Smart Vest for Posture Monitoring in Rehabilitation Exercises

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Abstract— **Rehabilitation at home has many advantages, both in terms of increased efficiency of health service and comfort for the patient. The monitoring of any human physiological parameters in home environment has the primary need to be non-invasive for the patient and at the same time motivating. This paper describes a wearable system for monitoring physiological posture during rehabilitation exercises to the spine in patients with mild scoliosis. The system can measure the posture of the subject through a sensorized T-shirt, which uses an inductive sensor. This article reports the conceptual framework and the description of the first fabricated device. The preliminary experimental results are reported and compared with the results obtained via an optical system that measures the position of markers over the patient's back. The instrumented T-shirt, integrated with an appropriate conditioning and transmission electronics, could be used as a remote support tool and as a feedback system for the identification of the patient's correct posture.**

Keywords- smart vest; posture monitoring; scoliosis; inductive sensor; instrumented shirt; rehabilitation; telemedicine; impedance analysis; optical measurements.

I. INTRODUCTION

Different disorders of the spine may occur in different phases of a person's life, during growth, work and aging. In addition to physical deformity of the spine, posture and dysfunction of the receptive position are suggested to be the cause of different diseases, which may result in deformity of the spine. Possible approaches in the rehabilitation of these disorders of the spine are surgical, medical, or use of restraints corsets and muscle strengthening exercises to counteract the postural deviations of the patients. For these non-surgical and non-medical interventions, different solutions for the monitoring of postural activity during postural rehabilitation are reported in the literature. There are numerous methods for the analysis of the spine posture, from simple visual observation in clinical practice to more complex motion systems used in the laboratory in much of medical researchers. Many laboratory methods based on posture analysis have been shown to be reliable and valid. Unfortunately, these systems are complex and long to use and cannot be easily used to analyze the posture outside the lab, such as at home. The use of wearable devices that use minimally invasive methods of posture analysis in situations outside the hospital environment can be useful to provide a quantitative measure of posture during daily activities. In recent years, various devices have been developed to analyze the posture of the spine outside of the hospital. The posture analysis of the spine is possible using accelerometers, gyroscopes, and optical sensors [1-3]. The analysis of posture and movement is usually performed measuring the cinematic variables of anatomic segments using specific inertial devices, electromagnetic sensors or cameras integrated in finer equipment as stereo photogrammetric systems. However, many techniques cannot be used to develop wearable devices. Accelerometers and gyroscopes are commonly used to provide information on the position and orientation in aerospace and robotic. For the analysis of trunk movements, these sensors are used to measure the cinematic parameters of body segments, including the inclination with respect to gravity, linear acceleration and angular velocity. The aim is to introduce integrated accelerometers and gyroscopes, or corsets that can detect the position change in terms of curvature change of the spine in the sagittal and coronal. Unfortunately, some of these devices are relatively large and invasive, and cannot be easily hidden or used for an extended period. Another limitation is that traditional systems are unable to provide immediate feedback, while the patient is involved in postural activities of daily living. This deficiency is significant if one considers that postural awareness and sense of position can play a key role in the treatment of scoliosis. In fact, recent studies show that postural awareness can help to improve clinical outcomes [4-5].

The main drawbacks of wearable sensors available on the market are their weight, the rigidity of the structures that support them, the size and other properties that make them invasive for the patient and therefore, hardly acceptable if worn continuously throughout the day. Based on this therapeutic approach, a monitoring system was developed by [6] to manage patients with scoliosis. The system was used to monitor the posture of the spine and to provide feedback signals to patients in order to correct their posture. This small device can monitor the posture of the spine in real time without the need for cumbersome cables, thus facilitating the movement and normal function in a wide range of activities. However, the device asks patient to fix with adhesive tape the sensor cable directly to the back, and this operation makes it difficult to enforce without the help of another person. In [5]

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sensorized busts are used for patients with lumbar scoliosis, patients with low back pain for the elderly and osteoporotic vertebral fracture. However, the use of these resources is limited by external factors such as invasiveness, clutter, physical restraint and thus low level of acceptance. Therefore, the rehabilitation at home is a challenge, especially for patients who are not self-motivated. Inappropriate attitudes for patients with spinal disorders may further deteriorate since their pain and deformities. Poor posture is defined as any deviation of the spine sustained naturally. Therefore, the approach used in recent years is to use the muscles of the back to keep the spine within the natural curvature. Thus, the corresponding symptoms can be prevented by increasing the awareness of posture. Postural training can raise awareness of upright posture and prevent the deterioration of some spinal deformities such as scoliosis and osteoporotic vertebral fractures.

The proposed system can give the patient information about his posture and can help to facilitate this therapeutic approach, ensuring continuous monitoring of posture and using feedback signals to indicate to the patient's incorrect posture. In addition, device users can learn the correct postural habits that could restore the proper physiological state. In this paper, the development and implementation of a T-shirt able to detect posture and movement of the human body using innovative inductive sensor are presented. The inductive sensor varies its impedance when a mechanical deformation is applied. The inductive sensor can be integrated into textiles or other flexible substrates, and then these inductive sensors can be used in the biomechanical analysis to realize wearable interfaces able to detect posture and movement of the human body. The system meets the clinical and psychological needs, such as patient comfort, ease of use and non-invasiveness. To avoid all these defects during the motion analysis, the need to make the system non-invasively has led to realize the wearable device in stretch fabric (Lycra) as a textile substrate. In this work, the system is fabricated and tested using a commercial impedance analyzer. An optical reading system by means of markers has been used as the comparison system of experimental results obtained from the designed device. The wearable conditioning electronics is proposed, and it is now under test. The electronic circuits can process the data directly on the T-shirt and then create a feedback system that can provide information about the correct posture of the patient. The data may be available for immediate presentation and analysis, or sent via the Internet to a hospital center for telemedicine purposes. The device can also be used to provide information in real-time biofeedback postural (sound or vibration) in order to change the incorrect posture or movement patterns and also improve the physical performance of those using the device. Thus, the device is designed to be a valuable aid in monitoring postural exercises during rehabilitation at home.

II. SYSTEM DESCRIPTION

Figure 1 shows the diagram of the T-shirt instrumented for posture measurement. The proposed system can be divided into two parts: the sensorized T-shirt and the readout unit. The instrumented T-shirt for monitoring the posture is formed of an inductive sensor, a conditioning and transmission electronics and feedback system to the patient. The data are transmitted wireless to a readout unit, which can be connected to a PC (Personal Computer) or directly to the internet for telemedicine activity. This paper reports only the description and characterization of the inductive sensor. The posture of the patient is monitored using an inductive sensor appropriately stitched to the shirt throughout the back and the chest of the patient. The sensing technique is simple: a change in posture causes a change in the geometry of the inductive sensor, generating an impedance variation across the terminals of the sensor.

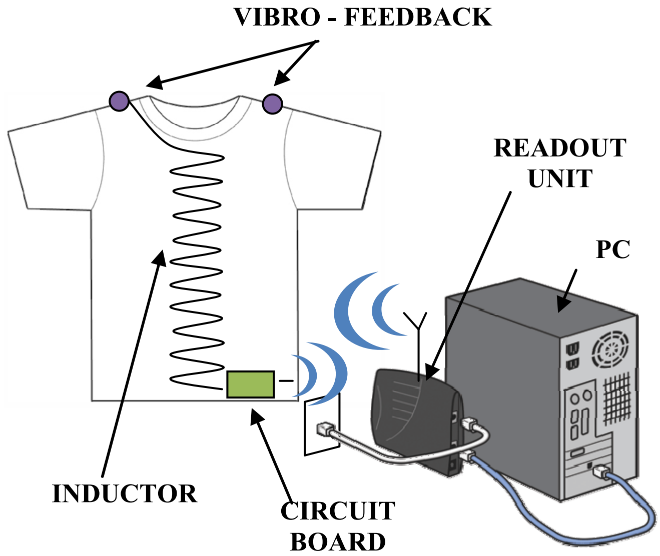

Fig. 1. Block diagram of the wearable system.

Two identically inductive sensors connected serially were sewn to the T-shirt, one front and the other back. Figure 2 shows an image of the inductive sensor created directly on the shirt. As you can see the inductive sensor affecting the central part of the back is sensitive to an activity that is essentially an elongation movement of the spine. The reference exercise for the reinforcement of the correct posture is given by a lengthening of the spine performed by the patient in a sitting position (Fig. 2). A lengthening of the spine performed in sitting position generates a variation of the geometry of the coils of the inductive sensor. The size of the single sensor wire measured when the shirt is worn is about 10 cm long and 3 cm wide with a total length of 50 cm. The conductive wire used is copper and has a diameter of 1 mm.

In this paper, the inductive sensor has been tested using commercial impedance analyzer (HP4194A), and then dedicated electronic circuits have been designed and are currently under production and testing. The measurement electronics linked to the T-shirt allows to measure the change in the sensor impedance and to transmit wirelessly the data to the acquisition unit connected to a PC or directly via LAN cable to the hospital for assistance and telemedicine. The wireless data transmission between the wearable electronics and the readout unit takes place via Bluetooth's module to 2.4 GHz (EDS200) marketed by Parani, creating a channel between the controller and the electronics on board the T-shirt. Figure 3 shows the block diagram of conditioning electronics for measuring the impedance of the inductive sensor. The reading unit is generally connected to a PC near the patient and the maximum allowed distance is up to 10 m, which is sufficient to guarantee a space for exercises. In the final implementation, the physiological data will be analyzed and automatic alerts will be generated locally or transmitted over the Internet for remote assistance or via vibro-feedback.

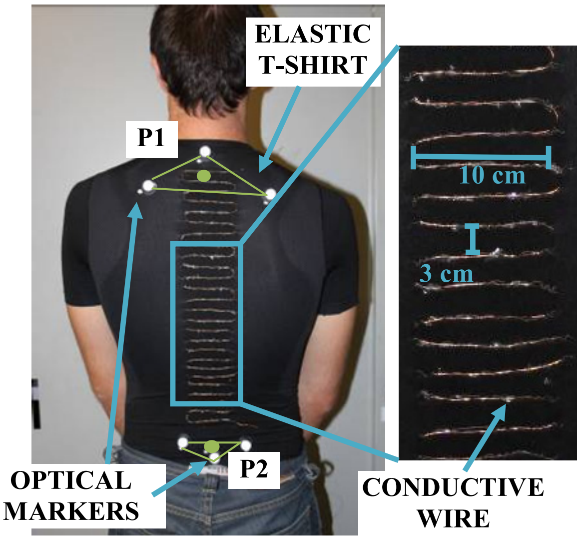

Fig. 2. Image of the inductive sensor realized over the T-Shirt.

In fig. 3, the block diagram of the conditioning electronics proposal is reported. A microcontroller commercialized by Freescale (S08GB60A) can be programmed to control and coordinate the activities of the data-acquisition system, establishing communication with the reader and putting the system into sleep or wake mode. The microcontroller has an Analog to Digital Converter (ADC) of 10 bits, which has been adopted with a bus frequency of 20 MHz. The conditioning system can be made by a first stage of generating sinusoidal reference signal obtained through a DDS (Direct Digital Synthesizer) low power (AD9834), and then the sinusoidal signal is adjusted at a correct amplitude level by an operational amplifier. The inductive sensor can be connected to a current-voltage amplifier; whose output is proportional to the impedance of the sensor module. A high-pass filter (HPF) of about 0.5 Hz is adapted to filtering the offset due to non idealities. The Schottky rectifier is a low forward voltage at about 0.3 V, and then a low-pass filter of 10 Hz is used to extract the continuous voltage. The system is powered by a rechargeable lithium battery of about 3.75 V and 2.2 Ah. The circuit has a DC-DC converter (TPS61200) and a charge circuit that uses LTC4062 commercialized by Linear Technology for rechargeable operations.

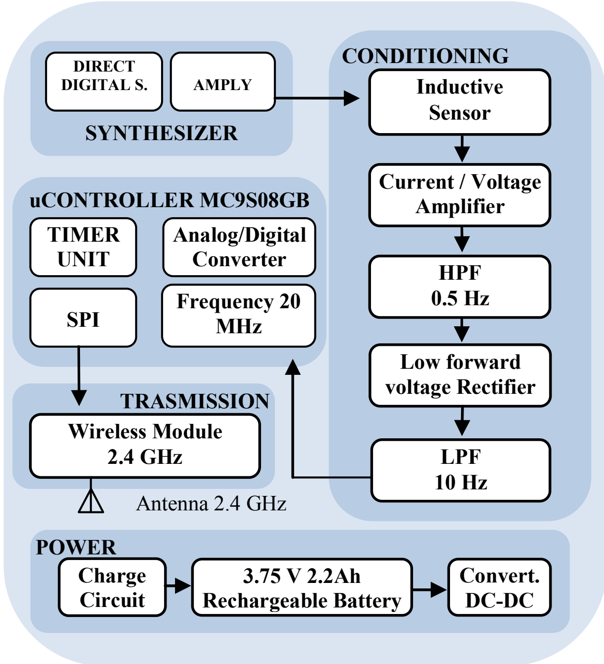

Fig. 3. Block diagram of the proposed conditioning electronics.

III. Experimental System

In fig. 4, the schematic diagram of the experimental system is reported. The inductive sensor which is mounted on the shirt was linked at this stage, to an impedance analyzer marketed by HP (HP4194A) to measure the modulus and phase of the sensor. An optical system was used to measure the distance between two points on the back: a point is located near the neck and near the basin. To measure the position of a single point, three optical markers were placed at the top of the back and three at the bottom. The central point of each rigid body formed by the three points was monitored and was calculated the distance between P1 and P2 for the different postures of the patient (fig. 2).

The optical system adopted is commercialized by OptiTrack. It is composed by three cameras (V100:R2) with a resolution of 640x480 (VGA) and a sub-millimeter accuracy. All the cameras are connected USB to a specific hub and then to a Personal Computer (PC). The software adopted for the optical system calibration and image analysis is Arena commercialized by OptiTrack. The cameras are located at about 60 degrees from one another over three tripods in order to properly track the motion of the markers on the patient’s back. The markers are reflective and with a diameter of about 5/8”. The six adopted markers are placed to the patient’s back as reported in fig. 2.

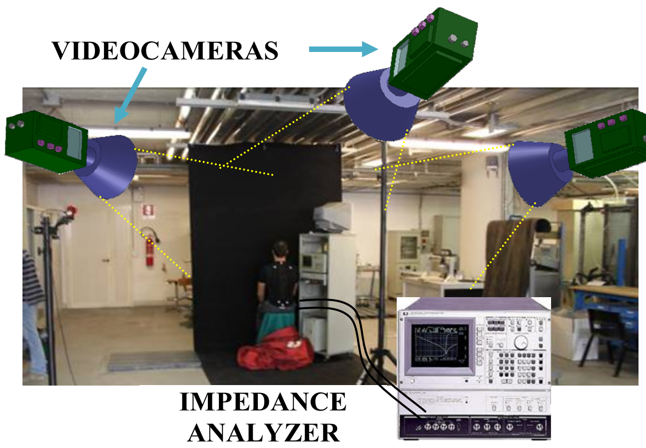

Fig. 4. Schematic diagram of the experimental system adopted for posture measurements.

Different postures have been taken into account, in Figure 4 shows two postures, the first called (A) shows a high degree of curvature of the spine and should be avoided as it can lead to an alteration of the normal curvature of the spine. The second called (F) has a correct position of the spine and is characterized by a lengthening and straightening of the back. Both postures show a significant difference due to an increase of the distance between points P1 and P2. The extension generates an extension of the inductive sensor as shown in the figure, in turn generating a variation of its impedance.

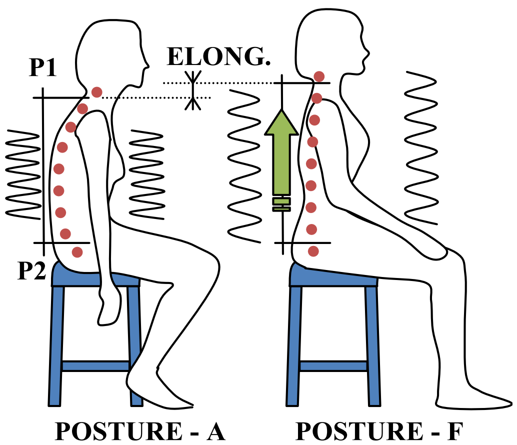

Fig. 5. Image of the experimental setup.

IV. Experimental Results

The inductive sensor sewed to the T-shirt was characterized using an impedance analyzer (HP4194A). The inductor is placed in parallel with a capacitor of about 330 pF with the aim to decrease the resonant frequency of the sensor. The impedance magnitude and phase diagrams are shown in Fig. 6 and show that for the operating frequency over 24 kHz, the sensor is mainly inductive.

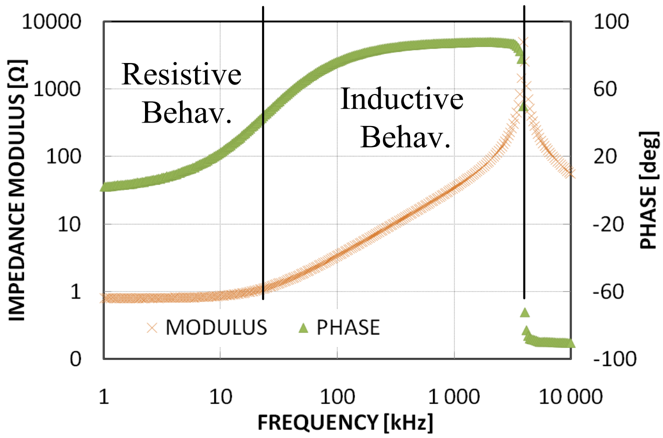

Fig. 6. Inductive sensor characterization.

TABLE 1. Equivalent circuit parameters.

	Inductance (μH)	*Capacitance (pF)*	*Resistance (Ω)*
Sensing Inductor	5.3	341	0.8

The equivalent circuit can be represented by an inductance in series with a resistance both in parallel with a capacitance. This frequency was considered as the reference frequency of the inductive sensor measures due to the high sensitivity. Preliminary experimental results were obtained for different postures between the two references (posture A and B – Fig. 5). In fig. 7, the different impedance modules are reported for the different postures. As it can be seen from fig. 7, the posture changing from A to F generates a lowering of the resonant frequency due to an increasing of the inductance of the sensor. This is due to an increasing in the magnetic flux couple by the windings.

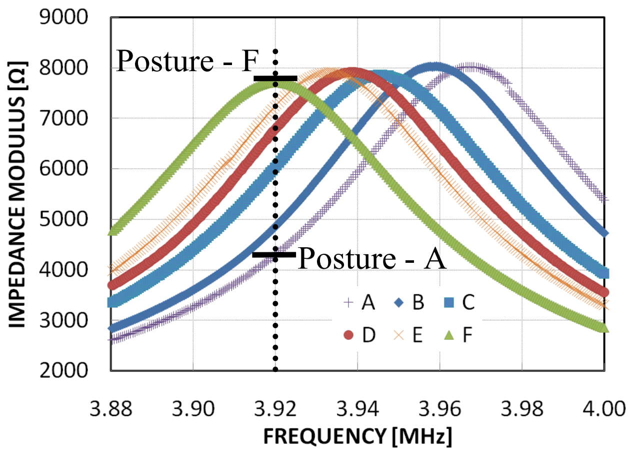

Fig. 7. Impedance measurement at different postures.

The possibility to monitor a single frequency with the designed conditioning circuit has been considered. The frequency of 3.92 MHz has been considered as reference frequency for the conditioning circuit. A variation of about 3400 Ω for the impedance modulus is measured.

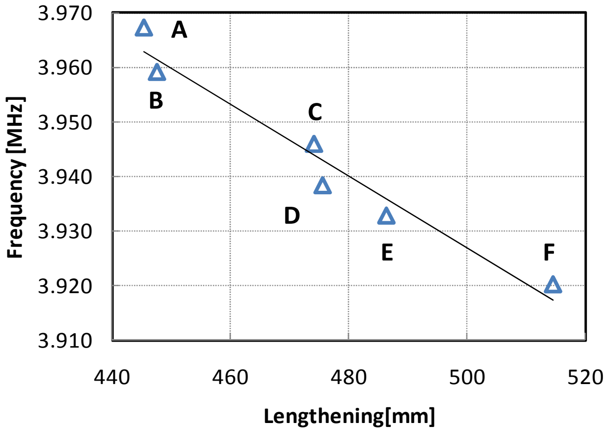

Fig. 8. Comparison between optical and resonant frequency measurements.

Fig. 8 shows the values of the resonant frequency of the inductive sensor versus the lengthening of the segment P_1P_2 obtained using the optical system. The six data reported are referred to the six different postures monitored. The distance between two points P_1 and P_2 was obtained by a mathematical processing of the results obtained considering the absolute position of the optical system. As it can be seen from the diagram, the maximum total distance is about 70 mm.

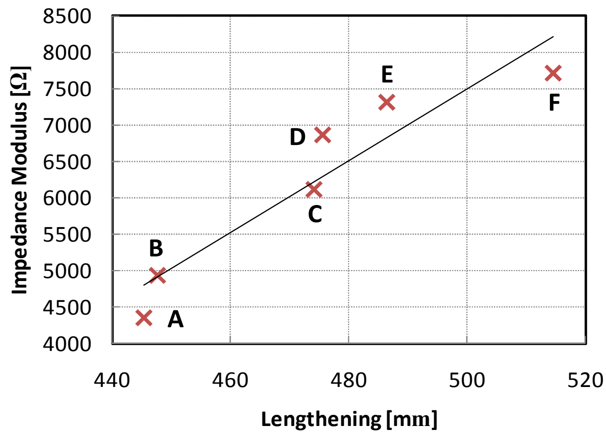

Fig. 9. Comparison between optical and inductive measurements.

In fig. 9, the impedance modulus values at different position for a fixed frequency of about 3.92 MHz have been compared with the distance between the points P_1 and P_2. The figure shows a good sensitivity of about 50 Ω/mm.

V. Conclusions

An instrumented T-shirt is presented to measure the posture of patients during rehabilitation activities at home. The system implements an inductive sensor; a change in posture results in a variation of the sensor impedance. In this work, the experimental results obtained using a commercial impedance analyzer and compared with results obtained by using a machine-readable were presented. The circuit architecture of the portable data-acquisition system has been presented and described. Currently, the work is in progress with the manufacture and testing.

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