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Review article

# Design and architecture of smart belt for real time posture monitoring

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ABSTRACT

The bad back flexions are the main cause of the back disorders and pains. Many working conditions require that the worker remain sitting and slouching for long time. Having a correct sitting posture over time is the greatest way to protect workers from the back pains according to the latest medical researchers. In this paper, we present the architecture and design details of the proposed posture monitoring system. The aim of this study is to propose a tracking posture system include complete information about the back posture. The existing posture monitoring systems in literature were limited to trunk flexion monitoring. In this proposal we introduce the shoulder bent monitoring in addition to the trunk flexion monitoring in order to provide complete information about the back posture. The proposed posture monitoring system is a smart belt equipped by inertial sensors to detect the trunk flexion and a shoulder bent to monitor the posture over time. A smartphone application was developed to notify the person in case of bad posture detection. The proposed system demonstrates encouraging results to monitor the posture over time of seating persons and improves their seating behavior by receiving a real time notification in case of bad posture detection.

## 1. Introduction

Many medical studies improve that the bad posture behavior in working place is the main factor of the back problems [1]. A 3-year prospective cohort study performed on workers of 34 Netherlands companies [1] demonstrates that the low back pain risk increases according to the workers trunk flexion over time and the activities. In fact, the study results present that the workers who their trunk flexion is over 60° during 5% of their working time, the workers who their trunk rotation is over 30° during 10% of their working time and the workers who lifted over 25 kg for more than 15 times during working day are the most experienced by the low back pain in different life time [1].

The low back pain has a severe impact on societal and personal patient's quality of life. The low back pain therapy is among the most expensive cares. The total cost of low back pain exceeded US$100 billion in United Status [2]. In Brazil, the societal low back pain cost is about US$2.2 billion according to the extracted data from the National database between 2012 and 2016 [3]. The low back pain cost consists of direct and indirect waists. The direct cost is related to the healthcare and the pain treatment. The working day lost and the productivity decreases are the indirect cost of the low back pain that is heavy on the society economy. In [4], the direct cost is about 12% of global cost and the indirect cost is estimated as 88% of the global back pain costs according

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a Netherlands study. In addition, the most of the low back pain patient suffer from a limited quality of life and a partial or total physical disability [5].

In the recent years, the number of the people affected by low back pain is increasing continuously. Many researches are focused to suggest instruments and systems in order to prevent the low back pains. The definition of the body shape is basic information to implement the monitoring posture systems. With the technologies advancements of the interactive video gaming, the cameras with software programs for body recognition are developed to track and motion the body movements. Worawat et al. [6] introduce a neck posture monitoring system based on camera data with sensors information to calculate the neck angle. The proposed system defines and classifies the neck posture in order to detect and notify the user in case of bad posture. The cameras based posture monitoring systems are based on image processing that can lead to privacy intrusion of the users. In addition, these systems are depended on the set up implementation. The accuracy and the reliability of these systems are related to the cameras' position.

In the last century, the sensing technologies have known a development and advancement. These technologies provide much information such as position, acceleration, pressure and physiological parameters. A huge amount of data will be treated and processed for healthcare applications. The sensors are characterized by small dimension and portability aspect. In fact, recently, the researchers are focusing on the study of the applicability of the sensing technologies to analyze the spinal posture [7] and the reliability of these technologies to monitor the seated workers [8].

In this paper, we will detail the design and the architecture of the proposed posture monitoring system based on the inertial sensors. In Section 2, we review the existing posture monitoring systems. We present the design and the architecture of the system proposal in Section 3. In Section 4, we introduce the implementation and the first system testing results. We conclude this paper in Section 5.

## 2. Literature review

In the last decade, the sensing technologies are known advancement in different aspects: connectivity, portability and power management. The sensors are characterized by tiny size. These devices integrate different connectivity technologies (WiFi, Bluetooth, etc ...). The sensors provide many information such as acceleration, pressure, spatial orientation, Blood pressure, ECG information, etc... These sensors' aspects lead to be wearable devices that can be integrated in different systems [9]. Many applications are known a growth development due to the advancement of the sensing technologies specially the healthcare applications. In [10], Tatjana et al. detail in the review the latest advancement of the wearable technologies regarding to the battery efficiency, communication architecture, data analysis and devices miniaturization in the wearable healthcare applications. This review confirms that the wearable technologies attend an acceptable maturity level that can be applied in different healthcare applications.

As a part of healthcare applications, the recent researches are focused on the proposal of systems to monitor the posture for rehabilitation and preventing the spine problems caused by the poor posture handling during the day.

Daniele et al. [11] propose a smart chair for posture monitoring of seated workers. The chair is equipped by textile pressure sensors. The sensors are placed on the backrest and the seat of the chair. The proposed system aimed to identify the variation of the posture during the stress tests for seated person. The experimental results show that the system is able to detect different level of stress on the spine during the posture variation. The system looks reliable for the detection of the posture stress level. Otherwise the authors do not detail how they will deal with this information for posture monitoring. The system does not integrate a feedback system to alert the user in case of high level stress detection. In addition, the system is related to a working platform and is not portable for anywhere use.

Manju et al. [12] 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 observed limitation 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 lumbar flexion.

A wearable system is defined in [13] based on the correlation of two sensing technologies for posture monitoring. The system is composed of flex sensors and inertial sensor. The wearable proposed robot is connected to the Smartphone application and cloud server in order to analyze the collected information for correction warning reception and telerehabilitation assist. The system is able to monitor the human body posture variation. However the system presents a complex architecture. And it is limited to define the trunk shape in order to detect bad posture.

In [14], Rik et al. propose BackUp which is a smart T-shirt that allow personalized sensor placement for low back posture monitoring. The proposed system contains two inertial measurement unit (IMU) sensors and a smart phone application that analyzes the collected data from the inertial sensors and sends feedback to the user in order to correct the posture. The experimental results of this system demonstrate positive results to define the low back shape and to detect the bad low back posture. This system is limited to low back posture monitor and the posture shape information. Otherwise the proposed system does not give precise information about the spine flexion over time. In addition, the system does not cover the whole posture variation specifically the shoulders movement.

The studies to monitor the trunk flexion are continued recently in [15]. Micaela et al. evaluate the use of one inertial measurement unit (IMU) to monitor the trunk flexion. The inertial sensor is placed in the low back of the warehouse workers to monitor the trunk flexion during two hours of their working time. The experimental results demonstrate that the one sensor placed in low back is able to define the trunk shape. However the main open question remains: is this architecture sufficient to detect and define the posture

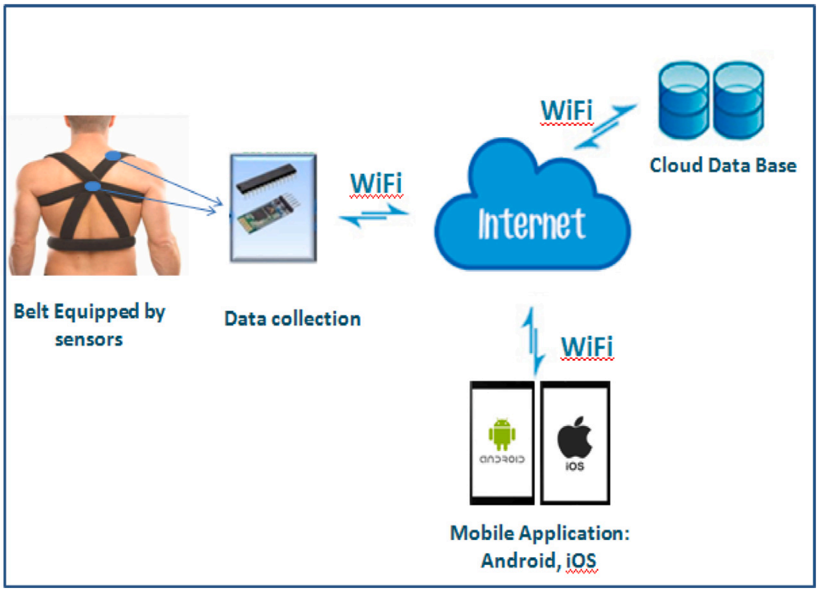


**Fig. 1.** Global System architecture.

variation for the users in different tasks? Although further studies are needed to monitor the bad posture of shoulders which can cause spine disorders.

Hung-Yuan et al. [16] introduce a posture monitoring system composed of three subsystems: notebook computer, smart necklace and Smartphone application. The notebook computer is equipped with a depth camera to collect data, define the structure of skeletal and calculate the reference point for user posture flexion. Then the reference data are sent to the smart necklace to calibrate the inertial sensor. The smart necklace measures the trunk tilt and sends information to the microcontroller for processing. After data analysis, feedback information is sent to the user via an application installed in his Smartphone in order to correct posture in case of bad posture detection. The main limitation of this system is the placement of the three subsystems in close proximity to each other.

In this paper, we propose a posture monitoring system. The proposed system is based on inertial information in order to define the posture information. In addition a mobile application is developed in order to monitor the posture variation over time and warn the user in case of bad posture detection. We focus in this work to propose a system simple to wear and use independent of the environment of implementation. A large study of the sensors location is performed in order to have an optimum number of sensors with complete information about the posture flexion. In the next sections, we will detail the design and architecture of the proposed system.

## 3. System design and architecture

### 3.1. Global system architecture

The proposed posture monitoring system is composed of two main components: A belt equipped with sensors and a mobile application. The smart belt is composed of orthopedic belt easy to wear and comfortable for use and inertial sensors stretched to the belt. The used belt is suitable for different users' age and body shape. It can be portable anywhere for workers in working space and young people in studying environment. The global system architecture is presented in Fig. 1.

The inertial sensor IMU used for system posture measurement is composed of 3D accelerometer, 3D gyroscope. The proposed IMU is able to measure proper acceleration and angular velocity in three axes.

The inertial sensor IMU can be composed of accelerometer, gyroscope and magnetometer or accelerometer and gyroscope. In this case we will use an inertial sensor composed of an accelerometer and gyroscope only as the information provided by these components are sufficient for trunk flexion and shoulder bent detection. Otherwise, the magnetometer is sensitive to the magnetic fields that can erroneous the measurements. A three dimension accelerometer measure the linear acceleration according the 3 axis (x, y and z). Using the acceleration measurement, the tilt angle during accelerometer movement according to 3 axis is defined as detailed in [17] using a basic trigonometric method. The 3D gyroscope measures the rotation velocity according to the 3 axis X, Y and Z. The angle according to an axis is defined by the equation in [18].

The accelerometer angles according to 3 axis (x, y, z) are detailed in the following equations:

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

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

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

$A_x$, $A_y$ and $A_z$ are the accelerometer measurements according the three axis (x, $y$ and z) [17].
The gyroscope angle is calculated as following:

$$\theta_n = \theta_{(n-1)} + \omega \times \partial t \tag{4}$$

$\omega$ : the angular velocity, $\theta$ : angle resulting

The accelerometer and gyroscope measurements are merged in order to get one information about the tilt angle using the technique complementary filter [18] defined as following:

$$\theta_n = \alpha \times (\theta_n - 1 + \omega \times \partial t) + (1.0 - \alpha) \times Angle\_accel \tag{5}$$

$\alpha$ is a constant: the common used value of $\alpha$ is 0.98 as defined in [18].

Angle_accel: is the accelerometer angle measurement according one of the axis X, Y or Z.

The collected measurement from the IMU is sent to microcontroller for data converting. The sensors are connected to the microcontroller via wire conductors. All collected data from the sensors, are sent to the microcontroller, itself sends data to a cloud server where the data is stored and processed. The using of cloud server to save and treat the collected Data is the best way to store a huge amount of data in real time. The microcontroller is equipped by a Wi-Fi interface that allowed it to send the collected data in real time to the cloud server.

A mobile application is implemented in order to monitor the posture variation over the time and alert the user in case of bad posture detection. For the case, the mobile application consists of many user interfaces that show the real time graphs of shoulders and trunk posture variation and alert messages in case of bad posture detection. The design of Mobile application will be detailed in the next section.

### *3.2. Inertial information choice*

Many sensing technologies are developed in the recent years. In fact, the main sensors types applicable for our system are the pressure sensors, the flexion sensors, optical sensors, inductor sensors and inertial sensors.

Many pressure sensors are designed to provide the load information for many systems use. In [19], 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 [20] 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 [21], the pressure sensors are placed under the legs of a chair in order to collect load information. The main limitation 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. [22] 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 [12]. 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 [23]. 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 [24]. 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 [25]. The inductor sensors are applied on the posture monitoring system as it can define the shape of the trunk. The observed limitation 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 [26].

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 [27]. 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 [28]. 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.


**Fig. 2.** Spinal regions or Curves [14].

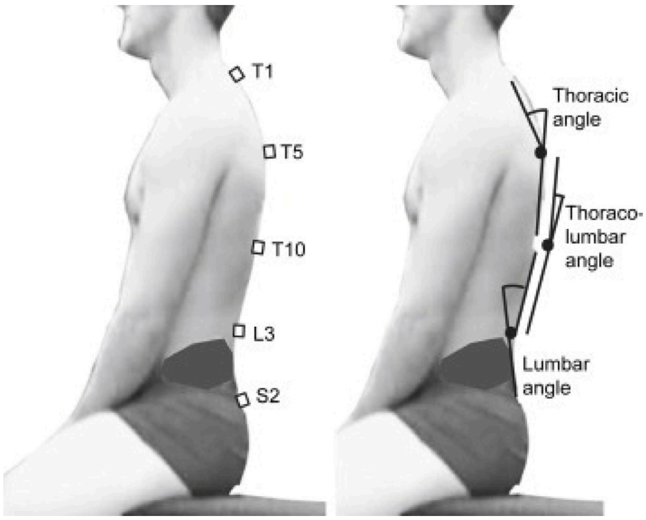


**Fig. 3.** Angles presentation of the spinal curves [29].

### 3.3. Sensors positions

The vertebral column is composed of four regions or curves as shown in Fig. 2: Cervical curvature, Thoracic curvature, Lumbar curvature and Sacral curvature. The variation of spinal curves defines the trunk flexion over time.

Clinically, the spinal posture refers to the position of spinal segments with respect to each other and with respect to gravity. In [29], the study quantifies the spinal curves and defines the directions and the angles of the spine curve at the thoracic and lumbar spine regions. In fact, the spinal curves are determined by three main angles according to this study: Thoracic angle, Thoraco-lumbar angle and Lumbar angle in Fig. 3.

The presented angles for spine curves can be measured by the inertial sensors placed in the three points presented in Fig. 3. The tilting angles along axis of inertial sensor modules are able to quantify the spinal curves and monitor the change of the spinal posture.


**Fig. 4.** Proposed Sensors positions.

The back posture is not limited to the trunk flexion but also the shoulders tilt. In many working or studying cases the spine posture is fixed, but the bad shoulders bent causes spine stress and back posture disorders.

The aim of our proposal is to define a simple system for the posture monitoring and bad posture detection as in Fig. 4. For this case, we propose to place the inertial sensors on the trunk and shoulders. The first sensor is placed in Thoracic (T5) position in order to get the information about trunk flexion. For the shoulders bent monitoring, we propose for this study to place the second sensor in one of the shoulders as on the most of time the two shoulders movements have a symmetric movement and provide same information.

### *3.4. 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. In literature, some posture monitoring proposed system introduce a mobile application specially for receiving warning in case of bad posture detection as in [13,14,16].

The developed Mobile Application provide the current posture information for the user and warn him in case of bad posture detection via visual and sound alert. The mobile application is composed of seven 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 shows interfaces for shoulders monitoring choice interface, real time graph interface for shoulder bent monitoring and an interface for user warning that will be displayed in case of bad posture detected. In addition the application provides interfaces for trunk monitoring containing the graph of the posture measurement monitoring in real time 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. 5.

## 4. System implementation and results

### *4.1. Technologies choice*

The proposed posture monitoring system is composed of hardware and software components. The hardware components consist of the belt, the sensors and the microcontroller. The software components are mainly the technologies used for the mobile application development.

For system implementation, we choose a belt that covers the key points of the back where we will place the sensors. The belt design is suitable to stretch the sensors in the proposed positions as shown in Fig. 6. The chosen belt is easy to wear, comfortable and adjustable according to user body. The inertial sensors used for the proposed posture monitoring system are the MPU6050 [30]. The MPU6050 is composed of 3 axis accelerometer and 3 axis gyroscope and numerical movement processor. All these components are compacted in 4 mm × 4 mm × 0.9 mm package. The MPU6050 dimension is small and simple to stretch on the Belt. This sensor model is equipped with I2C interface to communicate with the microcontroller. The chosen sensor characteristics cover the proposed system need as defined in Section 3.3. We use the Raspberry Pi 3 Model B as microcontroller for the system implementation [31]. The Raspberry Pi 3 Model B is a nano-computer with size of the credit card. This Raspberry Pi model runs several variants of the free GNU/Linux operating system, including Debian, and compatible software. It also works with Microsoft Windows OS: Windows

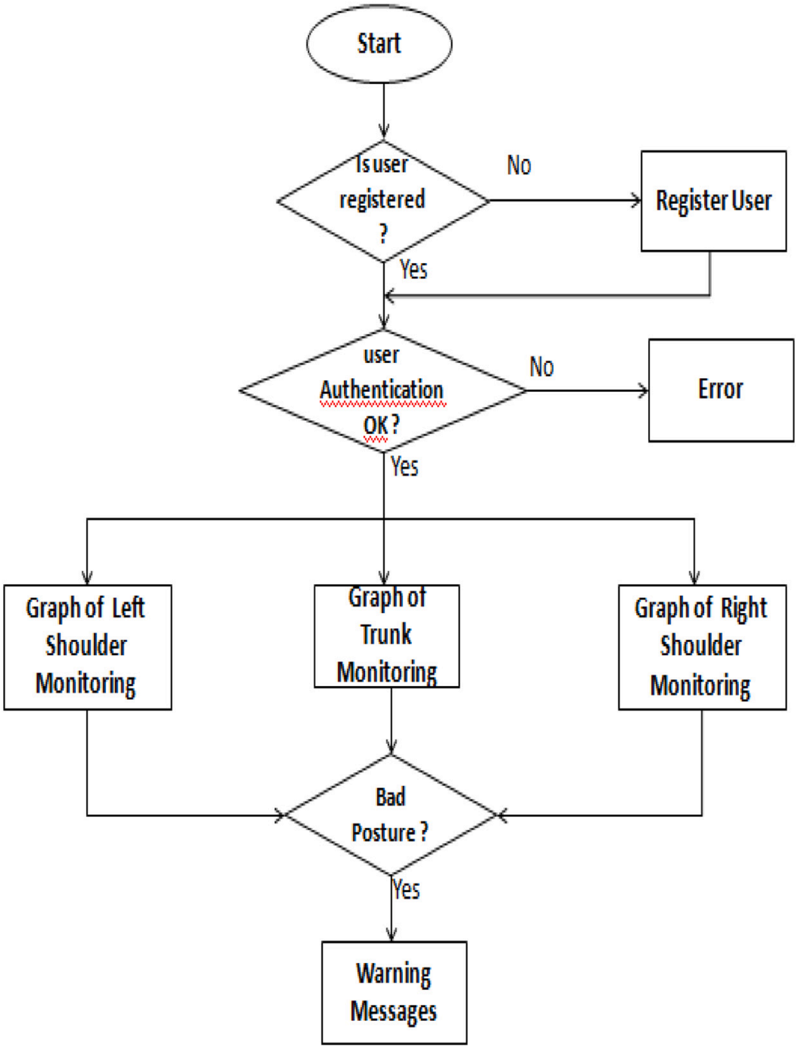


**Fig. 5.** Mobile Application Flowchart.

10 IoT Core3 and Google's AndroidPi4. The microcontroller used for the proposed posture monitoring system is equipped with wireless communication interfaces: Bluetooth and Wi-Fi. The chosen microcontroller model is easy to implement the development environment for the processing programs of the proposed system as it supports a variety of operating systems. In addition, this microcontroller model integrates the wire and wireless communication interfaces needed for ensure the communication between different proposed system components.

The database chosen for the posture monitoring system is the Firebase. The Firebase has a lot of features like real-time database, cloud functions, analysis tools, Crashlytics, Cloud Firestore, etc. The Firebase receives the collected data from the microcontroller each 5 s to process it for the mobile application. The Firebase is suitable to the proposed system as it is able to store a huge number of information and is the great choice for real time systems implementation [33].

We choose to develop two mobile applications with different technologies Android and iOS in order to cover the most used operating systems in the smart phones and tablets. The Android Studio SDK Version API 28 Android 9.0 (Pie) is the Android environment used for the development of the Android posture monitoring application [34]. Otherwise we use the Thunkable Drag-and-Drop Builder for iOS application development. It is an easier platform for iOS application creation [35].

The Wi-Fi communication technology is used to ensure the data transfer between the microcontroller and the cloud server, the cloud server and the mobile application. The Wi-Fi technology is the greatest wireless communication suitable for the proposed posture monitoring system as this technology ensures the communications between different system components and is available anywhere especially in working and studying spaces.


**Fig. 6.** Belt for system implementation (Reference: 6611) [32].

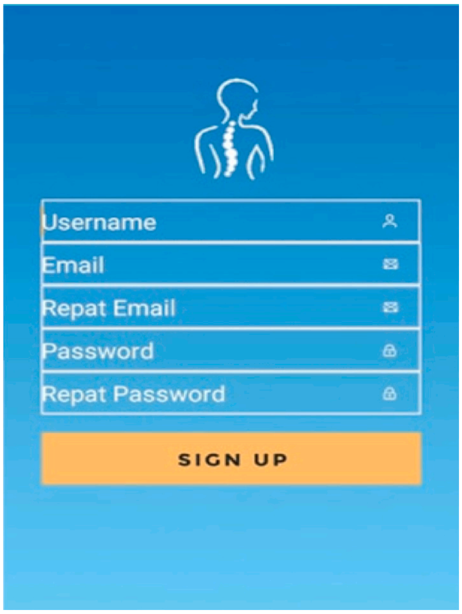


**Fig. 7.** Registration interface.

### 4.2. System results

The proposed posture monitoring system consists of the smart belt and the Mobile application. The inertial sensors are stretched on the belt in the thoracic and shoulder positions. The microcontroller is connected to the sensors via the wired connectors. The collected information from the sensors is converted by the microcontroller. Then the microcontroller processes the collected data from the sensors and sends it to the cloud server for storing the data in database in format of the (x, y, z) measurements and the tilt angle degree. The cloud data base is fueled by the collected information each 5 s. The stored information in real time will be processed by the Mobile applications for the user posture monitoring and warning in case of bad posture detection.

The application retrieves this data through a user authentication interface (Login/Register). The mobile application provides a register interface for user registration as shown in Fig. 7. In addition, an authentication interface is implemented for user access to the application with personnel profile presented in Fig. 8.

The application offers to the user a complete view about the back posture by introducing the trunk flexion monitoring and shoulder bent monitoring. The user can monitor in real time the shoulder bent variation. The user chooses the monitored shoulder as shown in Fig. 9. A real time graph will be displayed containing the variation of tilt angle of the shoulder bent in Fig. 10. In case of bad posture detection when the tilt angle achieves a defined threshold, a warning message will be displayed in order to alert the user about the need to adjust his posture.

In addition the user can monitor his trunk posture via another interface where a real time graph is displayed containing the trunk variations over time as shown in Fig. 12. The user receives a visual message in case of a bad posture detected according to a theoretical threshold of the right posture angles as example in Figs. 11 and 13.

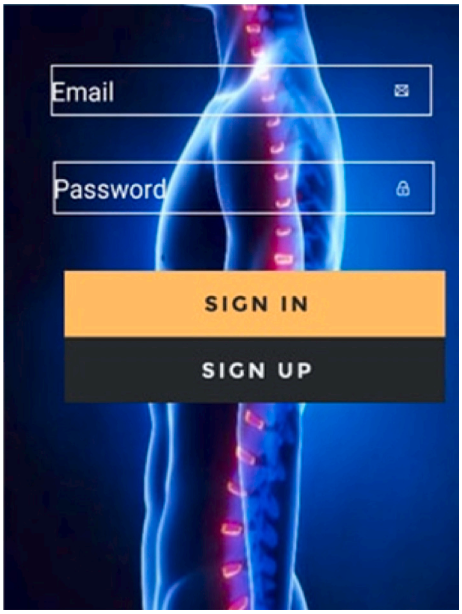


**Fig. 8.** Authentication Interface.

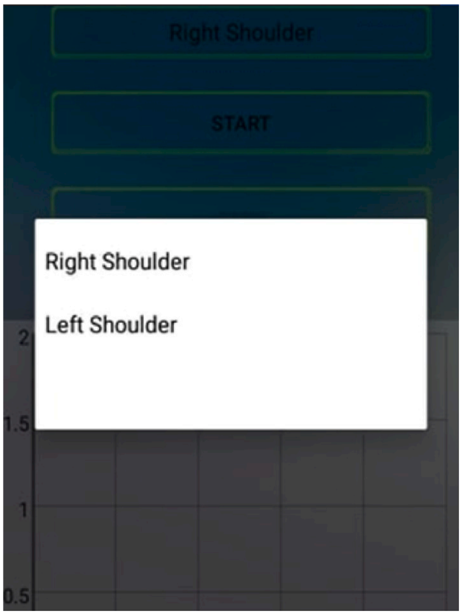


**Fig. 9.** Shoulder monitoring interface graph.

## 5. Conclusion and future works

In this paper, we introduce the design and architecture of the proposed posture monitoring system. The system consists of Smart belt equipped by sensors and Mobile application. The smart belt collects the bent variations of the trunk and the shoulder and sends them to the cloud server for data storage. A mobile application installed in the mobile phone of the user provides a personalized interface to the user for tracking the posture variation over time. In addition, the user receives warning messages in real time in case of bad posture detection.

The proposed system presents architecture for adding the shoulders movement monitoring to the trunk bent tracking in order to have complete information about the posture monitoring for seating person compared to the existing proposed posture monitoring system.

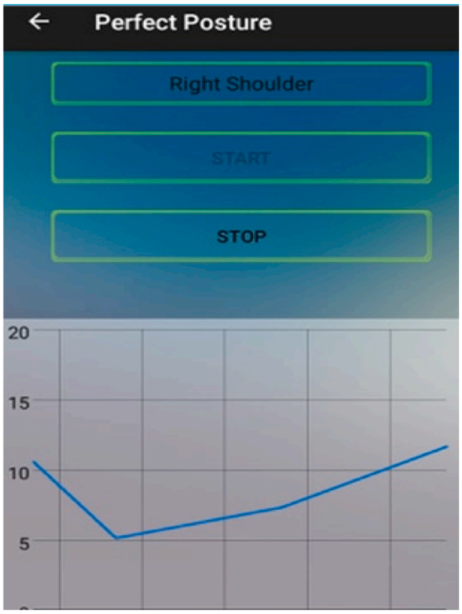


**Fig. 10.** Right Shoulder monitoring.

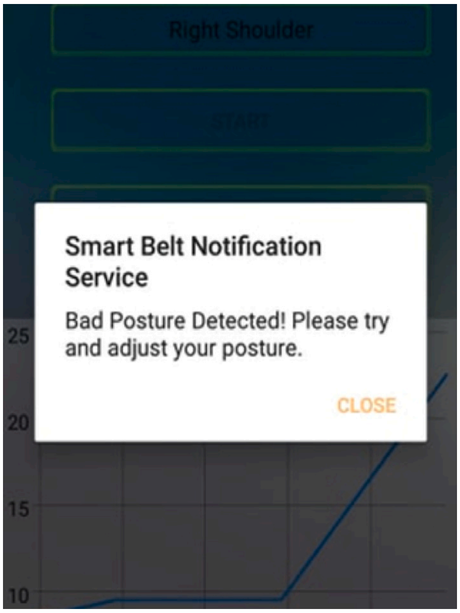


**Fig. 11.** Warning bad shoulder posture detection.

The preliminary results of the proposed posture monitoring system demonstrate encouraged results for improving the posture of seated person in real time.

As a future work efforts, we will continue to improve the efficiency of the proposed posture monitoring system. In fact, we will propose another sensors model and deeply study the sensors placement in order to improve the system accuracy. In addition, we will introduce the machine learning algorithms to classify the sitting postures.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

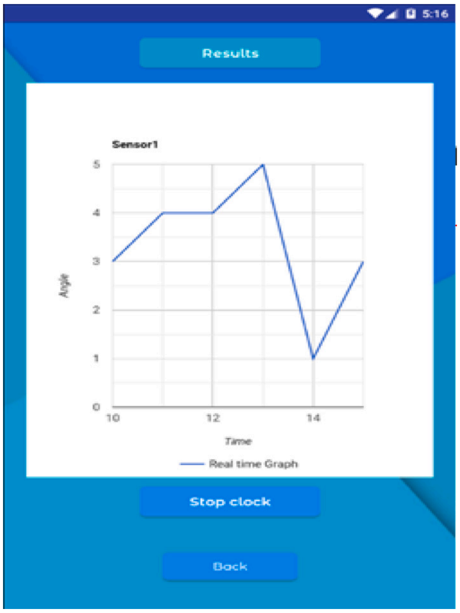


**Fig. 12.** Trunk monitoring graph.

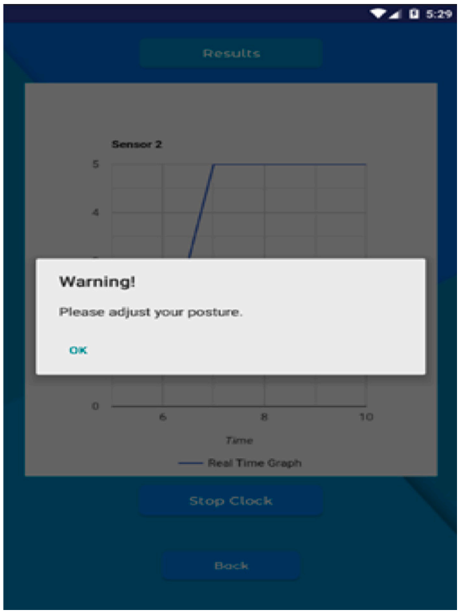


**Fig. 13.** Warning bad trunk posture.

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