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Posture Monitoring Device for Abnormal Spine Musculoskeletal Detection Using Flex Sensor

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Abstract: During activity of daily living involving standing, sitting or maneuvering, humans are typically susceptible to neck and shoulder strain, and other musculoskeletal conditions, severity of which may lead to posture deformity. To prevent these clinical conditions, we developed a low-cost and user-friendly posture monitor mainly built on a single flex sensor. The design was based on abnormal posture detection by a flex sensor whose signal triggers a buzzer to notify the user or care giver of these clinical conditions. Through Arduino IDE, an ATmega328 microcontroller controlled the sequence of the flex sensing to the audible alarm output. The buzzer was designed to go off automatically when the user adjusts his/her posture to normalcy. With a sensitivity of 84.6% during testing of this device, the developed posture monitoring device could be adjudged effective and suitable to monitor people's posture while sitting or standing especially in environments where menial jobs are prevalent. In these individuals, this device may prevent deformity prone diseases that may warrant surgical intervention for correction.

Keywords: Activity of daily living; Flex sensor; Musculoskeletal conditions; Posture deformity; Posture monitoring.

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1. INTRODUCTION

According to the world health organization (WHO), musculoskeletal illnesses are mostly responsible for physical disability globally irrespective of age [1]. This illness is characterized by shoulder, back and neck pains and may significantly affect physical and functional activities, and ultimately threatens useful productive life and healthy living [2, 3]. For example, slouching which may negatively affect the “transverses abdominis muscle” may lead to low back pain [4, 5]. Also shoulder and low back pains are common in workplaces where workstations are used [6] leading to “Work-Related Musculoskeletal Disorder” [7]. The global prevalence of this condition indicates one out of three persons living with chronic pain associated with a musculoskeletal condition and this increase with age [2]. Therefore, effective and inexpensive prevention of this condition is desirable in order to check the significant financial burden which may be associated with the management of the complication of musculoskeletal related illnesses. One important advantage of this is that upright posture promotes musculoskeletal integrity especially for individuals earning their daily living from menial and monotonous job requiring long hours of clinically bad posture. Literature evidence [8, 9] has shown that a good posture via clinically healthy muscle activity is required for a good metabolism.

Therefore, efforts to keep the human posture in a neutral position, to avoid poor posture complications, have led researchers to come up with several solutions. For example, a complex posture monitoring procedure based on gait analysis in a gait laboratory with installed infrared camera on anatomical locations has been suggested by Nault, Allard, Hinse, Le Blanc, Caron, Labelle and Sadeghi [10] and Engsberg, Lenke, Uhrich, Ross and Bridwell [11]. Apart from the complexity of this approach and long duration of set-up, it cannot be applied for posture monitoring in real time [12] except with huge financial implication. The use of accelerometer for posture monitoring also has been reported to be characterized by low sensitivity as accelerometers are mostly suitable for acceleration measurement [13] and need to be combined with other sensors for improved sensitivity. Flex sensor for posture monitoring was also proposed by Gopinath and Kirubha [14]. While this study provided good information on the application of flex sensors for posture monitoring, the study was limited to the effects of spine load variations to infer the flex sensor’s sensitivity to posture deformity. The study did not present information on the device’s sensitivity and its performance in real life’s task execution.

Apart from the fact that the available options have their associated limitations, efforts to design an alternative approach that is not only wearable [15] but could be used for individuals living in limited resource environments is therefore of research interest. Based on this background, we sought to develop a low-cost and user-friendly posture monitor based on a single flex sensor and associated and readily available accessories. The device was made to be wearable, easy to use and potentially relevant in clinical settings due to its ability to work off the main electricity supply.

2. METHODOLOGY

2.1 System design and description

Here the system design and the device's working principle are described. The main units are connected as shown in the block diagram (Figure 1). The sensor placement considered the anatomical location and attachment method [15]. Therefore, the flex sensor was securely attached (Figure 2), using an adhesive tape, to the upper back location over the trapezius muscle (i.e., "a large, paired, trapezium-like muscles in the back that extend longitudinally from the neck to the upper back and prominent in the cervical, thoracic, and shoulder regions [16]") being the position of interest for capturing trunk slouching or bending that may also lead to neck pain following neck craning and posture imbalance. Apart from being specifically responsible for neck extension, trapezius muscle generally supports upright postural stability [17, 18]. The muscle is also responsible for "side bending and turning of the head, elevation and depression of the shoulders, and internal rotation of the arm" [17].

The flex sensor is then connected to the Arduino Uno board which houses the 328p microcontroller [19]. The microcontroller interprets the flex sensor signal (i.e., which converts the bending angle into electrical resistance changes), and feeds the alarm with the appropriate response. The power supply unit that feeds the Arduino board, Flex sensor and Alarm is a 9V battery source.

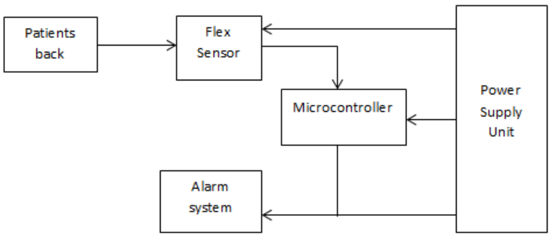

Figure 1. Block diagram of the design connections

2.2 Theoretical background/ Design specification

The resistive flex sensor (RFS) is a passive electronic component which works on the principle of bending the strip away from a reference. This bend results in change in the resistance of the device and hence, the output voltage from the device. Being a passive component, it does not require a power source to work [20]. The resistance therefore increases linearly as the bending angle increases. The equivalent circuit model of the sensor is as shown in Figure 2.

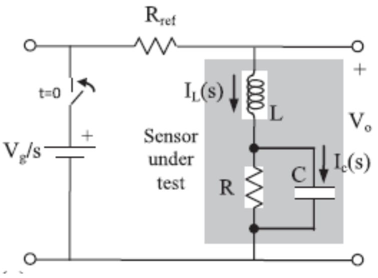

Figure 2. Equivalent circuit model for Resistive flex sensor [20].

Where I_L is the inductor current; L is the inductance of the inductor; R is the resistance; C is the capacitance of the capacitor, I_C is the capacitive current; V_g/s is the supply voltage and V_o is the output voltage.

A RFS is often utilized in series with a fixed resistor to form a voltage divider circuit configuration. The flex sensor serves as the variable resistor as shown in Figure 3. A fixed resistance of 10KΩ is adopted in this design, hence the express for output voltage (V_0) [20, 21] is as indicated in Equation 1:

$$V_0 = \left(\frac{R_{fixed}}{R_{fixed}+R_{flex}}\right)V_{cc} \tag{1}$$

Where R_{fixed} is the fixed resistance for this design; R_{flex} is the resistance of the flex sensor at that instance and V_{cc} is the supply voltage.

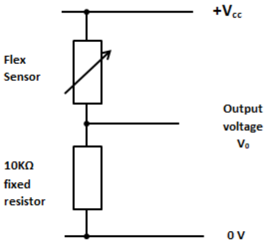

Figure 3. Flex sensor voltage divider configuration for this design.

2.3 Materials and Method

The device essentially consists of three sub-units including the sensor unit (i.e., flex sensor), control unit that house the microcontroller and power unit. The software used for designing the circuit diagram is Proteus Design Suite (Labcenter Electronics Ltd., North Yorkshire BD235AJ, England). The Arduino UNO (Arduino, Scarmagno, Italy) is the main part of the circuit of the system as all other components include resistor, buzzer, and others (Figure 4). Table 1 presents the justification for material selection in this study [22].

Table 1. Material selection and justifications

S/N	Materials	Device modules	Justification
1.	Flex Sensor	Hardware	It is cheap and can be used to implement a safe monitoring system.
2.	Arduino uno	Hardware/ Software	Easy to program to read input and generate useful output. It is inexpensive and readily available.
3.	Bluetooth	Hardware	It can be easily interfaced with Arduino uno. It is inexpressive and uses a low power radio frequency. It is interoperable, and it

			consumes very little energy.
4	Vibration motor / Buzzer	Hardware	Inexpensive, compact and easy way to realize a vibrating alarm system for the user.
5.	Battery (Lithium Polymer)	Hardware	It is cheap, flat, compact, rechargeable and available.

Table 2. Bill of quantity for the device

S/No.	Item	Quantity	Unit price (USD)	Total (USD)
1	Flex sensor	1	13	13
2	Arduino UNO	1	9	9
3	Buzzer	1	1	1
4	Jumper wires	10	0.05	0.5
5	Vero board	1	0.5	0.5
6	A reel of soldering wire	1	10	10
7	Battery (500mAh)	1	8	8
8	Battery connector	1	5	5
9	Pastress	1	5	5
10	Electronic components	lots	10	10
11	Miscellaneous	lots	10	10
Total				72

2.4 Operational Algorithm

Sequel to the sensor placemat as shown in Figure 5, the following steps [23] are required for the device operation:

Step I: Start — turn on the device.

Step II: Calibrate — after 10 sec of device use, a reference is created by the microcontroller.

Step III: Posture measurement /detection — microcontroller calculates the angle.

Step IV: Compare the angle with the threshold, which one is bigger? — decide posture situation.

Step V: Any flex sensor bending noticed? — Done by Microcontroller. If bent, slouching by the user is indicated, while otherwise indicates normal posture.

Step VI: Beep — Once the posture detected is poor (i.e. based on steps IV & V), the beep will be triggered by the buzzer controlled by the microcontroller for the posture adjustment by the user.

Step VII: End

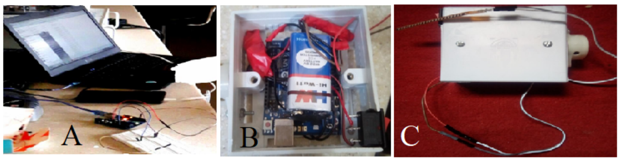

Figure 4. The device assembling stages: (A) Electronic component testing; (B) Components arrangement; (C) Final outlook of the assembled posture monitoring device

Figure 5. Experimental set up using the device while standing (A) and while in sitting position (B).

2.4.1 Study participants

Five individuals (3 males and 2 females), aged 23.2±2.4 years (mean ± standard deviation) volunteered for this experiment after the experimental procedures were thoroughly explained to them. They were made to understand their right to discontinue the experiment at will. The subject had no physical musculoskeletal deformity and could normally stand upright unaided.

2.5 Results

Eight separate trials (i.e., four at upright stance and four at upright sitting positions) (Figure 2) were performed by each participant with 5-degree reduction (i.e., starting from 180-degree as the reference point at upright stance/sitting to 145-degree) in the hip flexion angle at sagittal plane when the volunteers were in upright/normal anatomical position. These angles were measured by a goniometer. The results of the tests carried out on the volunteers to determine the functionality and sensitivity of the device showed that when the participants were in the upright postural position (180), which was considered normal postural position, where there was no alarm. However, when the participants were at other seven different hip flexion positions (i.e., 175, 170, 165, 160, 155, 150, 145) there were alerts in each case demonstrating that the device sensed that the participants were slouching indicating bad posture which may lead to bad musculoskeletal conditions.

To determine the device's sensitivity, we employed the standard formulae as detailed in Trevethan [24] and reported the results in Table 3. Based on the following formulae (Equation 2) was applied.

$$\text{Sensitivity} = [\frac{TP}{TP+FN}]x100 \qquad (2)$$

Where TB is true positive i.e. when the device correctly indicated that the participant was slouching and FN is when false negative i.e. when the device wrongly indicated that the participant was not slouching. Between sixteen (16) and twenty (20) trials at different randomized hip flexion angles were performed by the participants as desired (Table 3) excluding 180-degree which is normal postural position.

Table 3. Sensitivity of the device

Participants	Number of Trials	TP	FN	FP	Device Sensitivity
P1	16	12	2	2	85.7%
P2	17	13	2	2	86.7%
P3	19	13	3	3	81.3%
P4	18	13	2	3	86.7%
P5	20	14	3	3	82.4%

Abbreviations: TP- True Positive; FN- Force Negative; FP- Force Positive

Considering all the participants' results, the device had an average sensitivity value of 84.6% (between 81% - 87%) which may be adjudged good [25] and encouraging results for further exploration of this device in clinical settings.

2.6 Discussion

This study sought to develop a low-cost and user-friendly posture monitor based on a single flex sensor and related and readily available accessories. This low cost $72 (Table 2) device has been developed and showed very good sensitivity (84.6%) in detecting slouching/bending in young adults indicating a good diagnostic potential for clinical use. With this device, the common problem of inability to monitor posture will be ameliorated and secondary complications checked especially in persons doing menial jobs, skilled computer system users, and employees confined to sitting and standing position.

The device cost, audible alarm, ease of use, and portability are its specific uniqueness that make the device useful in low resources settings unlike the commercialized options. A posture monitoring system was developed by Alsuwaidi, and colleagues [23]. Although the device showed 85.1% selectivity when tested with a user, however, the device employed muscle sensors, it is bulky and expensive for people living in limited resource settings [23]. The posture monitoring solution suggested by Liao [26] was also too "sophisticated" for the large majority of our target population in resource limited settings. For example, this device required a smartphone and other accessories for set up and literacy is also required for its operation. Furthermore, the smart pillow designed by Birsan et al, 2017 [27] targeted low back pain prevention especially for individuals sitting for long duration. This device is cumbersome and specifically targets persons in sitting position. In contrary to these studies and other equally complex and cumbersome studies in the literature, the posture monitoring device described in the present study was specifically made to be easy to use, portable and cost-effective.

3. CONCLUSION

Using an affordable flex band sensor, an inexpensive (< USD 80) posture monitoring device has been designed, developed and tested. This device is particularly useful in low resource settings especially for peasants, laborers, and related employees that traditionally perform their activities of daily living. This is due to the fact that traditional and manual activity performance predisposes this category of people to posture deformity that must be monitored early in order to prevent secondary complications and medical emergencies. This developed device may also be useful to occupation therapists interested in monitoring their clients' posture while on duty.

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