Wireless Wearable T-Shirt for Posture Monitoring During Rehabilitation Exercises

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***Abstract*— The monitoring of any human physiological parameters during rehabilitation exercises requires noninvasive sensors for the patient. This paper describes a wireless wearable T-shirt for posture monitoring during rehabilitation or reinforcement exercises. The subject posture is measured through a sensorized T-shirt using an inductive sensor sewn directly on the fabric. The wireless wearable T-shirt design specifications are the following: independence from the remote unit, easy to use, lightweight and comfort of wearing. This paper reports the conceptual framework, the fabricated device description, and the adopted experimental setup. The instrumented T-shirt's output data are compared with the data obtained via an optical system, as a gold standard, that measures the marker positions over the patient's back and chest. The trials performed on four subjects obtained on different days demonstrate that the wireless wearable sensor described in this paper is capable of producing reliable data compared with the data obtained with the optical system. The constitutive sensor simplicity that includes only a copper wire and a separable circuit board allows achieving the objectives of simplicity, ease of use, and noninvasiveness. The sensorized T-shirt, integrated with designed conditioning and transmission electronics for remote communication, could be used as a support tool for postural monitoring during rehabilitation exercises.**

***Index Terms*— Impedance analysis, optical measurements, posture monitoring, sensorized T-shirt, smart vest, wearable system, wireless system.**

I. Introduction

DIFFERENT spinal disorders may occur through the phases of a person's life during growth, working, and aging period. In addition to physical spinal deformities, such as scoliosis and osteoporotic vertebral fractures, posture and receptive position dysfunctions are suggested to be the cause of different diseases, which may result in spinal deformity. Possible approaches in the rehabilitation of these spinal disorders are surgical, medical, or the application of restraint corsets and muscle strengthening exercises to counteract the postural deviations. For the nonsurgical and nonmedical interventions, a simple physical exercise consisting in the stretching of the body may help increasing the range of motion and improving the spinal mobilization [1], [2] since the muscle increases its capacity and better supports the postural reeducation by lessening muscle hypertonicity [3]. This exercise is typically performed for every type of subject including elderly and/or impaired people. One important effect of this exercise is the awareness improvement of the subject's upright posture as demonstrated by recent studies where the postural awareness improves the clinical outcomes [4], [5]. The awareness can be supported by a signal, generated by a monitoring system, indicating to the subject his/her postural state. The signal can be activated by an algorithm that implements the suggestions of the physician that has in charge the responsibility of the diagnosis on correct or incorrect posture. This way, the patients are encouraged to assume the correct postural habits that could restore the proper physiological state. A system that monitors the postural state should be wearable if it does not inhibit movements and it makes acceptable to be worn continuously during the exercise throughout the day. Other significant characteristics are that the vest equipped with the measurement system must be easily wearable without the help of other persons, easy to use, and should not compromise the patient's privacy. Finally, a postural system equipped with the possibility to send data via Internet opens the opportunity of remote medical supervision, since the physician can have objective data relating to the exercise execution.

Different solutions for the monitoring of postural activity during postural rehabilitation or reinforcement are reported in the literature, from simple visual observation in clinical practice to more complex motion systems used in medical laboratories. The analysis of posture is usually performed to measure the kinematic variables of anatomic segments using specific inertial devices, [accelerometers [6], [7], inertial measurement unit (IMU) [4], [8], [9]], electromagnetic sensors [10], [11] or cameras integrated in finer equipment as stereo photogrammetric systems [12]–[14], and hybrid systems [15]. Some of the mentioned techniques are not well suited to develop a wearable measuring system due to the weight of the electromagnetic sensor or to the impossibility to put on the patient's back a camera or optical sensors. Accelerometers and gyroscopes are commonly incorporated in corsets and in IMU. They detect the position change in terms of spinal curvature change in the sagittal plane measuring inclination and angular rates of rotations that are integrated to obtain the positions [16]. However, the position values are affected by drift problems due to the integration method used. The main drawbacks of wearable sensors available on the market are their weight, the rigidity of the structures that support them, and the size and other properties that make them uncomfortable for the patient, and therefore hardly acceptable

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if worn continuously throughout the day. Reference [17] manages patients with scoliosis monitoring the spinal posture and providing feedback signals to patients to correct their posture. Even if no cumbersome cables are used, thus facilitating the movement and normal function in a wide range of activities, the device requires sticking, with adhesive tape, the sensor cable directly to the back skin and this operation is difficult without expert help. In [5], 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.

In this paper, a posture monitoring system consisting of a wireless sensorized T-shirt integrating an inductive sensor is presented. The T-shirt is in stretch fabric (Lycra) as a textile substrate and it integrates a thin copper wire sewn on it resulting in this way lightweight and easily wearable. It meets also the clinical and psychological needs, such as patient comfort, easiness of use, and noninvasiveness. Thus, the device is designed to be a valuable aid in monitoring postural exercises during rehabilitation. The wire works as an inductive sensor that measures the deformation applied on the T-shirt by the lengthening and straightening in the sagittal plane of the body. The experimental results have been compared with those obtained by an optical measurement system (typically used in the experiment for postural analysis [4], [9], [11]–[13], [17]–[19]). This paper is a development of [19], where a preliminary sensor was characterized by a commercial impedance analyzer and preliminary experimental results have been reported.

II. Reinforcement Exercise Description

The adopted reinforcement exercise of the body is schematically shown in Fig. 1 [1], [2]. The subject is seated on a backless chair and performs the exercise stretching the body slowly. Fig. 1 shows the patient assuming two extreme postures: 1) (P_{slump}) has a high degree of spinal curvature and 2) ($P_{\mathrm{hyper-ext}}$) is characterized by a lengthening and straightening of the body, then postures P_{slump} and $P_{\mathrm{hyper-ext}}$ show a significant difference due to a lengthening of the body in the sagittal plane. With the aim to measure the deformation applied on the subject's T-shirt by the lengthening and straightening in the sagittal plane, we designed a new sensor integrated in a common T-shirt. The proposed sensor measures the lengthening at which the T-shirt is subjected to because of the reinforcement exercise.

III. Posture Monitoring System Description

Fig. 2(a) and (b) shows the block diagrams of the posture monitoring system. The proposed system can be divided in two parts: a wearable instrumented T-shirt and readout unit. The sensorized T-shirt is constituted by the inductive sensor, a circuit board, and a piezoelectric actuator. It weighs 175 g as a normal T-shirt. The sensor is a wire, appropriately stitched to the T-shirt throughout the patient back and chest. The circuit board, supplied by batteries, incorporates conditioning and transmitting circuits and it is housed in a box of about 13 × 7 × 5 mm fastened to the pants. The two terminals of the sensor on the T-shirt are two metal snaps that are used to connect the sensor to the circuit board using a snap connector. The actuator is a vibration micromotor (Pico Vibe) commercialized by Precision Microdrivers. The read-out unit is constituted by a Bluetooth module directly connected to a personal computer (PC) or directly to a local area network (LAN) integrated server module.

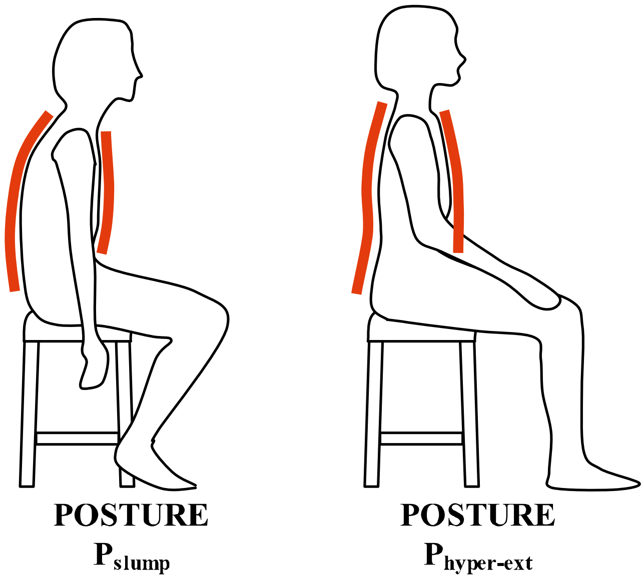

Fig. 1. Image of the postural exercise.

A. Sensor Description

An enameled copper wire of a 1-mm diameter was manually sewed to the T-shirt as shown in Fig. 2(a) and constitutes the sensor whose size is about 9-cm long and 2.5-cm wide with a total length of 50 cm. The copper wire is stitched with a zigzag pattern on the back and the chest allowing the lengthening of the T-shirt and sensor in the sagittal plane. Thus, the body lengthening and straightening of the patient back and chest due to the exercise execution produces a lengthening of the subject's T-shirt and then a variation of the sensor geometry causing an inductance variation. The sensor's impedance characteristic has been measured using a commercial impedance analyzer (HP4194A). The impedance magnitude and phase diagrams are shown in Fig. 3 and the data show that for the operating frequency over about 50 kHz, the sensor is mainly inductive. The equivalent circuit can be represented by an inductance in series with a resistance both in parallel with a capacitance while the measured equivalent parameters are reported in Table I.

The lengthening and straightening of the body in the sagittal plane induce a deformation on the T-shirt that generates a sensor's lengthening variation along the back and chest as well, and then an inductance change. In Fig. 4(a), sensor's inductance values at different postures changing from P_{slump}

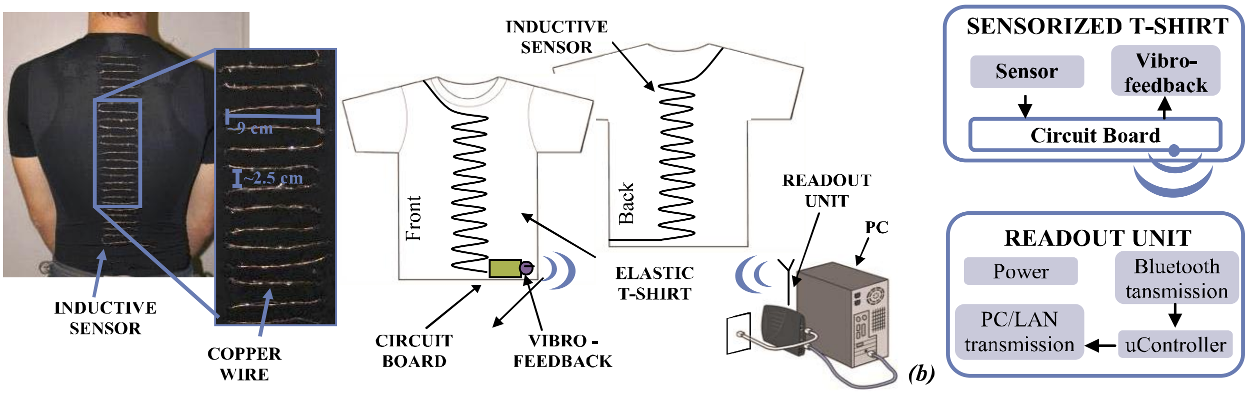

Fig. 2. (a) Posture monitoring system. (b) Block diagram.

TABLE I
EQUIVALENT CIRCUIT PARAMETERS

	Inductance (μH)	*Capacitance (pF)*	*Resistance (Ω)*
INDUCTIVE SENSOR	4.6	22	1.6

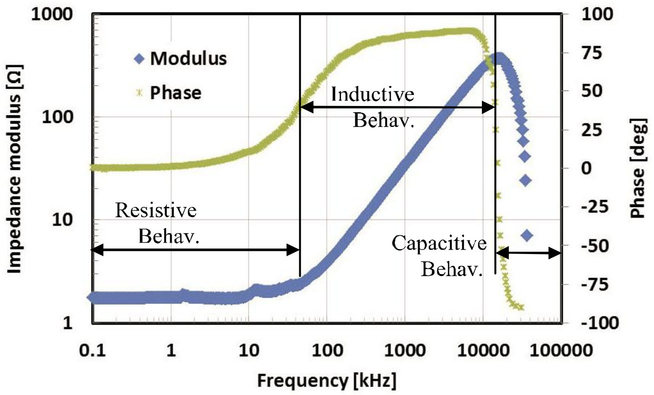

Fig. 3. Frequency behavior of the sensor.

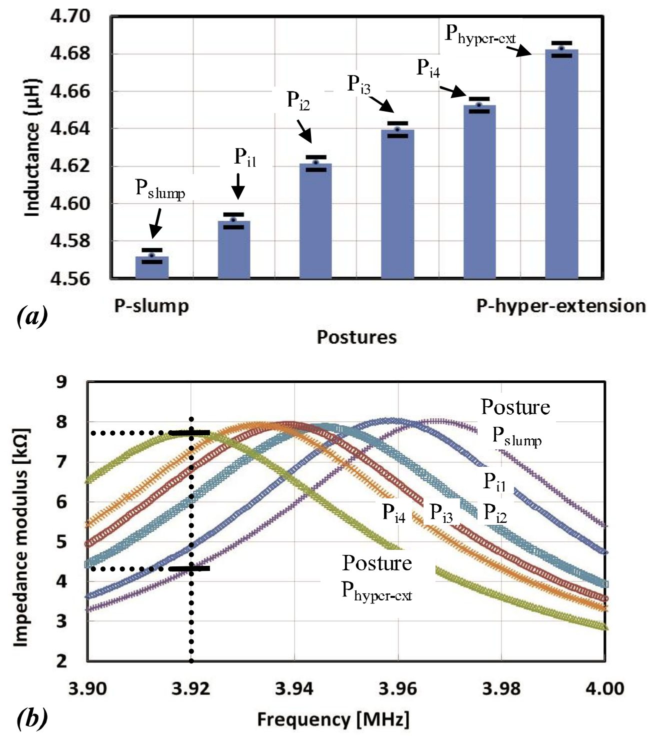

Fig. 4. (a) Sensor's inductance values at different postures (mean ±1 SD) of one subject. (b) Impedance modulus measurement at different postures.

to $P_{\text{hyper-ext}}$ during the exercise execution for one subject (Subject1) and corresponding to a sensor's lengthening variation along the back and chest of about 5 cm are reported. $P_{i1}, P_{i2}, \ldots, P_{i4}$ are intermediate posture between P_{slump} and $P_{\text{hyper-ext}}$ that correspond to the positions of the involved subject. The inductance values correspond to the deformations induced on the shirt by the different postures, whereas the clinical evaluation of these postures has to be entrusted by the physician. Since the range of the inductance variation is short, it has been decided to create a resonance point by adding a parallel capacitor to the sensor and to measure the impedance module variation along the rising edge of the resonance curve. Then, a capacitor of 330 pF has been mounted parallel to the sensor itself, and an analysis of the module impedance close to the created resonance of about 4 MHz has been conducted. In Fig. 4(b), the impedance modules as a function of intermediate postures ($P_{i1} \ldots P_{i4}$) changing from P_{slump} to $P_{\text{hyper-ext}}$ for the same previous subject are reported. Please note that P_{i1}, $P_{i2}, \ldots, P_{i4}$ are just intermediate postures of the same subject between P_{slump} and $P_{\text{hyper-ext}}$. Fixing a single frequency of 3.92 MHz, the experimental results show a variation of the impedance module of about 3.2 kΩ over a maximum of

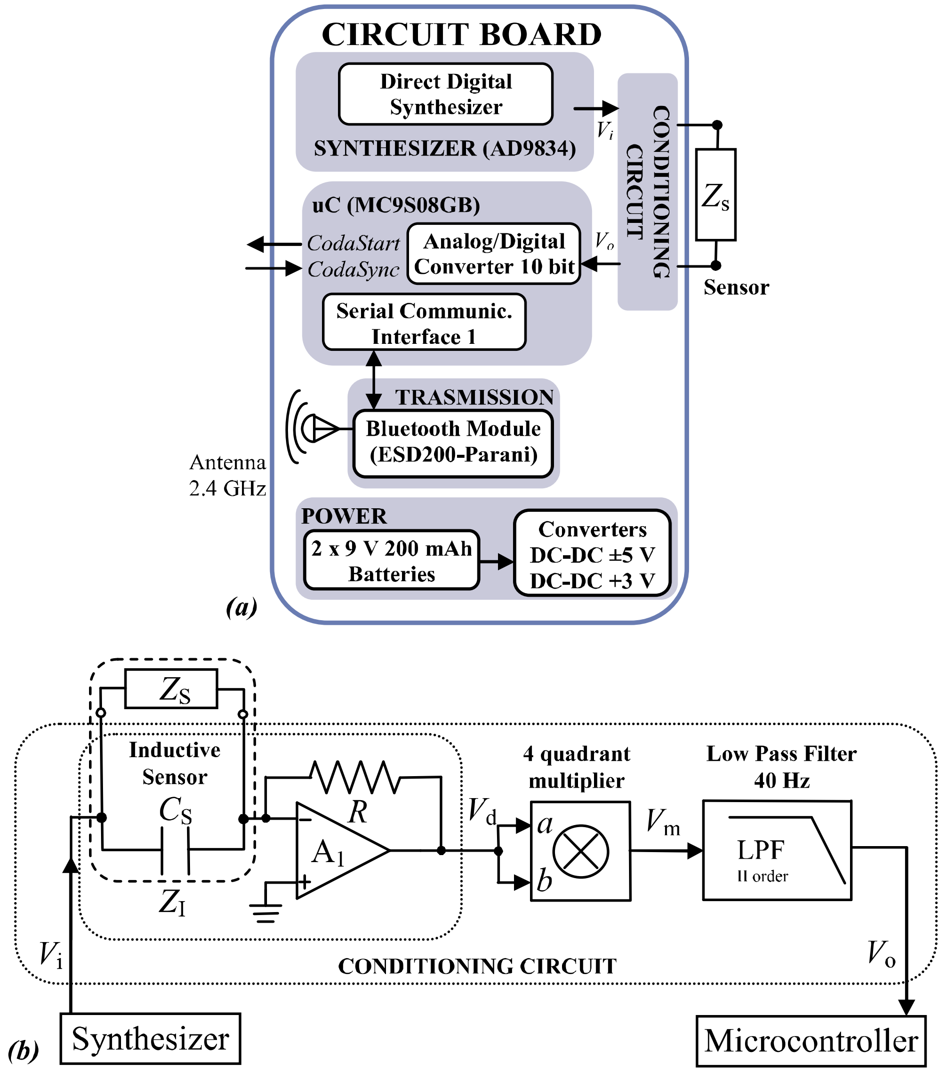

Fig. 5. (a) Block diagram of the circuit board. (b) Block diagram of the conditioning circuit.

about 7.6 kΩ corresponding to a deformation induced on the T-shirt of about 5 cm. A different subject can induce different deformations on the T-shirt, with the consequence of changing, even if slightly, the resonance frequency value and its variation range.

B. Circuit Board of the Sensorized T-Shirt

The previous analysis reported in Fig. 4 suggests exploiting the large variation of the impedance module along the rising edge of the resonance frequency by measuring its value at a single reference frequency that can be fixed at the resonance frequency of the $P_{\text{hyper-ext}}$ posture that for Subject1 is about 3.92 MHz.

The block diagram of the circuit board is shown in Fig. 5(a). A low-power direct digital synthesizer [(DDS) AD9834], which has a resolution of 0.28 Hz, generates a sinusoidal reference signal of 3.92 MHz. Then, the sinusoidal signal drives the input of the conditioning circuit reported in Fig. 5(b). Since different subjects could have different geometric characteristics, the deformation induced on the T-shirt could be different even if the same posture (for example, $P_{\text{hyper-ext}}$) is assumed. Due to the deformation change, also the resonance frequency changes in $P_{\text{hyper-ext}}$ posture and according to the consideration previously developed a new reference frequency can be chosen.

The sensor (Z_S) is connected in parallel to a capacitance C_S of about 330 pF and the resulting bipole, called in the following Z_I has a resonance frequency of about 3.92 MHz.

Supposing $V_i = \sin(\omega t)$, then

$$V_d(t) = \left(-\frac{R}{|Z_I|}\right)\sin(\omega t + \varphi) \tag{1}$$

where φ depends on the phase shifts caused by Z_I impedance and can be neglected for the purposes of this analysis. Subsequently, the signal is squared by a four-quadrant multiplier (AD835) and amplified with a gain of A_m value; V_m has a mean value proportional to the admittance module of Z_I, and a double frequency component

$$V_m(t) = \frac{A_m}{2}\frac{(R)^2}{(|Z_I|)^2}[1 - \cos(2\omega t)] \tag{2}$$

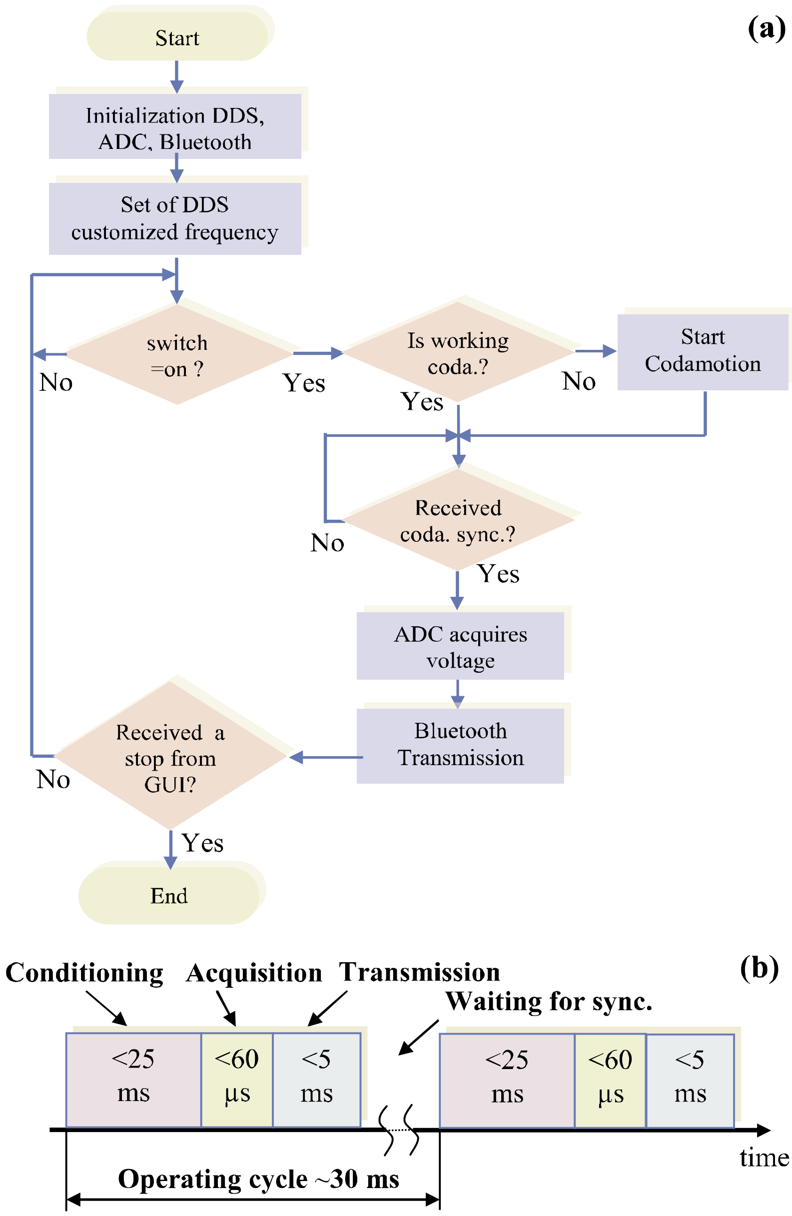

Fig. 6. (a) Schematic flowchart associated with the acquisition and transmission activities. (b) Schematic diagram of an operation cycle.

where V_m is the input of the second-order low-pass filter (LPF) that has a A_o gain, permitting to adapt the signal to the input rage of the analog-to-digital converter (ADC). The LPF extracts the mean value of the signal (V_m). Thus

$$V_o(t) = \frac{A_m A_o}{2} \frac{(R)^2}{(|Z_I|)^2} \tag{3}$$

where V_o is inversely proportional to the module of the impedance Z_I.

Voltage V_o is digitalized by 10-b ADC of the microcontroller. A_m, A_o, and R are chosen so as to adapt the range of V_o to the ADC input range 0–3 V.

The system is powered by two 9 V batteries, connected in series, of about 9 V and about 1200 mAh allowing a continuous functioning of a few hours; two dc–dc regulators permit to generate voltage levels of 3 and ±5 V.

A microcontroller commercialized by Freescale (S08GB60) acquires the impedance module through a 10-b ADC and coordinates the communication activities sending the data to the read out through the Bluetooth module. The firmware is written in C-language using the software CodeWarrior offered by Freescale. In Fig. 6(a), a schematic flowchart associated with the acquisition and transmission activities is shown. Initially, the operation of the program loaded into the microcontroller performs an initialization of program variables and peripherals, including the Bluetooth initialization. Then, the program enables the DDS to generate the working frequency, which could be personalized. When the switch on the board is pressed (switch = on), the firmware sends a start signal to the optical measurement system (commercialized by Codamotion [20] and described in Section IV) lowering a pin and waiting for the Codamotion sync signal. Then, the ADC

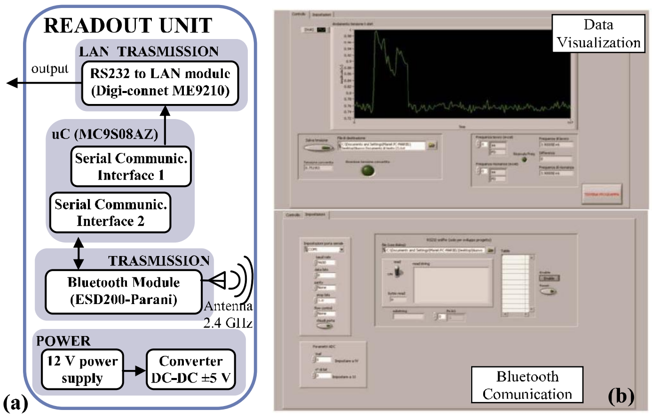

Fig. 7. (a) Block diagram of the read out unit. (b) Image of the realized GUI.

acquires the voltage (V_o). At this stage, the Bluetooth is not enabled to transmit. When the data have been acquired and is ready to be sent to the Bluetooth, the DDS and ADC are not functioning and then the transmission via Bluetooth is activated. Then, another cycle follows. If requested, the communication can be interrupted by the software on the PC or by pressing the switch on the circuit board. The typical measurement cycle, where each sensor value is conditioned, acquired, and transmitted to the readout unit, has a length of about 30 ms [Fig. 6(b)].

The Bluetooth (ESD200) is commercialized by Parani and it is connected to an antenna integrated over the printed circuit board. The Bluetooth establishes a communication serial port profile channel between the circuit board's and the readout's Bluetooth. The functioning is simple; first, the firmware resets the Bluetooth at every connection. Then, the Bluetooth is configured in discoverable mode and waiting for a connection from the readout unit. Finally, when the connection is established, the data transmission can be initiated by the software implemented on the PC or by a switch on the circuit board.

C. Readout Unit

The readout unit, whose block diagram is reported in Fig. 7(a), uses a Bluetooth ESD200, which is connected to a microcontroller HC9S08AZ commercialized by Freescale by a serial communication interface (SCI). The microcontroller elaborates the data and sent them to the PC for a local analysis or by a second SCI to a LAN integrated server module (Digi-connect ME9210) commercialized by Digi for remote connectivity. The virtual instrument (VI) software implemented in the PC is designed using LabVIEW marketed by National Instruments. In Fig. 7(b), an image with the developed graphical user interface (GUI) is shown. The VI can be run on any computer allowing you to manage the communication of data and save and display the received data. The program allows managing the Bluetooth communication, saving the data received from the readout unit, and visualizing the received data in a graph. When the exercise is completed, the program allows stopping the Bluetooth communication. If necessary, all the received data can be saved into a file for further processing.

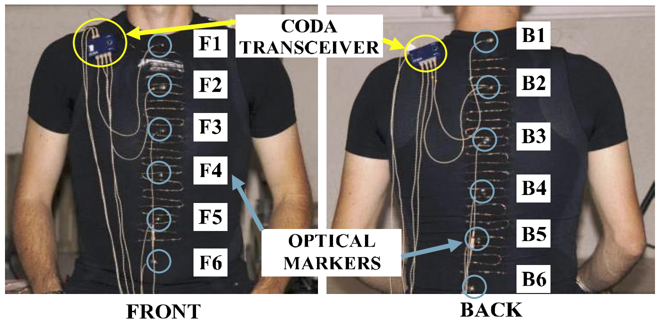

Fig. 8. Image of the inductive sensor realized over the T-shirt and the optical markers added for the comparison.

D. Characteristics of the Postural Measurement System

Different characteristics of the measuring postural system are shown here accompanied by design considerations. As reported before, the operation cycle is about 30 ms, this time, compared with the execution time of the reinforcement exercise that is slow, permits to consider a real-time acquisition of the posture monitoring. Furthermore, the maximum transmission distance between the T-shirt and the readout unit is up to 10 m, permitting a wide space for the subject and no constraints on the readout unit location. These features, combined with the simplicity of the sensorized T-shirt that does not affect the subject movements, makes the postural measurement system a valuable aid in monitoring postural exercises during rehabilitation.

IV. Experimental Setup

The postural monitoring system was tested during the rehabilitation exercise by comparing the results of the postural system with the data obtained by the optical measurement system Codamotion [20]. This optical measurement system is made of three cameras named Coda CX1, which acquire signals from active markers emitting in the infrared (IR) spectrum light. Each Coda CX1 contains three sensors mounted on a rigid frame. Each sensor is a linear photodiode array and has a flat window with designed a transmissivity mask located at known distance. When the LED IR marker moves, the light casts a shadow on the sensor array through the mask drawing a pattern on the sensor array. Then, a processor executes a real-time cross-correlation with the same pattern to calculate the plane angle of incidence. The angle information from the three array sensors are combined by a software (furnished with the hardware) to produce the marker space position. The two sensors at each end of the CX1 unit resolve the position in one direction, whereas the middle resolves in the orthogonal one. Each sensor determines three data representing the marker position respect to a fixed reference with very high resolution (0.05 mm in approx. 3 m). The average static variation of Coda marker positioning across 10 acquisitions is less than 0.1 mm achieved in a pyramidal volume between 2.0 and 4.5 m from the Coda CX1 [20].

The markers were glued to the T-shirt, as shown in Fig. 8. Six markers (from B1 to B6) are placed on the back and six on the abdomen (from F1 to F6). The distance between the markers is constant and it is approximately 90 mm. The markers are

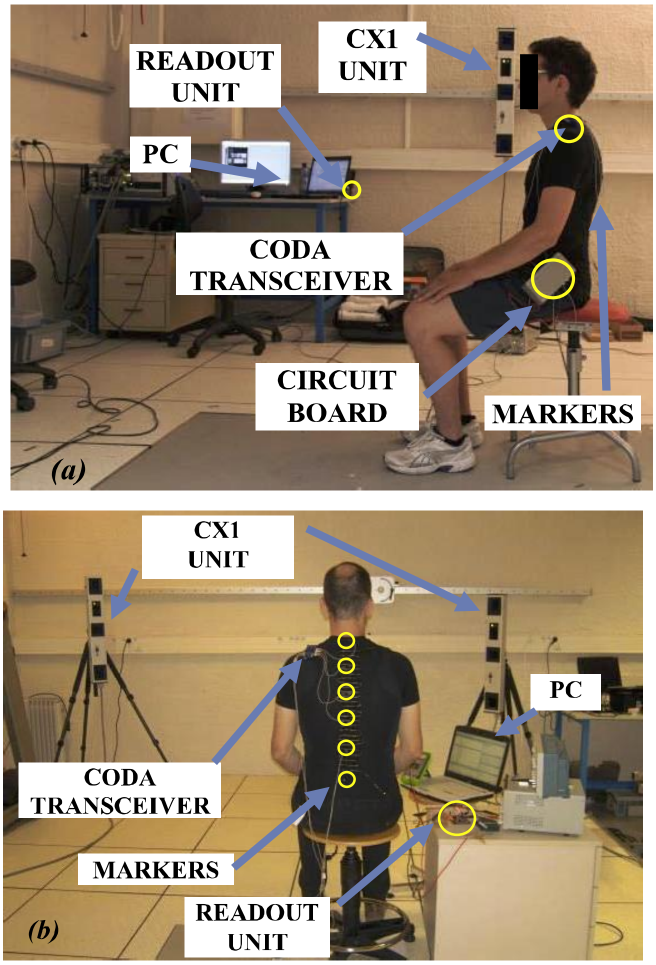

Fig. 9. (a) and (b) Images of the experimental setup during two different days with two different patients.

connected to a transceiver for communication of the marker's unique identifier (Fig. 8). Having active marker, which emits IR light (no interference with ambient illumination), despite the cost, enable more accuracy, and provides an intrinsic ID for each of them, being the CX1 unit capable to resolve confused or fragmented trajectories even when the markers are placed close to each other.

In Fig. 9, an image of the experimental system adopted for the trials is reported. The sensor on the T-shirt is connected to the circuit board, which wirelessly transmits the data to the readout unit. Two Coda cameras were placed in front of the subject and one rear. This configuration reduces the marker occlusion due to the interposition of the arms and/or head during the exercise executions. The active markers are rounded with yellow circles.

Four physically fit subjects took part in the study, called in the following from Subject1 to Subject4. The subjects have a mean age of 25.6 years, a mean height of 178 cm, and no pathologies at the spinal column. Each subject during the trials is seated on a backless chair. The subject first sits for 5 s as straight and tall as possible, in a hyperextended position ($P_{\text{hyper-ext}}$), then bends in a full slump position (P_{slump}) without forward flexion at the hip, which is held for 5 s, after which the hyperextended position is repeated.

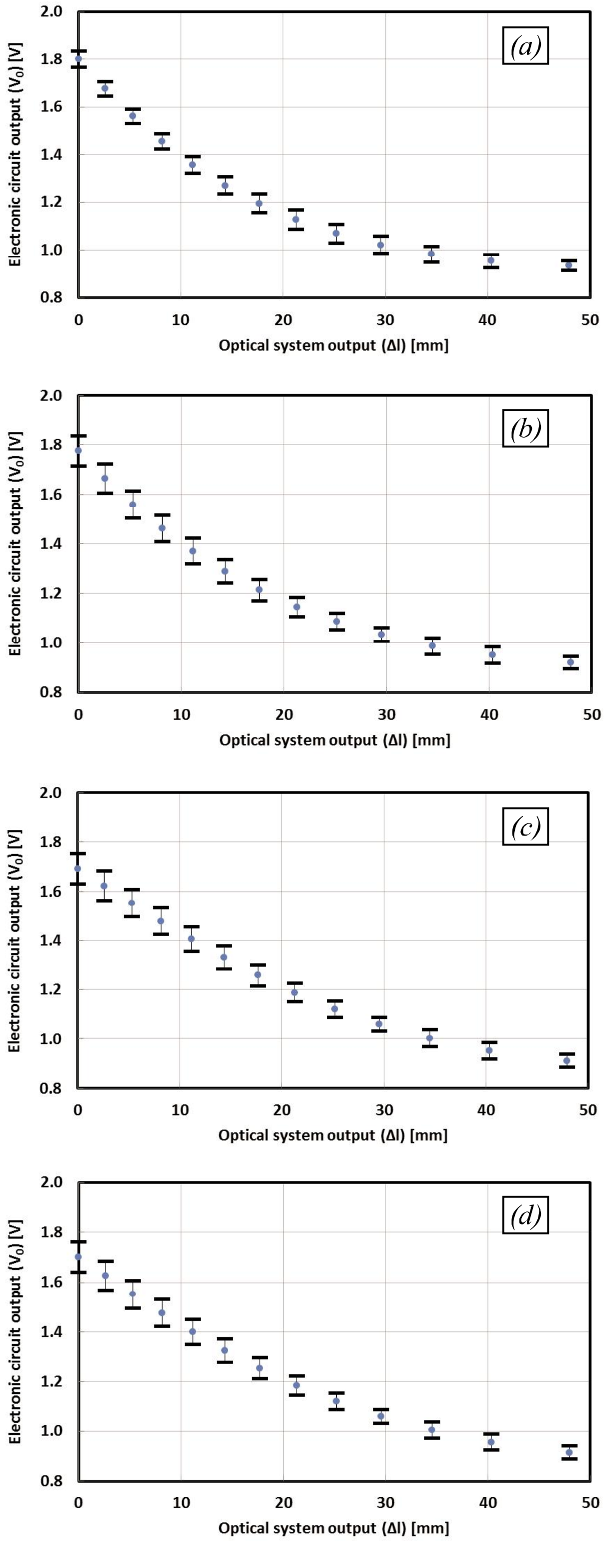

Fig. 10. Lengthening data obtained with the optical system versus the designed conditioning circuit (mean ±1 SD). (a) Subject 1. (b) Subject 2. (c) Subject 3. (d) Subject 4.

Before the test, to minimize the degree of natural variation in how the subject performs the task, he is asked to perform it a few times for practice. Therefore, the reinforcement exercise was executed by each subject with the previous specified

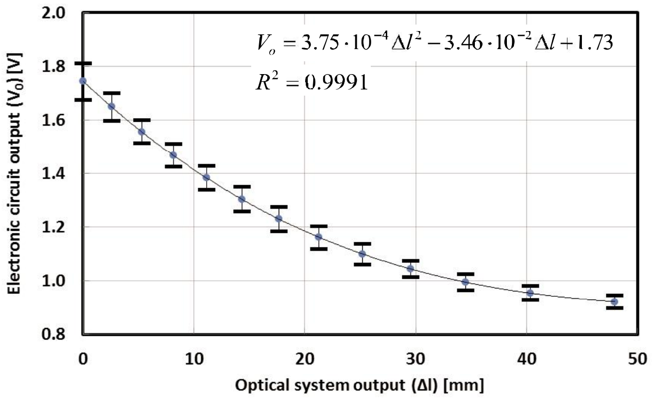

Fig. 11. Lengthening data obtained with the optical system versus the designed conditioning circuit (mean ±1 SD) for all the subjects.

protocol and the marker positions were monitored and registered using the optical system. Simultaneously, the voltage signal (V_o) was measured using the circuit board; the Codamotion sync channel was used to synchronize the two acquisition systems.

V. Experimental Results

The exercise described in Section II and with the experimental setup in Section IV was performed by the four subjects during one month, two days per week, to evaluate the behavior of the wireless wearable sensor. Twenty trials per day per subject were performed to investigate the sensor behavior compared with the optical measurement system for repeated measurement analyses. All the subjects have almost equal geometric characteristics influencing slightly the resonance frequency when they assume the $P_{\text{hyper-ext}}$ posture and for this reason a reference frequency previously chosen at 3.92 MHz has been used.

A consumption measurement was carried out during the tests. The current supplied during a continuous device operation, considering both the measurement operations and transmission, is about 180 mA permitting a continuous functioning for more than 2 h. The exercise used is that described previously in which the patient is sitting and slowly performs a lengthening and a straitening of the body (Fig. 1).

Fig. 10 shows the lengthening values (Δl) obtained with the optical system and the voltage values (V_o) obtained with the designed circuit board for all the subjects. The lengthening values (Δl) are obtained calculating the total elongation of all the segments on the back and chest (B1-B2, B2-B3, ... F5-F6). The experimental data shown in Fig. 10 represent the lengthening obtained with the measuring system and the lengthening obtained with the reference system, since the reference frequency is always the same. Therefore, all the data have been put together to obtain the most prospective values for uncertainty estimations.

In Fig. 11, the lengthening data obtained with the optical system versus the designed conditioning circuit (mean ±1 SD) for all the four subjects is shown. The relationship between the T-shirt's lengthening change measured by the optical system and the output voltage measured by the electronic circuit is shown. An experimental standard deviation of about 68 mV for low lengthening has been obtained, whereas for high lengthening values, the voltage output standard deviation is about 23 mV. Therefore, the maximum experimental uncertainty is about 4.9 mm. The 10-b resolution of the ADC gives a voltage resolution of about 2.9 mV, corresponding to a lengthening of about 0.6 mm in the worst case.

VI. Conclusion

In this paper, a wearable wireless T-shirt is designed for measuring the lengthening induced on a T-shirt adherent to the body by different postures during a reinforcement exercise. An inductive sensor is integrated in the T-shirt textile, sewn directly on the fabric; its impedance changes when a geometric deformation, caused by the lengthening and straightening of the body, is applied on the T-shirt. An electronic circuit measures the impedance value and outputs a voltage.

A clinical evaluation of posture assumed by the patient requires to be done by a physician who can, through the use of the prototype, establish a relationship between the quality of the posture of the patient and the voltage output. The system has a biofeedback postural signal (vibrations) that can help to facilitate therapeutic approach. This signal can be obtained through a vibratory stimulus achieved with a vibration micromotor and it can be activated by an algorithm that implements the suggestions of the physician that has in charge the responsibility of the diagnosis on correct or incorrect posture. This way, patients are encouraged to assume the correct postural habits that could restore the proper physiological state.

Each patient that use the proposed system can have different geometric characteristics influencing in this way the deformation induced on the T-shirt even if the same posture (for example, $P_{\text{hyper-ext}}$) is assumed. Due to the deformation change, the resonance frequency also changes when the subject is in $P_{\text{hyper-ext}}$ posture. Since this frequency is used as reference for the electronic circuit, the new value can be generated in an automatically way. This can be done automatically since a DDS is used and the resonance frequency at $P_{\text{hyper-ext}}$ can be recognized as the frequency in correspondence to the maximum impedance value when the subject is at $P_{\text{hyper-ext}}$.

Since the sensor output is a voltage related to the deformation of the T-shirt, the prototype has been tested by comparing its results with those obtained by an optical measurement system typically used in experiment for body movement analysis. Four volunteers have been available for the test letting us to evaluate a lot of experimental data. The volunteer has similar physique; therefore, it was not necessary to change the reference frequency. In this way, the voltage output of the system and the deformations of the T-shirt have a direct correspondence and all the data have been used to estimate the uncertainty. The maximum experimental uncertainty is about 4.9 mm, which is considered sufficiently for the proposed application.

The impedance value of the sensor can change due to the different factors, such as, for example, due to the relaxation of the T-shirt or due to the skin conductivity variation. The T-shirt with the sewn copper wire is washable; it was washed (expecting a relaxation) because of its use and then no variation of the L parameters reported in Table I was observed. Anyway, in case of fabrication, the synthesizer allows to change the frequency to obtain the maximum value of the impedance when the patient is in $P_{\text{hyper-ext}}$. Operatively, this means that the T-shirt can be calibrated, when necessary, pushing a button and recovering thus possible unwanted variations. The skin conductivity variation and the consequently effects have to be deepen by other studies and research activities even if, as the reported experimental results conducted over different days and places show, it can be concluded that these effects are secondary.

Since the inductive sensor consists only of a commercial copper wire, the T-shirt is simple and light. The electronic circuit board is separated and is placed in a pocket connected to the T-shirt by two snap buttons. Such electronics can be integrated in a silicon circuit, powered by battery, constituting a device of a few grams; then, a small lightweight battery can be adopted. Therefore, the proposed T-shirt is wireless, lightweight, wearable, and meets the clinical and psychological needs, such as patient comfort, easiness of use, and noninvasiveness.

Furthermore, other aspects were considered; during rehabilitation exercises, physical activity is not likely to make the subject sweats, however, even if this should happen, the sweat in normal condition does not interfere; the variation of the parasitic capacitance of the sensor, which may be generated, is not influential because negligible with respect to C_S. Furthermore, the variations in the conductive paths of the currents caused by the sweat are avoided because the copper wire is enameled, preserving it also form the possible environment influence and not in contact with the human body.

Furthermore, since the circuit board processes the data directly on the T-shirt, and then the data are available for immediate presentation and analysis, or sent via Internet using the readout unit, it is possible to monitor the rehabilitation exercise in remote with advantages such as:

1) reduction of the environmental impact created by unnecessary patient's travel;
2) increasing the effectiveness in terms of optimizing the use of resources and clinical nursing;
3) reduction of the social cost of caregivers.

Further research is underway to further reduce the consumption of electronics. The prototype that we have described here allows achieving the goal of this paper that aims to assess the behavior of T-shirt for this specific application. The research in progress will maximize the performance of the prototype.

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