Wireless Personal Communications (2021) 120:1207–1227
https://doi.org/10.1007/s11277-021-08511-2

A Real-time Posture Monitoring System Towards Bad Posture Detection

Ferdews Tlili[1] · Rim Haddad[2] · Ridha Bouallegue[1] · Neila Mezghani[3]

Accepted: 13 April 2021 / Published online: 4 May 2021

Abstract

The neck and back pains are the most spread health problems of the century caused by remaining slouching for long hours on the smart phones, the tablets and the computers. Many medical researches prove that the monitoring and the improving of the seating posture can prevent the spinal pains. In this paper we propose a Real-time seating posture monitoring system. The system is composed of a smart belt equipped with inertial sensors. The sensors collect the posture information and send them to a cloud server via Wi-Fi connection. The cloud server processes the collected data, then, sends the result to mobile applications via Wi-Fi connection. The mobile applications allow the user to monitor his posture over time and receive in Real-time a sound and a visual notification in case of a bad posture detection. Two mobile applications Android and iOS are implemented that can be used for different mobile phone OS. In this work we will detail the design and the architecture of the proposed posture monitoring system and the implemented mobile applications. We will present the posture measurements of good and bad posture using the proposed posture monitoring system.

Keywords Posture monitoring · Real time system · Sensors · Mobile application

✉ Ferdews Tlili
ferdews.tlili@supcom.tn

Rim Haddad
rim.haddad@eti.ulaval.ca

Ridha Bouallegue
ridha.bouallegue@supcom.tn

Neila Mezghani
neila.mezghani@teluq.ca

[1] Laboratoire Innov'Com, Ecole Suprieure des communications de Tunis, Université de Carthage, Ariana 2083, Tunisia

[2] Université Laval, Québec, Canada

[3] Laboratoire de recherche en imagerie et orthopédie, TELUQ university, Montreal, Qc, Canada

1 Introduction

The low back pain is the extremely common symptom of spinal problems. The back problems are experienced by people at any age during their life. The low back pain affects up 23% worldwide population according to the study in [1]. These back problems appear mostly to women than men in mid-life. Thus, with the spread of use of mobile technologies by young people in daily life the spinal problems become common pain for teenager and young people. Remain slouching for long hours on the smart phone, tablet or computer is the most common cause of back pain as demonstrated in medical research [2]. Looking to your phone with bad posture is like placing weights on your neck that stress the vertebrae [3].

The spinal therapy is among the most expensive therapy in the world. The UK estimated about £12.3bn a year for spine therapy, with £1.6bn spent on treatment for low back pain. In addition, the low back pain is the main cause of disability worldwide. In UK, the number of people lives with disability caused by low back pain rise by 54% during the last 25 years. The low back pain patient can lose many working days during the year because of the disability caused by the pain. In 2016, the UK lost 31 men workdays caused by the musculoskeletal including back pain. Many medical researches demonstrate that the treatment of the back problems with drugs or surgery therapy can lead to health complications, affect the quality of life and risk of falls or accidental overdose [4].

Many systems are proposed in literature to deal with the back problems due to the technology development in 21th century. These systems can be classified in two main categories: systems based on visual information using cameras and systems based on sensing information using different types of sensors.

The systems based on visual information are widely used in different applications of activity recognitions [5]. These systems are composed of cameras that record the subject image for different positions. Then an analyzer algorithm is used to compare the detected image with the image of straight position in order to define the bad posture and warn the subject using feedback systems [6]. These systems are efficient to detect the bad posture with high accuracy, but they are damaging to the user privacy. And they are expensive to implement because of the high cost of cameras used.

The second category based on sensing information is widely studied by researchers for medical applications due to the tiny size and the variety of information provided by sensors [7, 8]. The sensors are characterized by the small size that can be easy implemented in different platforms (garment, chair, clothes...). In addition, the sensors can provide different types of information such as acceleration, orientation, deviation angle and physiological information. These information can be useful to define the person posture and monitor the subject sitting behavior over time. Using the sensors for posture monitoring systems can save the subject privacy and money compared to the cameras based posture monitoring systems.

In this work we propose a Real-time posture monitoring system for sitting people. This system detects the subject posture and sends a message via a mobile application to the person in case of bad posture. In fact, the system collects data from sensors placed on the smart belt. Then, the data will be sent to a cloud server via Wi-Fi connection. The cloud server processes the existing data and sends them to the mobile phone via Wi-Fi connection. Android and iOS applications are developed for an accurate monitoring of the sitting person posture.

This paper is composed of three sections. In section II, we survey the existing researches related to the posture monitoring. In section III, we detail the design of the proposed posture monitoring system. In section IV, we present the proposed system implementation and the experimental results. In section V, we conclude the paper and we present the future work.

2 Related Works

2.1 Existing Posture Monitoring Systems

In literature, the posture monitoring systems are deeply studied in the recent years. In [9], an overview about the existing posture monitoring system is detailed. The posture monitoring systems are classified according to the sensing technologies used for the system implementation.

The posture monitoring systems based on force sensors are proposed in [10, 11]. The proposed systems are composed of flexible force sensors stretched in the seat and the backrest of the chair. The systems define the sitting positions according to the pressure measurements classification of the sitting positions. In some cases, the machine learning algorithm is applied for the sitting classification and bad posture detection. In addition, the load based posture monitoring systems consist of load sensors implemented in the seat and the backrest of the chair. The sitting posture is classified according to the body load based on a machine learning algorithm as detailed in [12]. The posture monitoring systems based on the force and load sensors are depending on the implementation platform. These systems are not portable and cannot be used anywhere.

The flex sensors are integrated in the some proposed posture monitoring systems. In fact, Manju et al. [13] present a posture monitoring system based on flex sensor and load cell. The flex sensor is stretched to the user spine in order to monitor the body bend. The load cell is placed in the stand platform of the user. The load cell detect the load stress on the body according to the posture change good and bad posture. The threshold limits of the good posture are personalized and identified by the users. The Drawbacks of this system is depending on the platform where the load cell is placed. And the flex sensor is limited to the spine shape and does not give precise information about the trunk flexion.

In [14], the authors propose a posture monitoring system using inductive textile sensors. The sensors are integrated in the garment in order to monitor the trunk bent based on the inductive variation during the body flexion. The proposed system introduces a new design of the inductive sensor in an elastic pattern that improves the sensor measurements and resolution. The experimental results show encouraging results for tracking the forward trunk bent. However, the lateral bent and spine rotation cannot be monitored by the current system design. In addition, the inductive sensors are unable to detect the small body bent.

Sangyong et al. [15] introduce a posture monitoring system using one 3 axis accelerometer. The inertial sensor is placed on the subject's neck in order to define the spine shape. Two classification methods are proposed for posture classification: Support vector machine (SVM) and K-means clustering. Experimental results demonstrate the advantages of using SVM method for sitting posture recognition compared to K-means clustering. In [16], Eugene et al. detail the architecture of a posture monitoring system based on inertial sensor. The system is proposed in order to improve the sitting behavior for the ophthalmologists in their working environment. An inertial measurement unit (IMU) sensor is used for measuring the trunk flexion. The IMU sensor is composed of accelerometer, gyroscope and magnetometer. The XBee wireless technology is proposed to ensure the wireless communication between the system's components. The posture monitoring systems based on the inertial sensors introduce a great advantage for the trunk deviation angle measurement and posture recognition. In addition, these systems are characterized by a portable architecture due to the inertial sensor's characteristics. However, we notice that there is a lack of the studying the optimum positions of sensors for the posture monitoring systems based on the inertial sensors and the introducing of the feedback unit for bad posture.

2.2 Wearable Devices for Posture Detection

Many back problems like kyphosis, musculoskeletal injury, neck and low back pain require assessment of the patient for many hours to correct their posture behavior and acquire good sitting modality during daily life [17]. The rehabilitation courses last for many hours to train the subject to detect bad posture and to correct it.

During the physiotherapy sessions the spine posture is monitored. The radiographic method is the method to analyze and monitor the spine shape in a clinical setting. This traditional method for monitor spine shape has many limitations. It is not practical and unhealthy to integrate this method in daily life to monitor the subject posture because of the high cost and the worst impact of the radiation broadcasted by these systems on the subject health [18].

In addition, with the electronic devices evolution during this century, the sensing technologies have known a spread of applications in different domains especially in medical applications. These devices are characterized by their tiny size and portability aspect. Recently many textile studies are focusing on the possibility of integration of sensors in the garment and defining specific yarns that ensure the connectivity and the communication between the different components of textile integrated electronic devices [19, 20].

This shows the need and the importance of the studies to define and implement wearable systems for posture monitoring [21]. In fact, the wearable system characteristics can help patients to self-monitoring their posture. These systems can offer to the subject the possibility to daily survey his posture and correct the bad postures in real time. In addition, these systems facilitate the implementation of patient monitoring remotely in order to assess patient for rehabilitation or disease monitoring that can save patient time and money.

2.3 Data Needed for Posture Monitoring Systems

In the recent years, many sensing technologies are developed to provide physical body information that can be useful for the posture monitoring systems implementation. In fact, the main information needed for posture monitoring is the angle flexion of the trunk. The sensors types applicable for the posture monitoring systems are the pressure sensors, the flexion sensors, optical sensors, inductor sensors and inertial sensors.

The pressure sensors are designed to provide the load information for many systems use. In [22], Ahmed et al. detail the different sensing methods of pressure sensing and the sensors design and technology. The pressure sensors indicate complete information about the body load according to the body movement. The load sensors are applied for body posture information by defining the bad posture according to the spine applied stress. The proposed method in [12] consists of the placement of four sensors onto the seat of the chair to classify sitting postures. The main limitation of this approach is the dependence on environmental variables. In

[13], the pressure sensors are placed under the legs of a chair in order to collect load information. The main drawback is that the posture monitoring system based on pressure sensors are not portable and depending on the environment and the platform implementation.

The flex sensors provide the resistance variation according to the body movement. The information collected by the sensors defines the body bent. Giovanni et al. [23] present the characteristics of the flex sensor and the ability to define the trunk shape for posture monitoring. The flex sensors are considered as wearable devices for the posture monitoring system as inserted in the clothes [24]. However the flex sensors are not able to detect the small bent that can damage to the flexion trunk accuracy.

The optical sensors are known many application fields due to the evolution of this sensor type architecture. In recent years, the optical sensors are applied in different fields: industry, military, social, atmospheric, healthcare, etc [25]. The information provided by the sensor consists of the amount of light detected between source and sensor. The variation of the measured light can define the shape of the objects. In fact, stretch the optical sensor on the shirt can detect the trunk shape and variation [26]. The main limit of the optical sensors is the accuracy of measurements depending on the sensor position. Otherwise the sensor must be stretch on the trunk length that made the sensor placement difficult to be maintained in the same position.

The inductor sensors are based on the oscillation variation in order to define the shape variation. The inductor sensors have many applications in position, speed and shape measurement [27]. The inductor sensors are applied on the posture monitoring system as it can define the shape of the trunk. The drawback of the inductor sensors are not the uncertainty of results due to the voltage output of the system and the deformation of the T-shirt which have a direct correspondence with the evaluation data [28].

In the recent years, the inertial sensors are known evolution due to the industrial development. The inertial sensors introduce wearable characteristics, low cost and accuracy properties [29]. In addition, the recent researches develop the inertial sensors characteristics in order to get complete information. The inertial measurement unit (IMU) correlates three technologies: accelerometer, gyroscope and magnetometer. The combination of these technologies provides information about acceleration, angular velocity and magnetic field. In addition, the IMU introduce the speed and the flexion of the object on which the sensors are implemented. Many healthcare and industrial application are based on the inertial sensors due to the characteristics and the information provided [30]. Recently, three axes IMU sensors are implemented in order to improve the degree of sensor freedom and the sensor accuracy. Compared to the other sensing technologies, the inertial sensors introduce great characteristics to be used for posture monitoring as it is simple to implement on the garment, improvement made for the accuracy and angle flexion precision provided by this technology.

In this paper, we present a new posture monitoring system. We will detail the global design of the system. Then, we will argument the sensors position and the used technology for system implementation. And we will present the main results to warn the subject in case of bad posture detection.

3 System Design

3.1 Global System Architecture

The global architecture of the proposed posture monitoring system consists of the smart belt equipped by the sensors, cloud database to storage the collected information and Mobile applications for monitoring the posture variation and sending notification is case of bad posture detection as presented in Fig. 1. In addition, the wifi connection ensures the communication and data exchanges between the different system parts .

The proposed system components can be classified on three main units: sensing unit, storage unit and feedback unit as presented in Fig. 2. The sensing unit is the system part to measure the information needed for posture defining. This unit is composed of the sensors and the microcontroller. The inertial sensors are used for the proposed system implementation. According to a literature study, the inertial sensors are the best wearable devices to measure the spine curvature. The inertial sensors are portable and characterized by their tiny size that makes them easy to be integrated on the garment. Moreover, they are sensitive enough to measure the trunk flexion according to each axes (x, y and z). The microcontroller collects the signal measurements from the sensors, converts them and sends them to the cloud server via Wi-Fi connection. The microcontroller is composed of 2 main interfaces: bus interfaces to communicate with sensors and wireless interface to send data to the cloud server. The microcontroller transmits data from the sensors to the data storage unit. The storage unit is composed of the cloud data base. The Database stores the information collected from sensors. The collected data are structured, saved and updated in real time according to users' profiles. The Database is hosted in cloud server that allows a Real-time

Fig. 1 Global system architecture

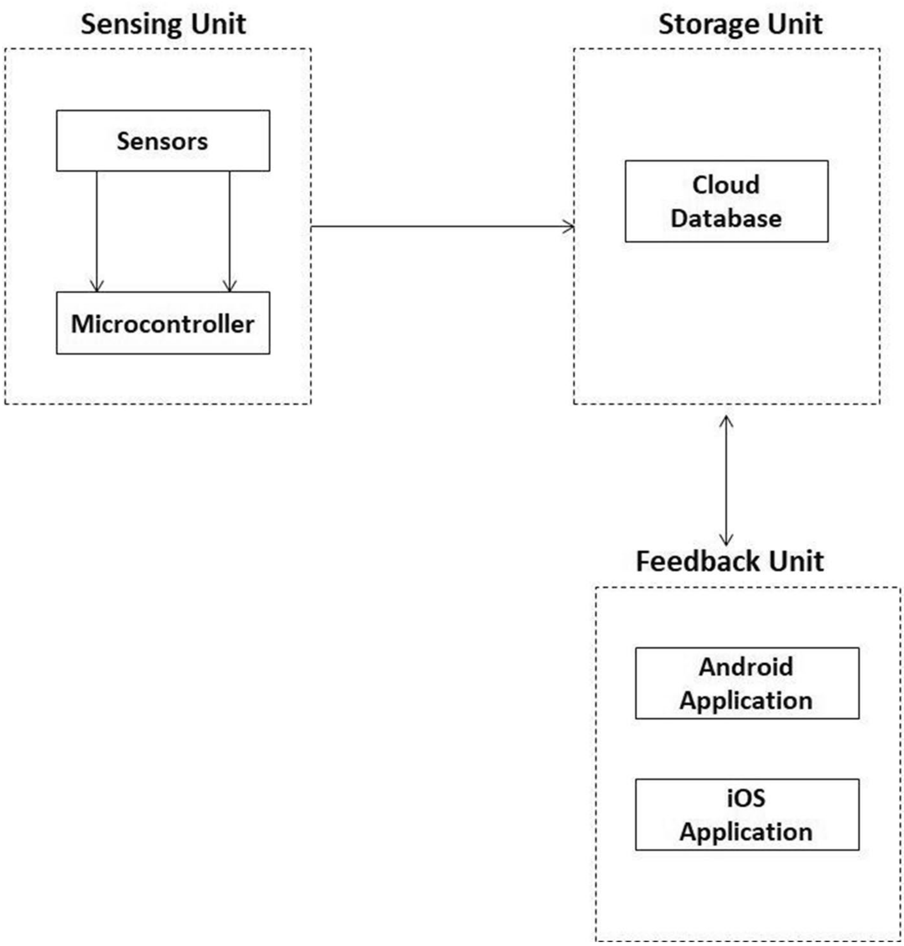

Fig. 2 Block diagram of the proposed posture monitoring system

and multiple access at the same time to the data stored. The feedback unit is the system part that allows the user to monitor his posture variation and receive warning in case of bad posture detection. This unit is rarely defined in the existing studies of posture monitoring systems. And it is mainly defined by vibrating sensors or a mobile application. With the spread of use of portable devices phones tablets, the mobile applications are the best way to monitor the person posture in real time. For the proposed posture monitoring system, two mobile applications Android and iOS are developed to monitor the posture variation. The user monitors the posture variation via real time graph presenting the angle flexion variation and receives a visual and sound notification in case of bad posture detection .

The smart belt follows several steps to monitor the sitting person posture as shown in Fig. 3. The first step is the data collection. The inertial sensors stretched on the belt measure the signals according to each axes (x, y and z) and send them to the microcontroller. The microcontroller converts the received signal from the sensors to analogical signal. It calculates the tilt angle using the program implemented in the processor and fulfills the file. Then the microcontroller sends the data to the cloud Database via the Wi-Fi

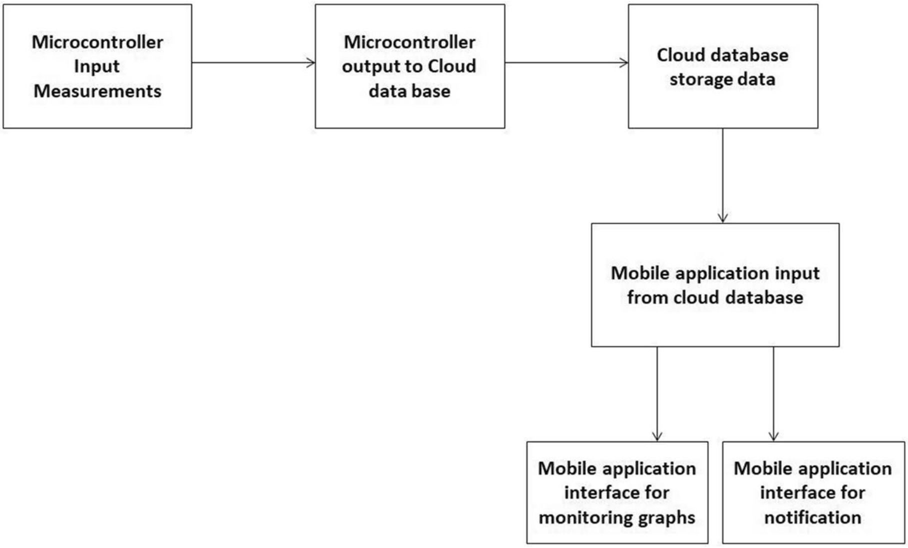

Fig. 3 Full functional diagram of the proposed posture monitoring system

connection. The next step is to storage the collected data. The collected data are stored in cloud Database in order to facilitate the data access for the multi-user application. The data are structured in profile for each user account. Each profile contains the user information of authentication and the angle measurements according to the different axes. The posture data are registered with time consideration for each sensor. The last steps are the posture monitoring via the mobile applications. The user creates account to monitor his posture. The mobile applications read data stored in the cloud Database and update in Real-time the user graph of the angle trunk flexion. In case of bad posture, visual and sound notifications are sent via mobile application in order to help the user to correct his posture.

3.2 Mobile Application Design

With the huge use of the smart phones, introducing a mobile application in posture monitoring system is a great way for the user to monitor in real time the posture variation and receive warning for bad posture detection. The developed mobile application provides the current posture information for the user and warn him in case of bad posture detection via visual and sound alert. The architecture of the mobile application is composed of four main interfaces. The first interface is for creating an account and inserting the user information. The second interface is the authentication interface. Based on the information stored in the cloud system, the mobile application provides interfaces for posture monitoring containing a real time monitoring graph of the trunk flexion measurements and interface for warning the user and advise him to improve his posture in case of bad posture detection. The mobile application flowchart is detailed in Fig. 4.

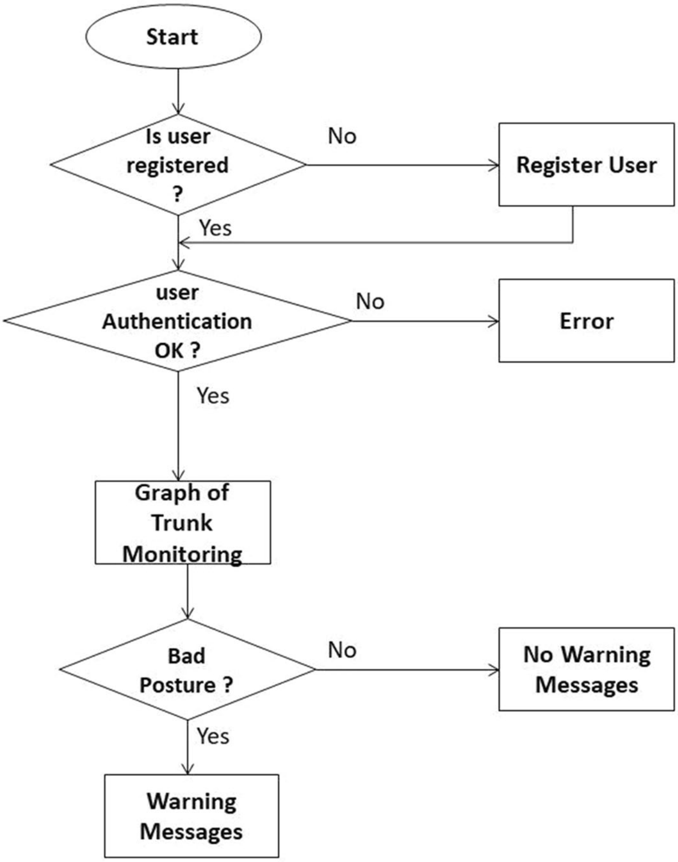

Fig. 4 Mobile application flowchart

3.3 Sensors Location

The main components of this system are the sensors. The role of the sensors is to measure the posture of the user and to provide Real-time posture information. As detailed in the previous section, the position of sensors in the system platform remains an important subject to treat in the study of the posture monitoring system. In fact, the number and the accuracy of defined postures by the proposed posture monitoring system are mainly depending on the sensors position. So many studies and tests are performed for the proposed system in order to define the optimum number of sensors to be used and the best location of sensors. The object of our study is to define the best posture monitoring system compared to the existing systems. The most important characteristics for a posture monitoring system are to define a maximum posture status with the minimum sensors used. For our system, initially, we proposed to use three inertial sensors: two sensors on the shoulders and one sensor on the upper back. After testing we find that only one sensor placed on one shoulder gives complete information about the shoulder's orientation. So, the proposed system is composed of two inertial sensors as shown in Fig. 5: one sensor on the shoulder and one sensor on the upper back.

Fig. 5 Sensors location on the Belt

The proposed system is able to define more spine postures compared to the existing posture monitoring systems [31, 32] with minimum number of sensors used. In fact, our posture monitoring system defines four spine bents according to the vertical and horizontal axes: the bent of the spine on the forward, on the backward, on the left and on the right. In addition, the proposed system provides the shoulder orientation due to the sensor placed on the one shoulder. This information is important to detect additional uncomfortable posture of the sitting person. The sensors locations chosen are the optimum position to define the maximum spine postures. The inertial sensor placed on the upper back detects the back bent on the forward, on the backward, on the left and on the right. The inertial sensor placed on the shoulder defines the shoulders orientation of the person.

3.4 Posture Information

The posture monitoring system is based on the sensor measurements to define the posture information. The proposed posture monitoring system is composed of inertial sensors that provide the tilt angle of the body.

An inertial sensor is composed of two or three sensors types. It could be an accelerometer, gyroscope and magnetometer or accelerometer and gyroscope. The 3-axis accelerometer measures the acceleration of the movement object according to the three axes (x, y and z). The accelerometer provides the linear acceleration of the object. The gyroscope measures the angular velocity. The angular velocity is the rotation rate of the device according to axis defined in a local coordinate system. The magnetometer senses the Earth‘s magnetic field. The magnetometer is sensitive to each magnetic field around. It is influenced by each magnetized object placed close to the sensor that can affect the magnetometer measurements [33].

The magnetometer measurements are influenced by each magnetic field around the sensor that can erroneous the system measurements. In addition the accelerometer and gyroscope measurements can define the inclination of the object according to different axes. In this case the inertial sensor composed of accelerometer and gyroscope is sufficient for the proposed posture monitoring system need.

The accelerometer measures the linear acceleration. The accelerometer does not differentiate between acceleration and gravity. In fact, the accelerometer measures the component of the force of gravity along 3 axes: the x-axis, the y-axis (oriented along the horizontal) and z-axis (oriented perpendicular to the horizontal).

The inclination angles of the accelerometer according to different axis (x, y and z) are defined on the accelerometer measurement along 3 axis as shown in Fig. 6.

The Fig. 6 demonstrates a reference position of accelerometer and three inclination angles according 3 axis (x, y and z).

The reference position Fig. 6a is defined as the x-axis and y-axis of the sensor oriented according to the horizontal and the z-axis of the sensor is orthogonal to the horizontal and parallel to the gravity vector g. The angle in Fig. 6b is the inclination angle between the horizontal and x-axis of the accelerometer. The angle in Fig. 6c is the inclination angle between the horizontal and the y-axis of the accelerometer. The angle in Fig. 6d is the inclination angle between the gravity vector and the z-axis of the accelerometer [34].

The different angles can be defined using a basic trigonometric method presented as follows:

$$\theta = arctg(A_x / sqrt(A_y^2 + A_z^2)) \tag{1}$$

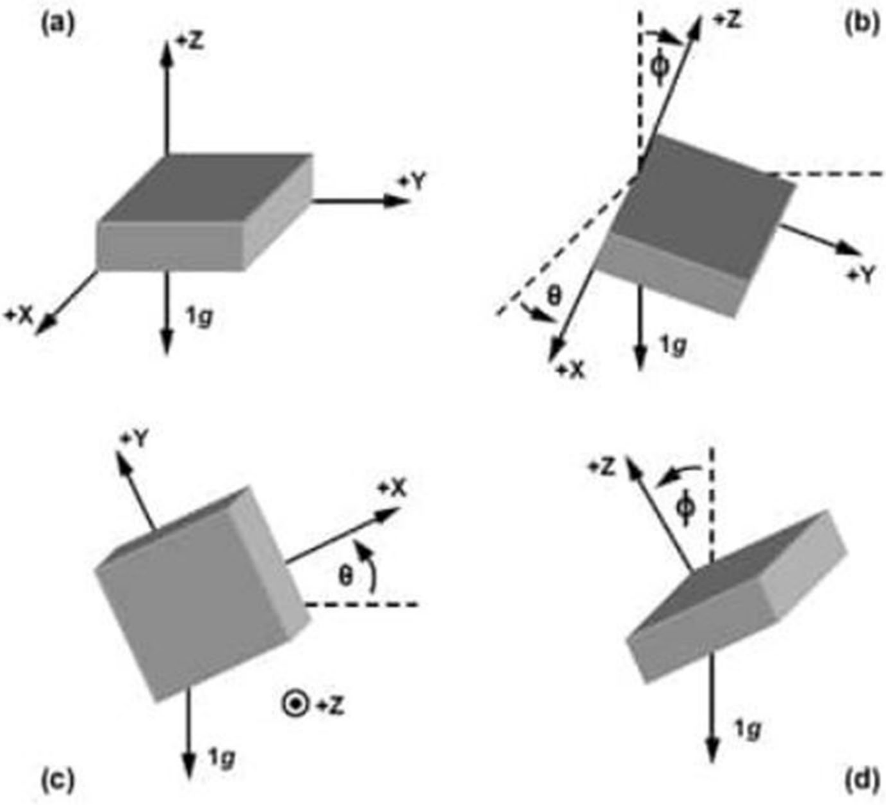

Fig. 6 Accelerometer reference position and inclination angles according three axis [34]

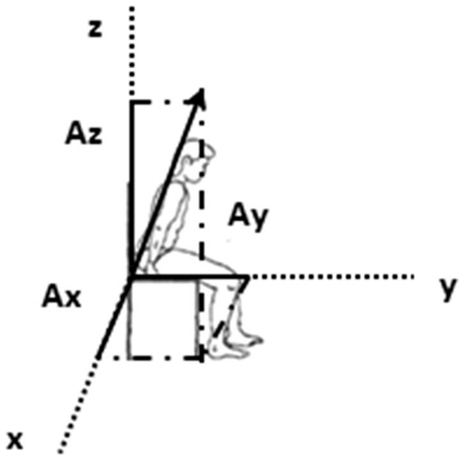

Fig. 7 Acceleration projection according the axis (X, Y and Z)

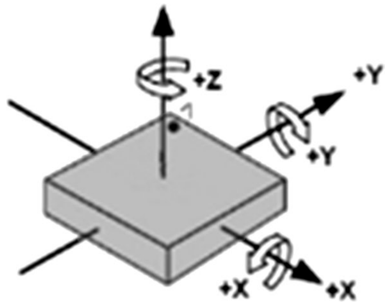

Fig. 8 Gyroscope rotation measurement

$$\Psi = arctg(A_y / sqrt(A_x^2 + A_z^2)) \tag{2}$$

$$\phi = arctg(sqrt(A_x^2 + A_y^2) / A_z) \tag{3}$$

A_x, A_y and A_z are the acceleration measurements according the three axis (X, Y and Z) as shown in Fig. 7.

The gyroscope measures the rotation around an axis. The 3-axis gyroscope defines the rotation measurements around X, Y and Z axis as shown in Fig. 8.

The tilt angle is defined by multiple the angular velocity with time as the following equation [33]:

$$\theta_n = \theta_n - 1 + \omega \partial t \tag{4}$$

ω : the angular velocity, θ : angle resulting

The accelerometer and gyroscope measurements are merged in order to have the advantages of the two devices properties. The technique called complementary filter [33] is used to combine the accelerometer and gyroscope measurements. The technique is based on having complementary value from the gyroscope and accelerometer values using constant weight α as following [33]:

$$\theta_n = \alpha(\theta_n - 1 + \omega\partial t) + (1.0 - \alpha)Angle\_accel \quad (5)$$

The common value of α is 0.98 as defined in [33].

Angle_accel: is the inclination angle calculated using the accelerometer measurement along one of axis as defined previously.

4 System Implementation

4.1 Hardware and Software Choice

The main object of our smart belt is to measure the posture bent of the sitting persons and to warn them in case of bad posture. In order to implement the proposed system, many choice of platform, hardware components, software tools and parameters are made.

4.1.1 Hardware Choice

The belt chosen for our system is an orthopedic belt. It is easy to wear. And it covers the main parts of the back: the shoulders, the center of the back and the low back as shown in the Fig. 9. So it is comfortable for users and suitable to place the sensors as defined in previous section.

The inertial sensor used to implement our posture monitoring system is the MPU6050 sensor. The MPU6050 sensor is suitable to our system specification. It is composed of 3-axis gyroscope, a 3-axis accelerometer. The 3-axis gyroscope is equipped with Micro Electro Mechanical System (MEMS) technology. It is useful to detect the rotation speed along the X, Y, Z axes. The 3-axis accelerometer is equipped with Micro Electro Mechanical technology (MEM). It measures the tilt angle along the X, Y and Z axes. The accelerometer and gyroscope are correlated in the same compact packet. The MPU6050 is used for our implementation because it is equipped with the latest sensing technologies to provide accurate measurements as needed for our system. It has lower cost. It is available in the market. And the MPU6050 sensors are simple to be integrated in the belt due to their tiny size 4 mm x 4 mm x 0.9 mm [35].

The Raspberry Pi-3 Model B microcontroller is used in the proposed system. The Raspberry Pi is a single board computer with ARM processor. This device with the credit

Fig. 9 Orthopedic back belt

card size allows the running of several variants of the free GNU / Linux operating system, including Debian, and compatible software. It also works with the Microsoft Windows OS: Windows 10 IoT Core3, the one of Google and AndroidPi4. The choice of this type of microcontroller is mainly because the ease of use and implementation. In fact, the Raspberry Pi-3 Model B microcontroller can be adapted to different applications, different OS and used platform [36].

4.1.2 Software Choice

Two mobile applications are developed Android and iOS applications for the proposed posture monitoring system. Nowadays the Android is the most used operating system for smart phones and tablets compared to the iOS. Our Android mobile application is developed using Android Studio platform. The Android Studio is the best tool to develop an Android application due to its power, simplicity and free. It allows the creation of compatible applications with different smart phones and tablets using the different integrated library [37].

A second mobile application is developed for our posture monitoring system. The second mobile application is compatible with iOS operating system devices. Thunkable plateform is used to develop our second mobile application to monitor the sitting person posture. This platform allows the development of iOS and Android application. It is simple and free [38].

The reliability of the mobile applications is related to the manner of structuring and storing data used. In fact, for our developed mobile applications, we used the cloud storage and Real-time database to ensure the efficient operating of the proposed system. We used Firebase as a platform to implement our cloud database. Firebase platform includes many features such as Real-time database, cloud functions and analysis tools. It ensures the structure of the data collected from different sensors and the multi-user access of the database [39].

4.1.3 Parameters Choice

The proposed system is based on two main parameters to monitor the user posture. The first parameter is the angle degree to consider a bad posture. The slouching degree is equivalent to placing weights on the person neck that apply stress on the cervical spine as defined in [40]. And according to our experience and testing, we choose 30 degree as the bent angle from which we consider that the person posture is bad.

In addition, as the database is refreshed in Real-time with the person bent degree; sending alert in each time that the system detects bad posture can be annoying for the user. For this case we choose to send alert in case bad posture detection when the user maintains the bad posture for more than five minutes. In fact, a warning is sent to the user when his posture is maintained with more than 30 degree for more than 5 minutes.

4.2 System Realization

In this section we detail the proposed posture monitoring system for sitting person realization. We prepare our hardware platform. We stretch the inertial sensor on the belt. We place the microcontroller. We connect it to the sensors using bus of connection. The person can wear the belt easily with the sensors and microcontroller connected as show in the Fig. 10.

Fig. 10 Wearing smart belt

Then we prepare our software environment. We install operator system on the Raspberry Pi card. We develop a Python code that acquires the sensors signal and processess the collected information. The Raspberry Pi sends the parameters as (x, y, z) and a degree of angle to the Firebase via Wi-Fi connection.

The sensor sends the measurement to Raspberry Pi card each 1 second. After 2.5 sec the data base is updated. The Firebase sends notification to the application in 1 sec. So each 5 sec the mobile application is updated with the new posture measurements.

We develop two mobile applications Android and iOS. We develop Android application using Android Studio technology. The user can create an account which can be used for the login to the application, monitor his posture in Real-time and receive alert in case of bad posture as shown in the Fig. 11.

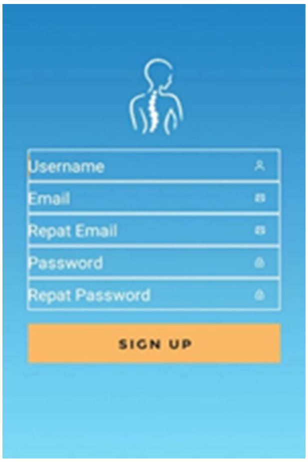

Fig. 11 Registration interface of Android Mobile Application

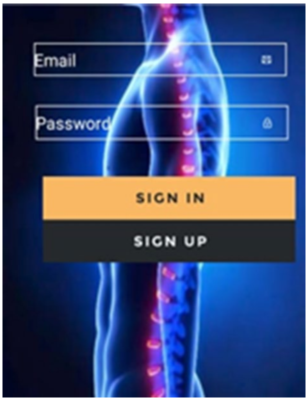

Fig. 12 Login interface of android mobile application

Fig. 13 First interface of iOS mobile application

A login interface is developed for Android mobile Application that the user can login to the application and monitor his posture Fig. 12.

As well, we develop iOS application using Thunkable Technology. The iOS application consists of different interfaces to monitor the person posture. The first interface of the iOS application allows the user to log in to the application or to create his account in case he has not an account as shown in Fig. 13.

The user monitors his posture in Real-time via mobile applications. A graph shows the variation of the bent angle of the sitting person over time as in Fig. 14.

In addition, our system detects the bad posture. As detailed in the previous section, the bad posture is defined when the bent angle of the sitting person exceeds 30 degree and the position is maintained for more than five minutes. In this case, the user receives a beep sound with a written message to warn him about his bad posture as shown in Figs. 15 and 16.

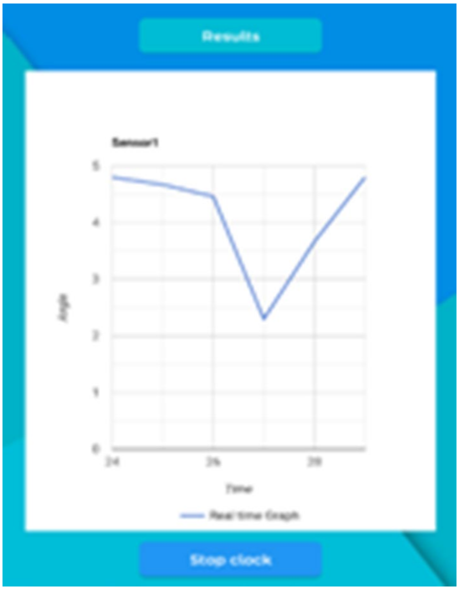

Fig. 14 Bent angle monitoring over time

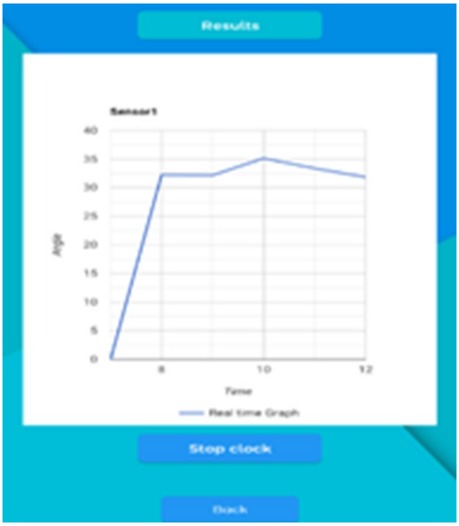

Fig. 15 Bad posture tracking

4.3 Conclusion

In this paper, we detailed the design and the architecture of the proposed smart belt for posture monitoring of sitting persons. The proposal consists of a belt equipped with inertial sensors and mobile applications developed in order to monitor the posture over time and send a visual and sound alert in case of bad posture detection in real time. The results of our preliminary tests demonstrate the efficiency of the system to survey the posture over time and detect the bad posture in real time. In future work, we expect to study and improve the accuracy and reliability of the proposed solution for complex postures using the different

Fig. 16 Bad posture warning

techniques of data classification. In addition, we will study the different aspects of energy consumption optimization and electronic devices integration in the smart garment.

Acknowledgements We would like to thank the Higher School of Communication of Tunis students for their contribution to reach these results. Also we thank the Higher School of Communications of Tunis (SUP'COM) to provide us the equipments used for our system implementation.

Author Contributions Ferdews Tlili studied the literature, designed the system architecture and drafted the manuscript. Rim Haddad participated to the system design and coordinated with the students of the Higher School of Communication of Tunis for system implementation. Ridha Bouallegue supervised all the study steps from design to implementation. All authors read and approved the final manuscript.

Funding This research was funded by the Higher School of Communications of Tunis (SUP'COM).

Data Availability Data sharing not applicable to this article as no datasets were generated or analyzed during the current study. The material used for system implementation are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Financial interests The authors declare they have no financial interests.

Code availability The code is available from the corresponding author upon reasonable request.

References

1. Will, J. S., Bury, D. C., & Miller, J. A. (2018). Mechanical low back pain. *American Family Physician Journal, 98*(7), 421–428.
2. John., J (2018). "What are the most likely causes of upper back pain?", Medical News Today, November .

3. Hansraj, K. (2014). Assessment of stresses in the cervical spine caused by posture and position of the head. *Surgical technology international, 25*(25), 277–279.
4. Ramin, C. J., (2018). "Back pain: how to live with one of the world's biggest health problems The Guardian, June .
5. Sathyanarayana, S., Satzoda, R. K., Sathyanarayana, S., & Thambipillai, S. (2015). Vision-based patient monitoring: A comprehensive review of algorithms and technologies. *Journal of Ambient Intelligence and Humanized Computing, 9,* 225–251.
6. Taieb-Maimon, M., Cwikel, J., Shapira, B., & Orenstein, I., (2011). The effectiveness of a training method using self-modeling webcam photos for reducing musculoskeletal risk among office workers using computers. *Applied ergonomics Journal, 48*, 376–385.
7. Zhang, J. , Zhang, H. , Dong, C., Huang, F., Liu, Q. , & Song, A., (2019). Architecture and design of a wearable robotic system for body posture monitoring, correction, and rehabilitation assist. *International Journal of Social Robotics, 11*, 423–436.
8. Ho, K. , Yao, C., & Lauscher, H. N. (2017). Part2: Health apps, wearable, and sensors: The advancing fraintier of digital health. *BC medical Journal, 58*, 503–506.
9. Tlili, F. , Haddad, R., Ouakrim, Y., Bouallegue, R. , Mezghaniy, N. (2018)"A Survey on sitting posture monitoring systems", International Symposium on Signal, Image, Video and Communications (ISIVC 2018), Rabat, Morocco.
10. Matuska, S., Paralic, M., Hudec, R., (2020)."A smart system for sitting posture detection based on force sensors and mobile application", Hindawi Mobile Information Systems Journal, pp. 13, November .
11. Ishaku, A. A., Tranganidas, A., Matuska, S., Hudec, R., McCutcheon, G., Stankovic, Lina, G, H., (2019). "Flexible force sensors embedded in office chair for monitoring of sitting postures", IEEE International Conference on Flexible and Printable Sensors and Systems (FLEPS), pp. 1-3, July .
12. Roh, J., Park, H. J., Lee, K. J., Hyeong, J., Kim, S., & Lee, B., (2018). Sitting posture monitoring system based on a low-cost load cell using machine learning. *Sensors (Basel), 18*(1).
13. Gopinath, M., & Kirubha, A. (2015). Real time monitoring of posture to improve ergonomics. *Journal of Biomedical Engineering and Medical Imaging, 2*(2), 22.
14. Patiño, Astrid García, Khoshnam, M., Menon, C., (2020). "Wearable device to monitor back movements using an inductive textile sensor", Sensors Journal, February .
15. Ma, S., Cho, W.-H., Quan, C. H, Sangmin, L., (2016). "A sitting posture recognition system based on 3 axis accelerometer", IEEE conference on computational intelligence in bioinformatics and computational biology (CIBCB), pp. 1-3, October .
16. Low, E., Sam, T. H., Tee, K. S., Rahim, R. A., Saim, H. Z., Wan, N. W., et al. (2020). Development of a wireless and ambulatory posture monitoring system. *International Journal of Integrated Engineering, 12,* 170–176.
17. Sankarganesh, A. Jacob, J. K. VPR Siva, (2017). "Managing low back pain: Attitudes and treatment preferences of physical therapists in Chennai", iMedPub Journals, November .
18. Eugene, C.,Lin, M. D. (2010). "Radiation risk from medical imaging", Mayo Clin Proceeding, pp. 1142–1146, December .
19. Gonçalves, C.,Silva Ferreira da, A., Gomes, J. Simoes, R. (2018)."Wearable E-Textile Technologies: A Review on Sensors, Actuators and Control Elements", Inventions Journal, March.
20. Tao, X. Koncar, V. Huang, T. H., Shen, C. L. Ko, Y.C., & Jou, G. T. (2017). How to make reliable, washable, and wearable textronic devices. *Sensors (Basel)*, *17*(4), 673.
21. Simpson, L.,Maharaj, M. M., Mobbs, R. J. (2019). "The role of wearables in spinal posture analysis: A systematic review", BMC Musculoskelet Disord., February .
22. Almassri, A. M., Hasan, W. Z. Wan, A., S. A., Ishak, A. J., Ghazali, A. M., Talib, D. N., Wada, C. (2015). "Pressure sensor: State of the art, design, and application for robotic hand", Journal of Sensors, July .
23. Saggioab, G., Orengo, G., (2018). "Flex sensor characterization against shape and curvature changes," Sensors and Actuators A Physical, pp. 221-231, April .
24. Cheng, J., Zhou, B. , Sundholm, M., Lukowicz, P., (2013). "Smart chair: What can simple pressure sensors under the chairs' legs tell us about user activity?", International Conference on mobile ubiquitous computing, systems, services and technologies (UBICOMM-13), pp. 81-84, January .
25. Sabri, N., Aljunid, S. A., Salim, M. S., Ahmad, R.B., Kamaruddin, R. , (2013). "Toward optical sensors: Review and applications", Journal of Physics Conference Series, April .
26. Dunne, L.E., Walsh, P., Smyth, B., Caulfield, B., (2007). "A system for wearable monitoring of seated posture in computer users," 4th International workshop on wearable and implantable body sensor networks (BSN 2007), pp. 203-207.
27. Howard, M. (2013). The new generation of inductive sensors. *World Pumps, 2,* 10–11.

28. Sardini, E., Serpelloni, M., & Pasqui, V. (2015). Wireless wearable T-shirt for posture monitoring during rehabilitation exercises. *IEEE Transactions on Instrumentation and Measurement, 64,* 439–448.
29. El-Sheimy, N., & Youssef, A. (2020). Inertial sensors technologies for navigation applications: state of the art and future trends. *Satellite Navigation, 1,* 1–21.
30. Seel, T., Kok, M., & McGinnis, R. S. (2020). Inertial sensors-applications and challenges in a nutshell. *Sensors Journal, 20*(21), 6221.
31. Wong, W. Y., & Man, S. W. (2008). Trunk posture monitoring with inertial sensors. *European Spine Journal, 17*(5), 743–753.
32. Wang, Q., Chen, W., Timmermans, A.A.A., Karachristos, C., Martens, J.B., Markopoulos, P., (2015). "Smart rehabilitation garment for posture monitoring," 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) .
33. Christiansen, K.R. Shalamov, A. (2017). "Motion Sensors Explainer", W3C Working Group Note, August.
34. Fisher, C. J., (2010). "Using an accelerometer for inclination sensing", ANALOG DEVICES.
35. Product specification, (2013). "MPU-6000and MPU-6050Product SpecificationRevision 3.4", InvenSense, August.
36. Technical specification, (2016)."RASPBERRY PI 3 MODEL B", element 14, March.
37. Rajput, M., (2015). "Why android studio is better for android developers instead of eclipse", Mobile Zone - Tutorial, May.
38. Pawlukiewicz, D. (2018). "Introduction to Firebase", Forever F[r]ame, May .
39. Singh, V. (2018). "Introduction to firebase", Coding Gurukul, December.
40. Hansraj, K. K. (2014). Assessment of stresses in the cervical spine caused by posture and position of the head. *Surgical Technology International, 25*, 277–279.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ferdews Tlili received the Engineering degree in IT engineering and the M.S degree in Networking and Multimedia Systems from the National School of Computer Sciences (ENSI), University of La Manouba, Tunisia, in 2012 and 2013, respectively. She is currently a Ph.D. student at Higher School of Communications of Tunis (SUP'COM). She is a researcher in the Research Laboratory Innov'COM/Sup'Com. Her main research interests are focusing on the following fields: wireless communications, wireless sensor networks, signal processing, classification theory, information technology and their application in Health Care systems.

Rim Haddad received the Engineering degree in telecommunications, the DESS degree in telecommunications and Radio Mobile, the M.S degree in telecommunications from the High School of Telecommunication of Tunis (SUP'COM) and the Ph.D degree in telecommunications from the National Engineer School of Tunis (ENIT), Tunisia, in 1998, 2002, 2004 and 2011, respectively. She is currently an Assistant Professor at Higher Institute of Communication Technology Studies of Tunis (ISET'Com). She is a researcher in the Research Laboratory Innov'COM/Sup'Com since 2005. She has the research collaborations with University of Gloucestershire, United Kingdom, on "Deep Learning for denoising of EEG signals" and Université TÉLUQ, Canada, on "IoT and e-health". Her current research interests include mobile communications, electronics and communication engineering, radio communication, information and communication technology, digital signal processing and signal processing for communication.

Ridha Bouallegue received the M.S., Ph.D., and Habilitation a Diriger des Recherches (HDR) degrees in telecommunications from the National Engineer School of Tunis (ENIT), Tunisia, in 1990, 1994, and 2003, respectively. He is currently a Professor at the National Engineer School of Tunis (ENIT) and the Director of the Research Laboratory Innov'COM/Sup'Com. His current research interests include mobile and satellite communications, access techniques, intelligent signal processing, code division multiple access (CDMA), multi in multi-out (MIMO), OFDM, and UWB systems.

Neila Mezghani received the Engineering degree in telecommunications, the DESS degree in information technology from the High School of Telecommunication of Tunis (SUP'COM), the DEA degree in automatic and signal processing from the National Engineer School of Tunis (ENIT) and the Ph.D degree in telecommunications engineering from the Quebec University, in 1996, 2001, 1999 and 2005, respectively. She is currently an associate professor at the École de technologie supérieure (ÉTS) and the National Institute of Scientific Research (INRS-EMT). She is also a researcher at the LICEF research center, a researcher at the CHUM research center and a member of the Imaging and Orthopedics Research Laboratory (LIO). She is interested in the analysis and classification of data in biomedical engineering and the development of tools based on artificial intelligence methods for the development of decision support systems.