures developed to be used in respirator rhythm evaluation and physicomechanical and electrical investigations performed for conductive yarns used and knitted textile structures based on conductive yarns.

CHAPTER 6 describes the wearable systems architectures based on conductive textile and classical electrodes used for heart electrical activity investigation, textile systems, and signal processing. In addition, the theoretical aspects concerning heart electrical activity investigation are presented, types of electrodes used in ECG monitoring, and wearable systems integrated into textile products and used for ECG monitoring.

CHAPTER 7 contains the theoretical aspects concerning absorption, reflectance and transmittance properties of the tissues and pulse evaluation through transmission and reflection photoplethysmography methods. Moreover, investigations concerning the reflectance and transmittance of the electromagnetic radiations having different wavelengths in human tissues are presented by spectrophotometric methods, development of a system for pulse monitoring integrated into a textile structure, signal processing, and system testing.

CHAPTER 8 presents theoretical aspects concerning brain electrical signals investigation, data processing, predictive analysis of the signals using artificial neural networks and correlation analysis for biomedical signals selected.

CHAPTER 9 presents some aspects of medical monitoring using IoT, MIoT platforms for real-time monitoring and Cloud Computing for data storage. In addition, the aspects related to information security and anonymization by differential confidentiality methods for monitoring applications are presented.

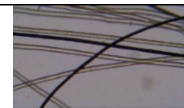
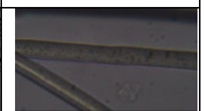
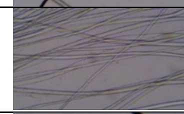
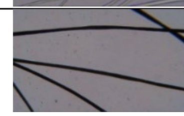
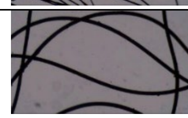
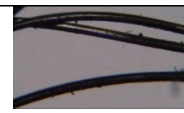
CHAPTER 10 presents the conclusions of this doctoral thesis concerning the results obtained through the research presented the results obtained from the research presented in this doctoral thesis, highlighting the results obtained, the original contributions, the list of original papers relevant to the field studied and the future perspectives of development.

Chapter 2

Textile materials with electroconductive properties

In the framework of the actual work, to develop the textile electrodes have been used yarns containing metallic fibers and monofilament yarns plated with different metals (Ag, Cu, stainless steel etc.). Morphological analysis of the yarns used was performed using electronic microscopy in transmission and reflection mode (with magnitude 4x, 10x şi 40x) and scanning electron microscopy. Table 2.1 is presented a selection of the conductive yarns conductive used. The surface electrical resistance analysis (Rs [Ω]) for knitted structures was performed in the laboratory using resistance meters having concentric electrodes and parallel electrodes, neglecting the polarization phenomena [3].

Table 2.1 *Morphological analysis of the conductive yarns*

Nr.crt	**Vedere 4x**	**Vedere 10x**	**Vedere 40x**
1. Conductive yarn based on 80% PES, 20% stainless steel, Nm 50/2			
2. Conductive yarn based on 65% mătase, 35% stainless steel, Nm 46/2			
12. Conductive yarn-based 100% stainless steel, Nm 22/2			
14. Conductive yarn 2 based on Pa 66 plated with Ag, 235/34 dtex			

Chapter 3

Wearable devices for biomedical monitoring

An intelligent system [4] is a complex system that can communicate with other systems [5] and improve their performance and contains:

- Hardware components such as a microcontroller, computer, sensors or actuators;
- Software components such as applications for data acquisition, signal processing and application-based artificial intelligence allow data classification and predictive analysis.

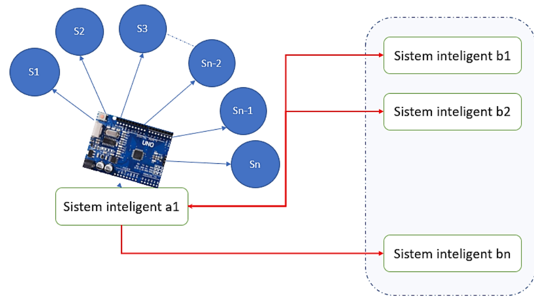


Figura 3.1 *Intelligent system based sensors*

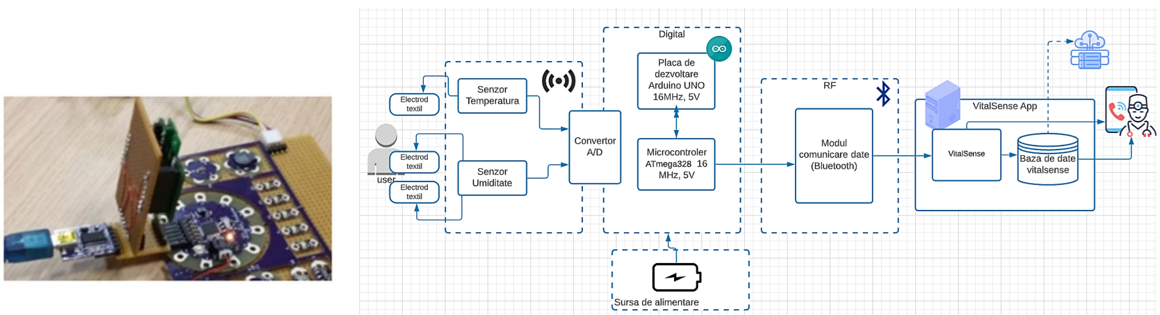
Medical systems, internet (Internet of Things (IoT), Medical Internet of Things (MIoT)) evolution lead to the development of the intelligent systems [6] for remote monitoring [7] at home [8] of the patients having chronic diseases by wearable devices, reducing in this way the costs and hospitalization time. Intelligent systems for monitoring use technologies such as Cloud Computing for data storage in the private cloud [23], Edge Computing for data, signal processing, patients' data anonymization, artificial intelligence (AI) for data classification and predictive analysis, but also Digital Twin [24] for anatomic/biologic virtual modeling and real-time simulation for predictive analysis using AI algorithms. Biomedical signals monitoring by wearable devices has as target the following user groups:

- ⇨ Older patients suffering from chronic diseases (cardiovascular diseases, diabetes, neurological diseases);
- ⇨ People who practice sports activities.

Chapter 4

Evaluation of temperature and humidity

The framework of this chapter presents theoretical aspects concerning the temperature and humidity and practical aspects concerning the investigation of the biomedical parameters such as temperature and humidity using biomedical sensors that can be integrated into textile structures. For evaluating the skin's temperature, a sensor MCP9700 integrated to board Arduino ATmega328 (Atmel), based on RISC microcontroller, having 32 bytes memory Flash, 2k bytes SRAM and 1k byte EEPROM [132]. For evaluating the humidity and skin conductance, an experiment was performed using a system developed on Arduino ATMega328 board (figure 4.7.a), communication module Bluetooth (figura 4.7.b) and a sensor GSR. In figure 4.7. a is presented the electronic components of the temperature and humidity monitoring system, and in figure 4.7.b is presented the system architecture. The experiments performed with this system (figure 4.7) allowed si simultaneous reading of data for temperature, electrical conductivity and skin humidity. Data readings from sensors were at 500 de milliseconds. After analog-digital transformation, the numerical values for temperature and humidity were displayed through a data logger [132]. The continuous signal discretization and noise reduction were performed in Matlab. Signal sampling was performed using a frequency of 1 Hz [132].



(a) (b)

Figure 4.7 *Monitoring system based Arduino ATmega328: (a) Components integration in the system; (b) System architecture*

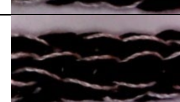
Monitoring the temperature and humidity-based sensors with textile resistive electrodes allows the measurement of the temperature and humidity due to the surface resistance modification in the textile electrode when the skin humidity or temperatures change. Analyzing the correlation coefficient between temperature and humidity ($r_{RH,T}$) was observed that between humidity and temperature, it weakly positive dependency because the correlation coefficient $r_{RH,T}$ has the value 0.0356.

Chapter 5

Respiratory rate investigation

In the framework of the doctoral thesis, using the conductive and insulators yarns previously presented in table 2.1 (chapter 2), have been developed tubular knitted textile structures (presented in table 5.1) in order to be used as electrodes/sensors electro resistive for monitoring systems used to monitor the respiratory rate. The knitted structure with high elasticity will increase its length at inspiration. At expiration, it will return to its initial length, thus generating fluctuations in the electrical resistance and implicitly different numerical values of the input and output voltage. Table 5.1 presents the numerical values experimentally obtained for electrical resistance and capacitance for several tubular structures developed to be used as electrodes/sensors. The sensor (figure 5.34) obtained may be integrated into clothing articles. In the phases of inspiration/expiration, the tubular structure is extended, suffering an elastic deformation. It does not damage and facilitates the rhythmic change of the impedance in the inspiration/expiration phases [155].

Tabel 5.1 *Electroconductive properties of the electrodes developed*

No	Composition *Fir1, **Fir 2	Vedere 5x	***R_1 [Ω]	****R_2 [Ω]	*****C [nF]	T [°C]
1	Yarn 1 -100 % Pa; Yarn 2- 100% stainless steel		$5.7x10^2$	17	0.14	25
2	Yarn 1 – 100% Pa; Yarn 2 – 80% stainless steel, 20 % Pes		$9.5x10^5$	$7.5x10^2$	0.19	25
3	Yarn 1 – 100% Pa; Yarn 2 –20% stainless steel + 80 % Pes		$7x10^4$	$1.2x10^3$	1.39	25
13	Yarn 1 20 % inox + 80% PES; Yarn 2 65% silk, 35% stainless steel		$7.8x10^2$	$1.7x10^2$	0.16	25

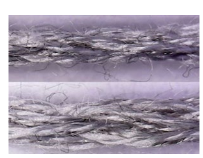


Figura 5.34 *Knitted tubular sensor [155]*

For respiration monitoring was use the tubular sensor (figure 5.34) was connected to Arduino board, having Atmel 328 microprocessor with working voltage 4.5-5.5 V. For reading the impedance variation at 2 seconds, the continuous signal was discretized (figure 5.37) using a sampling frequency of 0.5 Hz (5.30) [155].

$$fe = \frac{1}{T} = \frac{1}{2} = 0.5\ Hz \tag{5.30}$$

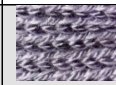
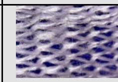
In order to obtain the impedance value software application was developed that uses a void loop function and a transfer function to program the microcontroller [155]. For flexible sensors used for respiratory rate monitoring, it is essential to have elastic deformations to count inspirations or expirations per minute. In the case of a structure having low elasticity, plastic or structural deformations may occur, which will no longer allow the sensor to return to its original position. It will be practically impossible to read the impedance variation [155].

Chapter 6

Evaluating heart electrical activity

This chapter presents theoretical and practical aspects concerning the heart electrical activity evaluation. For investigating the heart electrical activity, systems that monitor the variation of the surface resistance for the human body in different areas are used. Generally, wet electrodes are used to acquire the electrical signals based on electrolytes or conductive liquid gel, adhesive electrodes with solid gel or metallic electrodes (from stainless steel, orbitals, bulb electrode or clamp). In the framework of this doctoral thesis, textile ECG electrodes (Table 6.1) have been developed and integrated into an ECG_2 system to monitor electrical signals produced by heart activity.

Table 6.1 *ECG Electrodes*

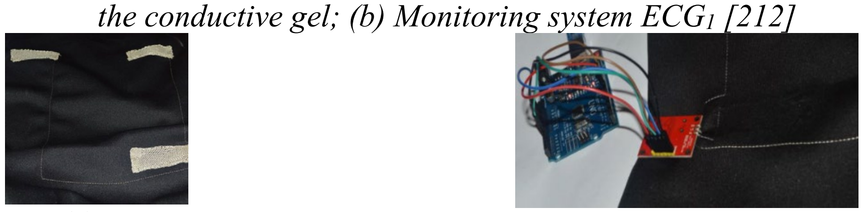
Electrode	Dry Electrode	Wet Electrode	Electrode gel	Support	Image
Flexible ECG electrode made during the doctoral thesis	x	-	-	Textile support (Cotton knit with elastane and conductive yarns (80% Stainless Steel, 20% PES))	
Flexible ECG electrode made during the doctoral thesis	x	-	-	Textile support (Knit made of conductive yarns (80% Stainless Steel, 20% PES))	
Flexible ECG electrode made during the doctoral thesis	x	-	-	Textile support (Cotton knit with elastane and conductive yarns (100% Stainless Steel))	
Flexible ECG electrode made during the doctoral thesis	x	-	-	Textile support (Knit made of conductive yarns (Pa electroplated with 99% Ag))	

For developing the heart electrical activity monitoring system, the experimental part consisted of developing the ECG_2 system integrated into the textile product (shirt).

In addition, a comparative study between the ECG_1 classical system based on conditioning signal block, 3 adhesive electrodes with conductive gel, cables, and ARDUINO board for data acquisition and transfer to the desktop application (figure 6.15 a and b), respective the ECG_2 monitoring system based on signal conditioning signal block, three textile dry electrodes (obtained by knitting the conductive yarns based on Pa and Ag) integrated into the textile product, conductive yarns and mainboard ARDUINO (figure 6.16 a and b) [212].

(a) [212] (b)

Figure 6.15 *Classical system for monitoring ECG_1: (a) Classical electrodes based on the conductive gel; (b) Monitoring system ECG_1 [212]*



(a) [212] (b) [212]

Figure 6.16 *System based on textile electrodes for monitoring ECG_2:(a) Textile electrodes integrated; (b) Monitoring system ECG_2 based on textile electrodes and textile conductive yarns [212]*

Conditioning signal block contains instrumentation amplifier, operational amplifier, RLD amplifier and reference.

To filter the signals have been applied:

- Lowpass filters: 35 Hz, 50 Hz, 90 Hz, 100 Hz, 150 Hz şi 200 Hz for signal acquisition from system ECG_1, respective ECG_2;

- Highpass filters: 0.01 Hz, 0.05 Hz, 0.1 Hz şi 0.4 Hz for signal acquisition from system ECG_1, respective ECG2;

In the case of the signal acquisition from system ECG_2 based on textile electrodes, the best signal accuracy was when a lowpass filter of 90 Hz and a lowpass filter of 0.05 Hz were applied. This aspect can be explained by the fact that the textile electrode does not offer uniform and continuous contact with the skin as the classic electrodes based on the electroconductive gel due to its discrete structure.

Chapter 7

Cardiac rhythm investigation

Optoelectronic photoplethysmography (PPG) methods in reflection or transmission mode are used for cardiac rhythm investigation. The photoplethysmography method is based on the phenomenon of light absorption, reflectance and transmittance in tissues [215]. To choose the best position for the wearable pulse sensor (PPG), we evaluated the reflectance and transmittance for the hand, finger and arm area using the spectrophotometric method. Analyzing the cumulative reflectance/transmittance ratio for the selected areas of the body (index finger, right arm, thumb, hand) depending on the wavelength, can be concluded: i) a better light transmission is obtained if photoplethysmography is used in transmission mode and UV-VIS light (UV or purple LED), ii) a better light reflection is obtained if you can use photoplethysmography used in reflection mode and red light source (red LED). A system based on integrated sensors into textile for pulse monitoring was developed. For system development, an optical sensor based on the photodiode, IR LED (light-emitting diode), electrical resistances, conductive yarns, and a development board ARDUINO UNO with ATmega328P microcontroller (figura 7.16) was used. The role of the photodiode, which uses a PN junction diode, is to convert light (reflected by tissues) into electricity. The role of the IR LED is to emit a luminous flux that is totally or partially absorbed by the tissues and transformed into heat. The rest of the luminous flux is reflected and captured by the photodiode [245]. A software application was developed for data acquisition, and the obtained signals were processed in Matlab [245].

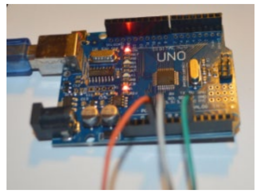


Figura 7.16 *Arduino UNO development board, based on ATmega328P microprocessor, used for heart rate monitoring system [245]*

The evaluation of light emission and absorption was performed based on the recordings of the reflective sensor composed of photodiode and IR LED. The hypothesis was that if light passes through human tissues, part is absorbed or reflected. The pulse monitoring system was made by integrating a reflective sensor on a flexible knitted textile support (figures 7.17, 7.18). For the integration of the sensor in the textile material, the classic components (cables and electrical resistors) have been eliminated and replaced with conductive yarns or resistors (R1 and R2) made of conductive yarns (figures 7.17 and 7.18) [245].

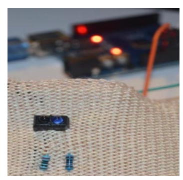


Figura 7.17 *Wearable system for pulse monitoring integrated into the textile product by classic resistors [245]*

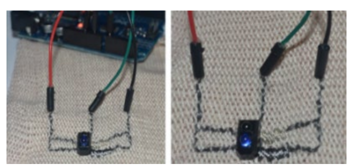


Figura 7.18 *Wearable system for monitoring the pulse integrated into the textile product by conductive yarns (4PLY, 2PLY)* [245]

The circuit diagram for the sensor integrated into the textile product was made in the Simulink program and is presented in figure 7.19 [245]. For pulse monitoring, an ARDUINO development board was used with Atmel 328 microcontroller having the operating voltage 4.5-5.5 V. The signal taken from Arduino was discretized in Matlab using a sampling frequency (fs) of 0, 5 Hz and 1 Hz, respectively.

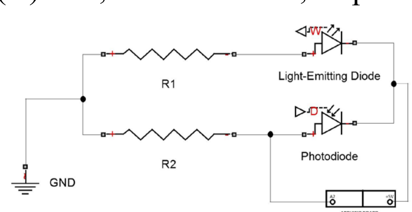


Figura 7.19 *PPG sensor integrated into the textile product and connected to the ARDUINO UNO development board [245]*

Chapter 8

Investigating brain electrical activity

This chapter presents theoretical aspects concerning electrical brain signals investigation. The biomedical signals selected from Cap Sleep Database were processed in Matlab using the wavelet method and Daubechies function. Several selected signals have been analyzed using feed-forward artificial neural networks based on the Levenberg–Marquardt backpropagation optimization algorithm. Using the selected signals have been evaluated the correlations and covariations between the biomedical signals emitted by the brain (EEG), muscle (EMG) and pulse (PPG).

For predictive analysis, the feed-forward artificial neural network method and the optimization algorithm Levenberg–Marquardt backpropagation were used.

The functional elements used in neural networks are [259]:

➔Input units (Input) represented by the values of the matrix EEG1 for patients with the epileptic crisis.

➔Hidden units (Hidden) represented by the neurons number (10, 20, 30, 40, 50, 100, 150 and 200 neurons).

➔Output units (Output) represented by the values of the matrix EEG2 for patients without epileptic crisis.

The prediction and optimization have been performed using multilayer neural network feed-forward backpropagation. Input data are the independent variables represented by the input matrix X1 [13x5120] obtained from signal EEG1 acquisition from a patient with no epileptic crisis. Output data are the dependent variables represented by the output matrix Y1 [13x5120] obtained from signal EEG2 acquisition from a patient with epileptic crisis [259].

Based on regression values (R) obtained for test, training, validation and cumulative regression, it follows that R has the higher value for a neural network with 200 neurons ($R_{Training}$=0.92796, R_{Test}=0.83147, $R_{Validation}$=0.82298, R_{all}=0.88956). However, the disadvantage is that training a network with 200 neurons requires approximately 60-70 minutes for training, test and validation. In addition, it was observed that using a network with a high number of neurons (200) leads to error diminution. utilizarea unei reţele cu număr mare de neuroni (200) conduce la diminuarea erorilor.

The covariation and correlation between the biomedical signals (EMG, PPG, EEG) for patients with or without epileptic crisis show positive correlation coefficients and a direct dependence between the signals analyzed. Furthermore, this aspect can be exploited for predictive analysis using neural networks or systems based on the decision [259].

Chapter 9

Cloud Computing and IoMT services for monitoring

This chapter presents the main theoretical and practical aspects of medical monitoring applications using IoMT, Cloud Computing and data anonymization services. Systems IoMT may be vulnerable and should be designed to minimize negative aspects and ensure personal data protection through the private cloud and data anonymization for use in statistics [316, 317, 318]. In the framework of the doctoral thesis have been achieved: a) a system for vital parameters monitoring using an IoT platform and Cloud Computing services; b) data anonymization using the method of differential confidentiality; c) a software application VitalSense which allow biomedical signals acquisition from sensors and storage in database vitalsense. For biomedical parameters monitoring by IoT platform and Cloud Computing services has developed a system for monitoring (figure 9.12) integrating the following components [305]:

- Arduino development board based on Atmega32U4 microcontroller, CMOS 8-bit using AVR Atmel RISC architecture and WiFi Atheros AR9331 module [305];
- a PPG sensor in reflection mode having the functional components a phototransistor and a green LED;
- an analogical temperature/humidity sensor and an external battery of 3000 mAh.

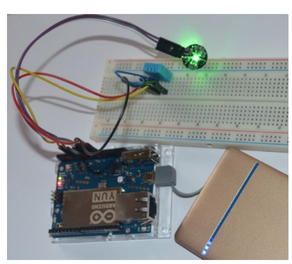


Figura 9.12 *Biomedical monitoring system using IoT and Cloud Computing SaaP*

Microcontroller programming was developed as a software application that allows data readings from analogical sensors. In ace of the pulse sensor, the sensor was defined in the IoT platform as variable and authentification of the electronic device in the IoT platform was achieved using a token. For IoT and Cloud Computing services was used the web interface API REST (Application Programming Interface) allows connecting devices and storage of the data in the cloud. I used a token obtained for the device connect request (figura 9.13). In the case of the initial data collected, signal processing in Matlab was necessary. [305].

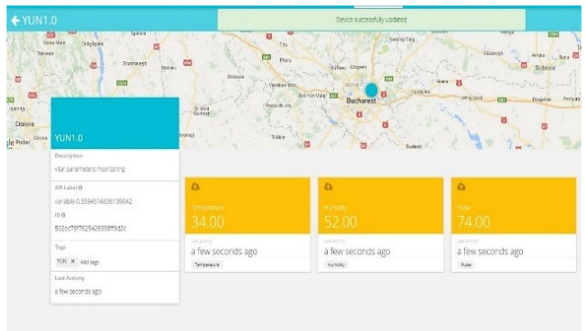


Figure 9.13 *Cloud PaaS service for data acquisition from a system [305]*

Data transmitted can be saved in the cloud, real-time visualized and can be used to send alerts type SMS /email in case of the patients monitoring by selecting the minimal and maximum critical values for monitoring parameters (figure 9.15). This system allows sending notifications to the medical staff and data visualization in real-time (figure 9.16) [305].

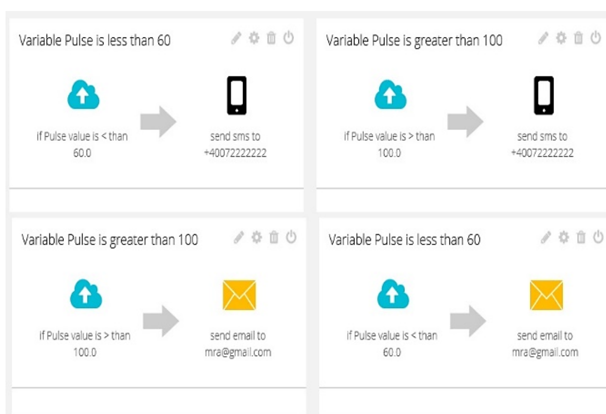


Figure 9.15 *Critical values for sending SMS/email [305]*

The software application VitalSense allows numerical data acquisition from sensors connected to the Arduino board allocated to each patient, which can send data wirelessly or using a USB cable. The application VitalSense allows data reading and saving in database vitalsense. The VitalSense software architecture (figure 9.17) includes hardware components that allow data acquisition (biomedical sensors, development board

Arduino, AD convertor, RF communication module). The VitalSense application's software components ensure collecting, saving, viewing, deleting and storing data in the vitalsense database. Software architecture design involved the hierarchical division into interconnected microcomponents, modules and software objects needed to make the VitalSense software application.

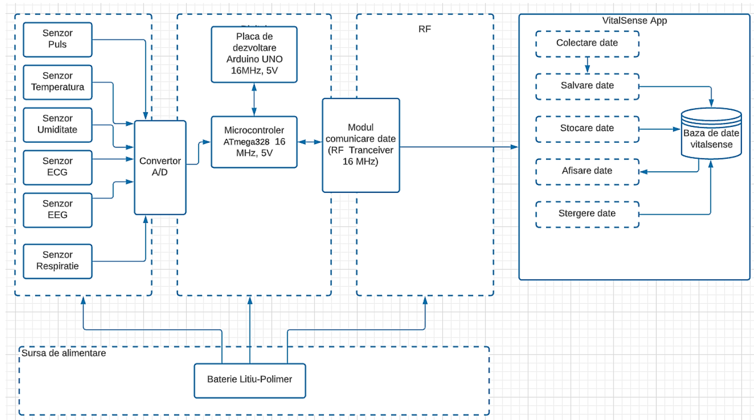


Figura 9.17 *Software architecture – application VitalSense*

User-specific data (doctors or patients) is stored in a VitalSense MySql database. The administrator of the medical unit can create new accounts for doctors affiliated with the medical unit, and data will be stored on the table doctor. The user doctor has the right to create accounts for patients allocated, and the information will be stored in the pacient table. The patients cannot create new accounts or visualize the information afferent to doctor users. Database vitalsense also contains six tables for data from ECG, temperature, respiration, pulse, humidity, and EEG. In figure 9.29, the entity-relationship diagram for database vitalsense.

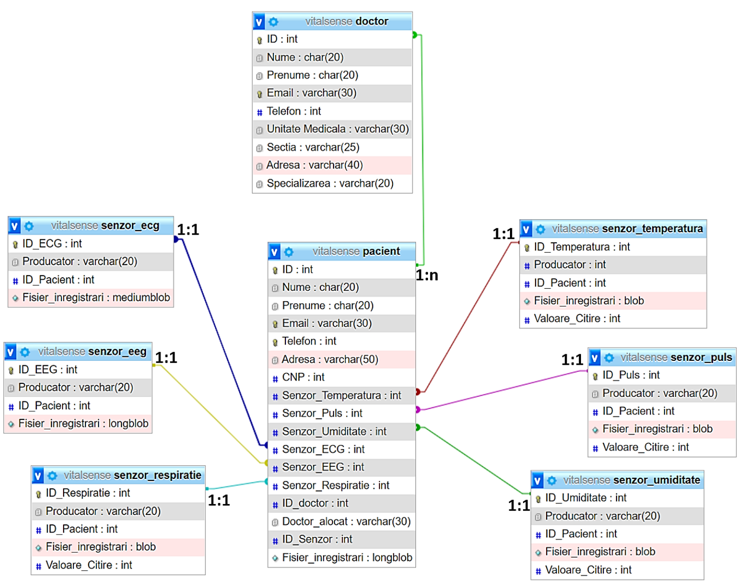


Figure 9.29 *Entity-relationship diagram for database vitalsense*

Chapter 10

Conclusions

The development of the internet has enabled the integration of IoT, IoMT, or Cloud Computing technologies for remote medical monitoring. The miniaturization of electronic components for wearable devices by advanced technologies driven the need to develop new conductive, flexible and lightweight materials that can be easily integrated into wearable products, thus generating a new direction of research related to personalized preventive medicine. Personal biomedical monitoring used to aquisite vital parameters by remote communication technology can provide valuable data to medical staff or patients.

10.1 Results obtained

Chapter 1 presents the field of the doctoral thesis (the field of sensor-based monitoring systems integrated into textile products) and continues with the description of the purpose of this doctoral thesis and the objectives proposed for its fulfillment.

Chapter 2 presents the technical data for the raw materials used to obtain textile electrodes and sensors through mechanical processing (knitting) technologies. The surface morphology of the conductive and insulating yarns was analyzed by optical and scanning electron microscopy, which highlighted the presence of micro/nano particles of Ag, Al, C or stainless steel on the conductive yarns. Helpful information was obtained in defining the group of structures used as textile electrodes in monitoring systems by evaluating the surface electrical resistance of knitted structures. This chapter presents a preliminary selection of knitted structures that can be used as insulating elements or electrodes in the monitoring systems of humidity, conductivity, respiratory rate, heart rate and electrical activity (ECG).

Chapter 3 presents a scientific study on wearable devices for monitoring biomedical parameters, the sensor networks topology suitable for personal biomedical monitoring (BAN, WBAN, MBAN and PAN), and data communication technologies (Bluetooth BLE, ANT, ZigBee, ANT, WiFi, LoRa).

Chapter 4 presents the software application for programming the microcontroller and a temperature and humidity monitoring system made by integrating electrical components such as Arduino development board with Atmel processor, Bluetooth communication module, temperature sensor, GSR sensor and textile electrodes for measuring the temperature and humidity for a specific area of the human body.

Acquired signals were processed in Matlab to reduce noise. Since electroconductive textile surfaces change their surface electrical resistance to variations in humidity and temperature, it is evident that textile electrodes have the potential to be used as resistive sensors for measuring humidity and temperature. In addition, this chapter presents a scientific study on the mechanisms that control and determine temperature and humidity variation in the human body.

Chapter 5 presents the two electro-resistive sensors made by sewing the conductive yarns (100% Pa 6.6 electroplated with Ag) on a textile structure made by knitting (100% bamboo), respectively by making a conductive tubular structure based on four stitches. Using an Arduino development board, the developed electro-resistive textile sensors were tested in respiration monitoring systems. A program was developed that allows the programming of the microcontroller and the calculation of the respiratory rate. Moreover, this chapter presents the physical-mechanical and electrical properties of conductive yarns. The tubular electrodes were developed to be resistive sensors that change their electrical resistance when elongated (in the inspiration phase, the electrical resistance decreases) or return from elongation (in the expiration phase when the electrical resistance returns to the initial value). A scientific study on determining respiratory rate using wearable systems is also presented.

Chapter 6 presents the four knitted structures made of conductive yarns (100% stainless steel, Pa electroplated with 99% Ag, 80% stainless steel and 20% polyester), which can be used as electrodes integrated into clothing products for ECG monitoring. The monitoring system is based on: a 3-lead system made of knitted electrodes obtained by conductive yarns (99% Ag electroplated Pa) and integrated into a T-shirt, a signal conditioning block (instrumentation amplifier, operational amplifier, RLD amplifier and reference) connected to textile electrodes by electroconductive yarns, Arduino development board for signal acquisition and transmission to the desktop application. The system made of electroconductive textile electrodes (ECG_2) was tested compared to an ECG_1 monitoring system that uses conventional electrodes based on the electroconductive gel. The signals acquired from both ECG_1 and ECG_2 systems were processed in Matlab to reduce noise using low pass filters of 35, 50, 90, 100, 150 and 200 Hz and high pass filters of 0.01, 0.05, 0.1 and 0.4 Hz. As a result of the analysis of the signals acquired through the ECG_2 system based on textile electrodes, it was found that a signal with good accuracy can be obtained using a low pass filter of 90 Hz and a high pass filter of 0.05 Hz. Also in this chapter are briefly presented the main methods, types of ECG electrodes, and wearable systems for investigating the heart's electrical activity using textile electrodes.

Chapter 7 presents the pulse monitoring system made by integrating into a textile material with the help of conductive wires, some resistors made of conductive wires and an Arduino development board. The purchased signal was processed in Matlab to reduce noise. A scientific study was performed using the spectrophotometric method to investigate the reflectance and transmittance in human tissues in 4 body areas (arm, hand, fingers) to determine the types of photoplethysmography that can be used. The chapter presents a theoretical study on heart rate monitoring using the plethysmographic method. Moreover, using the spectrophotometric method, a study on absorption, reflectance and transmittance was elaborated in human tissues of radiation having different wavelengths.

Chapter 8 presents Matlab processing of EEG signals, selected from the Cap Sleep Database, and an analysis of signals based on feed-forward neural networks using the

Levenberg – Marquardt backpropagation optimization algorithm. An analysis of the correlations and covariations between the biomedical signals emitted by the brain (EEG) or muscle (EMG) and pulse (PPG) was also performed for these signals. In addition, the chapter presents a documentary study on the acquisition of electrical signals emitted by the brain.

Chapter 9 presents the results obtained using a monitoring system based on sensors (pulse, humidity, temperature) and a development board compatible with IoT applications. A program was developed that allows the sensor to connect to the IoT platform and testing system. The anonymization of data was performed using the method of differential confidentiality. Also, a vitalsense database and the VitalSense application were developed to display sensor data for the selected patient, search for data in the database, and store data in the vitalsense database. Also, this chapter presents the main theoretical and practical aspects of medical monitoring applications using IoMT services, Cloud Computing and patient data anonymization using differential confidentiality methods.

Chapter 10 presents the conclusions of this paper on the results obtained from the research presented in this doctoral thesis, highlighting the results obtained, the original contributions, the list of original papers relevant to the field studied and future development prospects.

10.2 Original contributions

The original contributions were disseminated in the scientific publications and contain aspects such as: conductive textile electrodes spectrophotometric analysis of reflectance/transmittance, monitoring systems made of electroconductive textile components, software for microcontroller programming, signal processing, predictive analysis using neural networks, correlations and the covariance between different biomedical signals are as follows:

• [A2, C10, C11, C14] present the conductive and electrically tested textile structures that can be used as electrodes for wearable ECG or temperature and humidity monitoring systems.

• In [C5] is presented the ECG system made with three leads and composed of 3 electrodes knitted from 99% Ag electroplated Pa yarns, a block for signal conditioning (instrumentation amplifier, operational amplifier, RLD amplifier and reference) connected to textile electrodes by electrical wires, Arduino motherboard for signal acquisition and transmission to the desktop application. For the comparative analysis of the acquired signals, 2 ECG monitoring systems were used, the first (ECG_1) based on classical electrodes with electroconductive gel and the second (ECG_2) based on conductive textile electrodes. The signals acquired from the 2 ECG monitoring systems were processed to reduce noise in Matlab.

• [C16, B9] present the system designed to monitor humidity and temperature by integrating humidity, temperature, textile electrode sensors, the Arduino development board and the Bluetooth communication module. Acquired signals were processed in Matlab to reduce noise. A software application has been developed and allows microcontroller programming and temperature and humidity calculation. This system is of particular importance for medical monitoring in patients with diabetes.

• In [C6, C8] are presented the two electro-resistive sensors made by sewing the conductive yarns (100% Pa 6.6 electroplated with Ag) on a textile structure made by knitting (100% bamboo), respectively by making a conductive tubular structure of 4 stitches. The developed electro-resistive textile sensors were tested from a physical-mechanical, electrical point of view and within the breath monitoring systems using an Arduino development board. A program was created that allows the microcontroller's programming to calculate the respiratory rhythm. A system to investigate the respiratory rate was developed because the electrical signal is produced during the expiration and inspiration phase. This system records the variation of the electrical resistance of conductive electrodes made in inspiration (when the electrode lengthens, the electrical resistance decreases) and expiration (when the electrode returns from elongation and electrical resistance increase again to the initial value).
• In [C2, C7] is presented a scientific study on evaluating reflectance and transmittance in human tissues in 4 areas of the body (arm, hand, fingers), using the spectrophotometer. Also, was presented the pulse monitoring system based on conductive yarns and the following components: textile electrical resistors, LED, photodiode and Arduino development board whose microcontroller was programmed based on the monitoring breathing software application. The signal processing was performed in Matlab to reduce noise.
• [C3] describes a sensor-based monitoring system (pulse, humidity, temperature) using a development board compatible with IoT applications and a software application developed to connect the sensor to the IoT platform and test the system.
• In [A1, C1, C4] are presented the aspects related to the EEG signal processing in Matlab using discrete wavelet transform, predictive data analysis based on artificial intelligence techniques such as artificial neural networks feed-forward based on the Levenberg – Marquardt backpropagation optimization algorithm. In addition, the analysis of correlations and covariations between biomedical signals emitted by the brain (EEG) or muscle (EMG) and pulse (PPG) is presented.
• [B3, B8, C9] presents an application for predictive data modeling using machine learning techniques and sensor data fusion by specific statistical techniques (data mining) to develop decision-based support systems.
• [C12, C13] presents aspects related to storing data purchased from sensors using cloud computing services, anonymizing and merging medical data to generate adequate predictive models in decision-based support systems.
• [B1, B2, B4, B5, B6] presents theoretical and practical aspects of data security in remote monitoring systems and data protection by anonymization using the method of differential confidentiality, in the context of using Cloud Computing and IoMT technologies. Anonymization was necessary to the subsequent use of data in public predictive analytics.
• [B5, B7] presents scientific studies on wearable technologies for remote monitoring using radio (cognitive radio) communication in the context of the use of IoT or IoMT technologies.
• In [B10, B11, C15], the theoretical studies on wearable devices and the types and topology of sensor networks used for personal monitoring were presented.

10.3 List of original publications

The original papers list includes: 11 book chapters, 2 scientific papers published in ISI indexed scientific journals, and 16 papers published in ISI indexed volumes of international conferences and symposia, totaling 37 ISI citations, 16 IEEE citations and 2 SCOPUS citations. All scientific papers can be found in the bibliography and have content related to the doctoral thesis topic.

I. Book chapters

B1: R.M. Aileni, G. Suciu, C. Valderrama, S. Pasca, IoT Performability for Medical Wearable Device by Data Privacy and Fault Tolerance, In: Idoudi H., Val T. (eds) Smart Systems for E-Health, Advanced Information and Knowledge Processing, Springer, Cham., 2021, Print ISBN: 978-3-030-14938-3, Online ISBN: 978-3-030-14939-0, DOI: 10.1007/978-3-030-14939-0_5 [316].

B2: R.M. Aileni, G. Suciu, IoMT: A Blockchain Perspective, In: Khan M., Quasim M., Algarni F., Alharthi A. (eds) Decentralised Internet of Things, Studies in Big Data, vol 71, Springer, Cham., 2021, Print ISBN: 978-3-030-38676-4, Online ISBN: 978-3-030-38677-1, DOI: 10.1007/978-3-030-38677-1_9 [322]. Nr citări SCOPUS: 1, Nr citări ISI: 5.

B3: R.M. Aileni, G. Suciu, S. Pasca, C.A. Valderrama Sukuyama, Data Fusion-Based AI Algorithms in the Context of IIoTS, In: Kanagachidambaresan G., Anand R., Balasubramanian E., Mahima V. (eds) Internet of Things for Industry 4.0, EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp.17-38, 2020, Print ISBN: 978-3-030-32529-9, Online ISBN: 978-3-030-32530-5, DOI: 10.1007/978-3-030-32530-5_2 [312]. Nr citări ISI: 3.

B4: R.M. Aileni, G. Suciu, C. Valderrama Sukuyama, S. Pasca, R. Maheswar, Cybersecurity Technologies for the Internet of Medical Wearable Devices (IoMWD), In: Shandilya S., Wagner N., Nagar A. (eds) Advances in Cyber Security Analytics and Decision Systems, EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp.117-140, 2020, Print ISBN: 978-3-030-19352-2, Online ISBN: 978-3-030-19353-9, WOS:000670754200007, DOI: 10.1007/978-3-030-19353-9_6 [318]. Nr citări IEEE: 1, Nr citări ISI: 1.

B5: R.M. Aileni, G. Suciu, C.A. Valderrama Sukuyama, S. Pasca, Internet of Things and Communication Technology Synergy for Remote Services in Healthcare, In: Gupta N., Paiva S. (eds) IoT and ICT for Healthcare Applications, EAI/Springer Innovations in Communication and Computing. Springer, Cham., pp. 59-82, 2020, Print ISBN: 978-3-030-42933-1, Online ISBN: 978-3-030-42934-8, DOI: 10.1007/978-3-030-42934-8_5 [295].

B6: R.M. Aileni, G. Suciu, M. Rajagopal, S. Pasca, C.A. Valderrama Sukuyama, Data Privacy and Security for IoMWT (Internet of Medical Wearable Things) Cloud, In: Gupta N., Paiva S. (eds) IoT and ICT for Healthcare Applications. EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp. 191-215, 2020, Print ISBN: 978-3-030-42933-1, Online ISBN: 978-3-030-42934-8, DOI: 10.1007/978-3-030-42934-8_11 [317]. Nr citări SCOPUS: 1, Nr citări ISI: 1.

B7: R.M. Aileni, G. Suciu, V. Suciu, S. Pasca, R. Strungaru, Health Monitoring Using Wearable Technologies and Cognitive Radio for IoT, In: Rehmani M., Dhaou R. (eds) Cognitive Radio, Mobile Communications and Wireless Networks, EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp.

143-165, 2019, Print ISBN: 978-3-319-91001-7, Online ISBN: 978-3-319-91002-4, WOS:000456340100006, DOI: 10.1007/978-3-319-91002-4_6 [76]. Nr. citări ISI: 5.

B8: R.M. Aileni, G. Suciu, V. Suciu, J. Ciurea, S. Pasca, Assistive Mobile Technologies for Health Monitoring and Brain–Computer Interface for Patients with Motor Impairments, In: Paiva S. (eds) Mobile Solutions and Their Usefulness in Everyday Life, EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp. 209-224, 2019, Print ISBN: 978-3-319-93490-7, Online ISBN: 978-3-319-93491-4, DOI: 10.1007/978-3-319-93491-4_11 [310]. Nr. citări ISI: 1.

B9: R.M. Aileni, A.C. Valderrama and R. Strungaru, Wearable electronics for elderly health monitoring and active living, In Ambient Assisted Living and Enhanced Living Environments, pp. 247-269, 2017, Butterworth-Heinemann, ISBN: 978-0-12-805282-2; 978-0-12-805195-5, WOS:000413778000011, DOI:10.1016/B978-0-12-805195-5.00010-7 [101]. Nr. citări ISI: 5.

B10: R.M. Aileni, G. Suciu, C.M. Balaceanu, C. Beceanu, P.A. Lavinia, C.V. Nadrag, S. Pasca, C.A. Valderrama Sakuyama and A. Vulpe, Body Area Network (BAN) for Healthcare by Wireless Mesh Network (WMN), In: Maheswar R., Kanagachidambaresan G., Jayaparvathy R., Thampi S. (eds) Body Area Network Challenges and Solutions, EAI/Springer Innovations in Communication and Computing, Springer, Cham., pp.1-17, 2019, Print ISBN:978-3-030-00864-2, Online ISBN:978-3-030-00865-9, WOS:000618315800002, DOI:10.1007/978-3-030-00865-9_1 [309]. Nr. citări ISI: 3.

B11: R. M. Aileni, S. Pasca and C. V. Sukuyama, Wearable health care: Technology evolution, algorithms and needs, in Book Enhanced Living Environments: From Models to Technologies, IET, pp. 315-343, 2017, ISBN: 9781785612114, e-ISBN: 9781785612121, DOI: 10.1049/PBHE010E_ch [25].

II. Articles published in scientific journals

A1: R.M. Aileni, S. Pasca and A. Florescu, EEG-brain activity monitoring and predictive analysis of signals using artificial neural networks, Sensors, 20(12), p.3346, 2020, WOS:000553489200001 (Q1 journal article, Impact Factor: 3.576), eISSN: 1424-8220, DOI: 10.3390/s20123346 [259]. Nr. citări ISI: 5.

A2: R. M. Aileni, L. Dinca, S. Pasca, S. and R. Strungaru, Flexible material for wearable ECG electrodes, University Politehnica of Bucharest Scientific Bulletin Series C-Electrical Engineering and Computer Science, 79(2), pp.127-132, 2017, WOS:000405770800012, ISSN: 2286-3540, eISSN: 2286-3559 [3].

III. Papers published in the proceedings of international scientific events (conferences, symposia) ISI indexed:

C1: R.M. Aileni, S. Pasca and A. Florescu, Epileptic seizure classification based on supervised learning models, In 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 1-4, 2019, March, WOS:000475904500159, ISBN: 978-1-4799-7514-3, ISSN: 1843-8571, DOI: 10.1109/ATEE.2019.8725004 [263]. Nr. citări ISI: 1.

C2: R.M. Aileni, S. Pasca and A. Florescu, E-health monitoring by smart pulse oximeter systems integrated in SDU, In 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 1-4, 2019, March, WOS:000475904500023, ISBN: 978-1-4799-7514-3, ISSN: 1843-8571, DOI: 10.1109/ATEE.2019.8724865 [247]. Nr. citări IEEE: 2; Nr. citări ISI: 1.

C3: R.M. Aileni, S. Pasca and G. Suciu, MIoT applications for wearable technologies used for health monitoring, In 2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. 1-4, 2018, June, WOS:000467734100138, ISBN: 978-1-5386-4901-5, ISSN: 2378-7147, DOI: 10.1109/ECAI.2018.8679069 [305]. Nr. citări ISI: 2.

C4: R.M. Aileni, B. Hurezeanu and S. Pasca, Wavelet transform for seizures detection in EEG Records, In 2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. 1-6, 2018, June, WOS:000467734100046, ISBN: 978-1-5386-4901-5, ISSN: 2378-7147, DOI: 10.1109/ECAI.2018.8678976 [264].

C5: R.M. Aileni, S. Pasca and R. Strungaru, Wearable platform for cardiac rhythm monitoring and signal processing, In 2017 9th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. 1-4, 2017, June, WOS:000425865900115, ISBN: 978-1-5090-6458-8, ISSN: 2378-7147, DOI: 10.1109/ECAI.2017.8166499 [212].

C6: R.M. Aileni, S. Pasca, R. Strungaru and C. Valderrama, Biomedical signal acquisition for respiration monitoring by flexible analog wearable sensors, In 2017 E-Health and Bioengineering Conference (EHB), IEEE, pp. 81-84, June 2017, WOS:000445457500021, ISBN: 978-1-5386-0358-1, ISSN: 2575-5137, eISSN: 2575-5145, DOI:10.1109/EHB.2017.7995366 [141].Nr citări ISI:1, Nr. citări IEEE: 1.

C7: R.M. Aileni, S. Pasca and R. Strungaru, Heart rate monitoring by using non-invasive wearable sensor, In 2017 E-Health and Bioengineering Conference (EHB), IEEE, pp. 587-590, IEEE, 2017, June, WOS:000445457500147, ISBN: 978-1-5386-0358-1, ISSN: 2575-5137, eISSN: 2575-5145, DOI: 10.1109/EHB.2017.7995492 [245]. Nr citări ISI: 3.

C8: R.M. Aileni, L. Dinca, S. Pasca and R. Strungaru, Flexible structures with electro-conductive properties for wearable electronic devices, In 2016 International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-5, 2016, June, WOS:000392434400094, ISBN: 978-1-4673-9575-5, DOI: 10.1109/ISFEE.2016.7803242 [156].

C9: R.M. Aileni, Healthcare Predictive Model Based on Big Data Fusion from Biomedical Sensors, In Conference proceedings of eLearning and Software for Education (eLSE), No. 01, pp. 328-333, " Carol I" National Defence University Publishing House, 2016, WOS:000385395900046, ISSN: 2066-026X, DOI: 10.12753/2066-026x-16-046 [303].

C10: R.M. Aileni and L. Dinca, Optimization of the electro-conductive yarns distribution in flexible wearable dielectric structures, In 2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 539-542, 2015, May, WOS:000368159800102, ISBN: 978-1-4799-7514-3, DOI: 10.1109/ATEE.2015.7133879 [157].

C11: R.M. Aileni and L. Dinca, Electroconductive materials with high potential for wearable electronic devices integration, In 2015 7th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. Y-5, 2015, June, WOS:000370971100033, ISBN: 978-1-4673-6647-2, ISSN: 2378-7147, DOI: 10.1109/ECAI.2015.7301168 [300]. Nr. citări IEEE: 1.

C12: R.M. Aileni, S. Pasca and C. Valderrama, Cloud computing for big data from biomedical sensors monitoring, storage and analyze, In 2015 conference grid, Cloud & High Performance Computing in science (ROLCG), IEEE, pp. 1-4, 2015, October, WOS:000380444300013, ISBN: 978-6-0673-7039-3, DOI: 10.1109/ROLCG.2015.7367419 [287]. Nr. citări IEEE: 2.

C13: R.M. Aileni, S. Pasca and C. Valderrama, Biomedical sensors data fusion algorithm for enhancing the efficiency of fault-tolerant systems in case of wearable electronics device, In 2015 Conference Grid, Cloud & High Performance Computing in Science (ROLCG), IEEE, pp. 1-4, 2015, October, WOS:000380444300002, ISBN: 978-6-0673-7039-3, DOI: 10.1109/ROLCG.2015.7367228 [143]. Nr. citări IEEE: 3.

C14: R.M. Aileni and L. Surdu, Obtaining the optimal surface for electronic device deposition using nanotechnologies, in International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp.1-4, 2014, November, WOS:000380570500017, ISBN:978-1-4799-6821-3, DOI: 10.1109/ISFEE.2014.7050549 [299].

C15: R.M. Aileni, P. Bruniaux and R. Strungaru, Wearable sensors modeling for healthcare, In International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp.1-4, 2014, November, WOS:000380570500054, ISBN:978-1-4799-6821-3, DOI:10.1109/ISFEE.2014.7050586 [302]. Nr. citări IEEE: 3.

C16: R.M. Aileni, C. Valderrama, S. Pasca and R. Strungaru, Skin conductance analyzing in function of the bio-signals monitored by biomedical sensors, in 2016 International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-4, 2016, WOS:000392434400095, ISBN:978-1-4673-9575-5, DOI:10.1109/ISFEE.2016.7803243 [132]. Nr. citări IEEE: 2.

10.4 Future perspectives

The scientific research in this thesis has focused on investigating the possibilities of integrating electronic components into textile supports or making textile sensors or electrodes by mechanical processes. In the future, the textile electrodes must be improved using other conductive micro/nanoparticle deposition techniques such as screen printing, lamination or 3D printing (Stereolithography (SLA) or Fused Deposition Modeling (FDM)) directly on the conductive textile support. Another direction of research that derives from current research consists of using conductive and insulating textiles to make flexible graphene-based batteries or capacitors for energy storage. Also, should be developed electrodes to monitor the electrical signals emitted by the brain and improve the size of the ECG electrodes to investigate the possible effect on the quality of the biomedical signal purchased. Regarding the use of predictive analytics based on artificial intelligence algorithms, the data used in this thesis have been previously stored in a database. In addition, the possibility of predictive analysis can be explored based on real-time biomedical data for intelligent support systems.

References

[3] **R. M. Aileni**, L. Dinca, S. Pasca, S. and R. Strungaru, *Flexible material for wearable ECG electrodes*, University Politehnica of Bucharest Scientific Bulletin Series C-Electrical Engineering and Computer Science, 79(2), pp.127-132, 2017.

[4] *Sisteme cu inteligenta artificiala*, iota.ee.tuiasi.ro/~mgavril

[5] *Intelligent system*, online available: whatis.techtarget.com/definition/intelligent-system

[6] S. Yang, F. Zhu, X.Ling, Q. Liu and P. Zhao, *Intelligent Health Care: Applications of Deep Learning in Computational Medicine*, Frontiers in Genetics, 12, p. 444, 2021.

[7] S. Basu, M. Ghosh and S. B. Mandal, *Intelligent remote health monitoring system*, International Journal of Information Technology, Communications and Convergence, 3(4), pp.259-275, 2020.

[8] L. Vadillo, M. L. Martín-Ruiz and M. A. Valero, *Deployment of a Smart Telecare System to Carry out an Intelligent Health Monitoring at Home*, 2016.

[23] **R. M. Aileni**, A. Iftene, *Software application for health state monitoring and data modeling for health risk factor evaluation, based on wearable sensors and observer patterns for sensors data tracking*, The 9th International Conference on Virtual Learning (ICVL), Bucharest, Romania, 2014.

[24] www.siemens-healthineers.com/perspectives/humanizing-medtech

[25] **R. M. Aileni,** S. Pasca and C. V. Sukuyama, *Wearable health care: Technology evolution, algorithms and needs*, Book Enhanced Living Environments: From Models to Technologies, pp. 315-343, 2017.

[76] **R.M. Aileni**, G. Suciu, V. Suciu, S. Pasca, S. and R. Strungaru, *Health monitoring using wearable technologies and cognitive radio for IoT*, Cognitive Radio, Mobile Communications and Wireless Networks, pp. 143-165. Springer, Cham, 2019.

[101] **R.M. Aileni**, A.C. Valderrama and R. Strungaru, *Wearable electronics for elderly health monitoring and active living*, Ambient Assisted Living and Enhanced Living Environments, Butterworth-Heinemann, pp. 247-269, 2017.

[141] **R.M. Aileni**, S. Pasca, R. Strungaru and C. Valderrama, *Biomedical signal acquisition for respiration monitoring by flexible analog wearable sensors*, E-Health and Bioengineering Conference (EHB), IEEE, pp. 81-84, June 2017.

[132] **R.M. Aileni**, C. Valderrama, S. Pasca and R. Strungaru, *Skin conductance analyzing in function of the bio-signals monitored by biomedical sensors*, International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-4, 2016.

[143] **R.M. Aileni**, S. Pasca, C. Valderrama, *Biomedical sensors data fusion algorithm for enhancing the efficiency of fault-tolerant systems in case of wearable electronics device*, ROLCG Conference Proceedings, Cluj-Napoca, 2015.

[155] **R. M. Aileni**, S. Pasca, R. Strungaru and C. Valderrama, *Biomedical signal acquisition for respiration monitoring by flexible analog wearable sensors*, E-Health and Bioengineering Conference (EHB), IEEE, pp. 81-84, June 2017.

[156] **R. M. Aileni**, L. Dinca, S. Pasca and R. Strungaru, *Flexible structures with electro-conductive properties for wearable electronic devices*, International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-5, June 2016.

[157] **R. M. Aileni** and L. Dinca, *Optimization of the electro-conductive yarns distribution in flexible wearable dielectric structures*, in 2015 9th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 539-542, May 2015.

[212] **R. M. Aileni,** S. Pasca and R. Strungaru, *Wearable platform for cardiac rhythm monitoring and signal processing*, 9th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. 1-4. June 2017.

[215] NS-running-woman ECG vs PPG, for Heart Rate Monitoring: Which is Best?, www.neurosky.com/2015/01

[245] **R.M. Aileni**, S. Pasca and R. Strungaru, *Heart rate monitoring by using non-invasive wearable sensor*, E-Health and Bioengineering Conference (EHB), IEEE, pp. 587-590, June 2017.

[247] **R.M. Aileni**, S. Pasca, A. Florescu, *E-health monitoring by smart pulse oximeter systems integrated in SDU*, 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 1-4, March 2019.

[259] **R.M. Aileni**, S. Pasca and A. Florescu, *EEG-brain activity monitoring and predictive analysis of signals using artificial neural networks*, Sensors, 20(12), p. 3346, 2020.

[263] **R.M. Aileni**, S. Pasca, F. Florescu, Epileptic seizure classification based on supervised learning models, 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, pp. 1-4, March 2019.

[264] **R.M. Aileni**, B. Hurezeanu and S. Pasca, *Wavelet transform for seizures detection in EEG Records*, 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. 1-6, June 2018.

[287] **R.M. Aileni**, S. Pasca and C. Valderrama, *Cloud computing for big data from biomedical sensors monitoring, storage and analyze*, conference grid, Cloud & High Performance Computing in science (ROLCG), IEEE, pp. 1-4, October 2015.

[295] **R.M. Aileni**, G. Suciu, C.A.V. Sukuyama and S. Pasca, *Internet of Things and Communication Technology Synergy for Remote Services in Healthcare*, IoT and ICT for Healthcare Applications, Springer, Cham, pp. 59-82, 2020.

[299] **R.M. Aileni** and L. Surdu, *Obtaining the optimal surface for electronic device deposition using nanotechnologies*, International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-4, November 2014.

[300] **R.M. Aileni** and L. Dinca, *Electroconductive materials with high potential for wearable electronic devices integration*, 7th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), IEEE, pp. Y-5, June 2015.

[302] **R.M. Aileni**, P. Bruniaux and R. Strungaru, R., *Wearable sensors modeling for healthcare*, International Symposium on Fundamentals of Electrical Engineering (ISFEE), IEEE, pp. 1-4, November 2014.

[303] **R.M. Aileni**, *Healthcare Predictive Model Based on Big Data Fusion from Biomedical Sensors*. in Conference proceedings of eLearning and Software for Education (eLSE)," Carol I" National Defence University Publishing House, No. 01, pp. 328-333, 2016.

[305] **R.M. Aileni**, S. Pasca and G. Suciu, *MIoT applications for wearable technologies used for health monitoring*, 10th international conference on electronics, computers and artificial intelligence (ECAI), IEEE, pp. 1-4, June 2018.

[309] **R.M. Aileni**, G. Suciu, C.M. Balaceanu, C.M., Beceanu, C., Lavinia, P.A., Nadrag, C.V., Pasca, S., Sakuyama, C.A.V. and Vulpe, A., *Body area network (BAN) for healthcare by wireless mesh network (WMN)*, Body Area Network Challenges and Solutions, Springer, Cham., pp. 1-17, 2019.

[310] **R.M. Aileni**, G. Suciu, V. Suciu, J. Ciurea and S. Pasca, *Assistive Mobile Technologies for Health Monitoring and Brain–Computer Interface for Patients with Motor Impairments*, Mobile Solutions and Their Usefulness in Everyday Life, Springer, Cham., pp. 209-224, 2019.

[312] **R.M. Aileni**, G. George, S. Pasca and C.A. Valderrama, *Data fusion-based ai algorithms in the context of iiots*, Internet of Things for Industry 4.0, Springer, Cham., pp. 17-38, 2020.

[316] **R.M. Aileni**, G. Suciu, C. Valderrama and S. Pasca, *IoT Performability for Medical Wearable Device by Data Privacy and Fault Tolerance*, Smart Systems for E-Health, Springer Charm., pp. 113-133, 2021.

[317] **R.M. Aileni**, G. Suciu, G., M. Rajagopal, S. Pasca and C.A.V. Sukuyama, *Data Privacy and Security for IoMWT (Internet of Medical Wearable Things) Cloud*, IoT and ICT for Healthcare Applications, Springer, Cham, pp.191-215, 2020.

[318] **R.M. Aileni**, G. Suciu, C.A. Valderrama Sukuyama, S. Pasca and R. Maheswar, R., *Cybersecurity technologies for the internet of medical wearable devices (iomwd),* Advances in Cyber Security Analytics and Decision Systems, Springer, Cham, pp. 117-140, 2020.

[322] **R.M. Aileni** and G. Suciu, *IoMT: A blockchain perspective*, Decentralised Internet of Things, Springer, Cham., pp. 199-215, 2020.