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Low Cost E-textile IoT System for Posture Monitoring

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ABSTRACT : *In this paper, the design of a low-cost e-textile design for mobile internet of things (IoT) posture monitoring is presented. The prototype exhibits good performance and provides comfortable user experience. The design is accomplished with conductive connection between the electronics part and the fabric easier and less costly than similar products on the market. The results show that the product can accurately monitor posture while also providing effective communication and not causing physical discomfort to the user. In addition, it can set a standard for this industry by solving the washing and folding problem experienced in e-textile applications with its easily removable part feature.*

KEYWORDS -*Electronic Textile, Internet of Things (IoT), Posture Monitoring, Wireless Communication*

I. INTRODUCTION

Posture correction is a highly emphasized subject in protecting spinal cord health and preventing related health issues. During unconscious actions such as sitting or walking, long-term incorrect posture can cause deterioration of spinal cord health, leading to diseases such as kyphosis and scoliosis [1][2]. Electronic textile (e-textile) products are emerging in order to monitor the health of the user as a pre-warning for these and similar medical conditions. However, the problem of e-textile products is the obstacles that arise during the joining process of solid and sensitive electronic components with soft and stretchable fabrics[3]-[5]. Electronic components should be chosen from the smallest possible parts in order not to cause discomfort, but at the same time, system performance should not be compromised. Although some studies offer solutions for some of the above-mentioned problems, they present new challenges due to high cost, very specific manufacturing requirements, and the absence of a standardized testing procedure.

In this study, a posture monitoring e-textile product, which was developed to support the protection of the spinal cord health of the user, contains effective communication within the scope of engineering standards and also has the possibility of mass production due to its low cost, is discussed. We demonstrated the ease of use, system design and effective communication performance of our design. The results show that our product will set a suitable standard for future work in the field of e-textiles and posture correction.

The rest of the paper is organized as follows: In Section II, we compared our work with other work in the field of e-textiles. Section III describes our system design and overall product. In Section IV, it shows the product's posture monitoring signal output and communication performance results. In Section V, a conclusion is given.

II. RELATED WORK

This section provides a literature overview of similar solutions and products on the market and compares them to the functionality and main design features of the proposed prototype.

In reference [6], a wearable obstacle detection system for visually impaired people is presented by incorporating neuro-fuzzy controller-based algorithm into textile structures using silver-plated nylon yarn. In [7], the smart wear product with electrocardiogram (ECG) feature, which provides signal transmission through specially produced dry electrodes, is designed to transmit heart and activity tracking signals via Bluetooth Low Energy (BLE). In [8], a smart textile product with an ECG sensor is presented in order to monitor heart activities on a polymer based special production conductive fabric. In this study [9], while the receiver embroidered on the chest part detects the heartbeat and respiratory changes caused by chest movements, the signals are transmitted to the computer by passing through hetero-core optical fiber sensors surrounded by woolen yarn. The split ring resonator (SRR) antenna working with the Radio Frequency Identification (RFID) tag with the maximum reading distance is combined with the Ethylene Propylene Diene Monomer (EPDM) featured textile material to create a smart glove product for industrial areas [10]. In this article [11], a low-budget posture monitoring system is combined with conductive copper wiring and textile, and with the flexibility sensor, it can detect bending in the back area during movement with less than 3 degrees sensitivity. In [12], around 100 meters of conductive silk yarn was produced using the PEDOT:PSS based watercolor bath technique, and as a result, these yarns exhibited a high conductivity of about 70 S cm^{-1} compared to other coated fibers and yarns. In this study [13], pressure sensors made of piezoresistive material are embroidered with silver-coated nylon thread and designed to report physical damage to the wearer. In [14], an electro-chemical sweat biosensor embroidered with conductive yarn coated with zinc oxide nanowire on a headband is designed to measure lactate and sodium formed in sweat during physical activity. In [15], an e-textile mat with sensors sewn to fabric using silver-coated spun polyester polyfilament is presentedto monitor body position and preventdecubitus ulcers in bedridden people.

In contrast, in this paper, the connection between electronics and fabric with a conductive thread made of stainless steel fibers is provided. When we look at the e-textile studies in general, it is claimed that the yarns coated with silver and stainless steel are the best options for the studies in this field [16][17]. The cost of this thread is in the low budget range and it is suitable for use in most e-textile studies in terms of ease of use. The disadvantage of non-insulation due to being uncoated is eliminated by strategically sewing the conductive thread on the insulating textile fabric so that they do not touch each other.

III. SYSTEM DESIGN OF THE E-TEXTILE PRODUCT

3.1 Work Principle

The prototype proposed in this study registers the resistance change from the bending of the flexibility sensor as an analog signal and transmits it to the mobile device via the Bluetooth module after analyzing it in the micro-controller. If the signal value remains below the predetermined threshold for a certain period of time, the vibration motor is activated and gives a warning to the user.

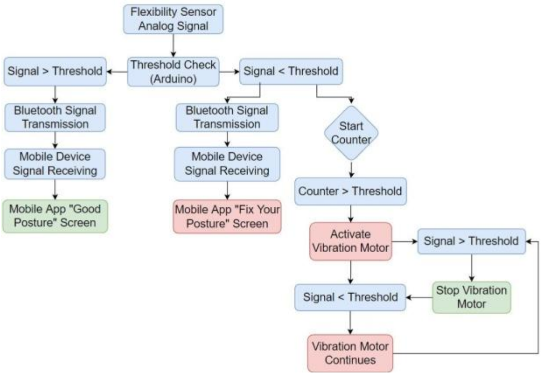


Fig.1. System Work flow

The overall system is designed to work with 7.4 volts. The 5V and 3.3V inputs of the Arduino Nano are arranged for the Bluetooth module and the flexibility sensor, respectively. While the flexibility sensor requires 0.50 Watts, the Bluetooth module has a maximum current usage of about 40 mA.

The Bluetooth module, used for communication in the general system, works with the Bluetooth 2.0 protocol and provides file transmission speed of approximately 2.0-2.4 Mb/s. Serial data is transmitted by the module at 9600 bps over the TXD pin, and received at 9600 bps over the RXD pin.

3.2Materials

The proposed system consists of a flexibility sensor, Arduino Nano Micro-controller, vibration motor, Bluetooth HC- 06 communication module, 10K ohm resistor and 7.4V lithium battery. The type, size and number of parts selection for the prototype is based on the examination of similar solutions in the literature. The common point of view for the selection of parts in electronic textile works is to use the smallest and minimum number of parts.

Arduino Nano is a small and complete micro-controller. Although it has very similar features with other controllers in the Arduino brand, it is chosen for projects that require the use of small parts. It is 45 mm long and 18 mm wide, weighs only 5 gr. In addition to its small size and light weight, it has been deemed suitable for use in the project with 20 mA DC current per I/O pin and 5V I/O voltage feature.

The most important element in the prototype for posture monitoring is the flexibility sensor. It is based on resistive carbon elements. These elements are arranged on a flexible thin sheet. When this sheet bends, the sensor outputs a resistance proportional to the bending radius. The smaller the bending radius, the higher the resistance value. Figure 2 is the flexibility sensor used in the project. The sensor has a width of 6 cm and a length of 12 cm. The flexibility sensor, which has a resistance value of 25K ohm when not under pressure, has a resistance range of 45K ohm to 125K ohm depending on the bending radius.

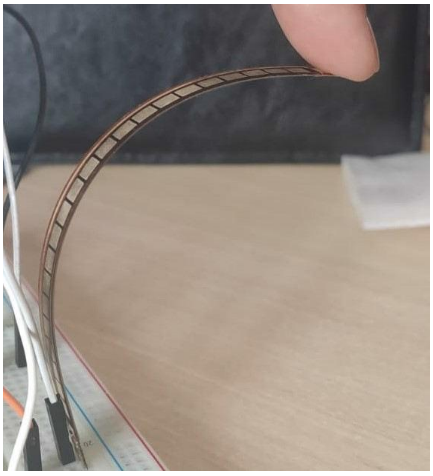


Fig. 2. Flexibility Sensor

The Bluetooth HC-06 communication module used in the system is responsible for transmitting the signals received by the micro-controller to the mobile device. HC-06 with Bluetooth 2.0+Enhanced Data Rate protocol also works with2.4 GHz frequency. The HC-06 module is 43x16x7 mm in size and has an operating voltage of 3.6-5V. Although it has less than -80 dBm in sensitivity, it allows asynchronous transmission at 2.1 MBps/160 KBps.

There is a vibration motor placed in the system to give a physical warning to the user. The vibration motor is 10x3 mmin size and weighs 1.2 g. The motor, has an operating voltage of 2.5-3.5V, and works at 13500 RPM/60 mA current.

The battery used to power the overall system is a 7.4V 2S Li-Polymer battery. It is produced using lithium and polymer chemicals. The abbreviation "2S" in its name indicates that it consists of cells and has a cell value of 7.4V. The battery has a capacity of 420 mAh, a voltage of 12.6V±0.05V, and a nominal voltage of 7.4V±0.05V. Since the designed product is a prototype, a strong and long-lasting battery was desired, so it was decided to use it considering its size and weight. However, the system is also suitable for use with different types of batteries, given that it provides the necessary power. The battery used in this system weighs 32 gr and is the heaviest element of the system.

The electronic components other than the flexibility sensor and vibration motor are on the PCB board. The connection of the flexibility sensor and vibration motor with the PCB board is made with a stainless steel coated conductive thread. The only downside is that being uncoated requires a strategic sewing without touching each other to prevent accidental short circuits. However, since the stainless steel has a high resistivity against water and low concentrated acid, this product can be exposed to dry cleaning and not affected by sweat [18].

3.3 Textile Integration

In order to check the performance of the designed circuit, first all the parts were installed on the breadboard and tested. Then the circuit was built on a 6x8 cm perforated board which was later optimized and reduced to 3x8 cm. The points where the conductive thread is to be connected to the circuit have been adjusted for processing with copper wire.

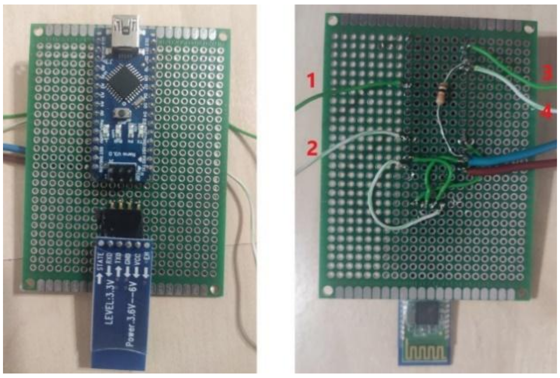


Fig. 3. Circuit Board (Front - Back)

Figure 3 shows the front and back sides of the electronic board, respectively. The numbers marked as 1 and 2 in the figure 3, show the connection points of the vibration motor, while numbers 3 and 4 show the exposed connection points of the flexibility sensor.

Fig. 4. Conductive Thread Sewing

Figure 4 shows an example of sewing open-ended cables on the PCB board to the fabric with the help of conductive thread. The strength and conductivity of the seams have been test edat every stage of sewing. The simple and functional sewing of the conductive thread is prioritized.

3.4 User Interface

The proposed mobile application is developed for mobile devices with the Android operating system and is designed with the Massachusetts Institute of Technology's "MIT App Inventor" program.

A welcome screen is launched when the application is first launched. The country flag symbol and the "Bluetooth Pair" button on this screen provide access to the language options and Bluetooth devices pages, respectively.

The Bluetooth device page updates itself and lists the addresses and names of the devices using active Bluetooth within the device communication range. The Bluetooth HC-06 module that we want to pair here requires a password for security, after the password is provided, the connection is established and the home page screen turns into screens showing the current posture of the user.

The determination of these screens depends on the signal values from the prototype. Signal values are compared with the threshold values specified in the application algorithm.

IV. RESULTS

This section presents the empirical results from several groups of tests carried out with the prototype. These include sensor tests, transmission tests and total prototype operation tests. The results are compared with simulations and the final product is tested with an actual user.

4.1 Experimental Setup

The experimental setup is divided into two parts. In the first part, the signal test of the flexibility sensor is compared with the results obtained in the simulation environment, while in the second part, the product function and wireless communication test were performed in a 12.5m x 12.0m apartment. Since this apartment environment includes walls, closed doors and furniture, it creates Line of Sight (LoS) and Non-Line of Sight(NLoS) situations for Bluetooth signals. In the second part, the user exhibited his daily life activities in the apartment by wearing the product for 2 hours without interruption.

4.2 Sensor Measurement

Flexibility sensor is the most important functional part in the prototype. The flexibility sensor's value in the correct range is an important point to ensure the accuracy of the received signal and the robust construction of the next steps. For this purpose, circuit and simulation values are compared for different angles between 0-180 degrees.

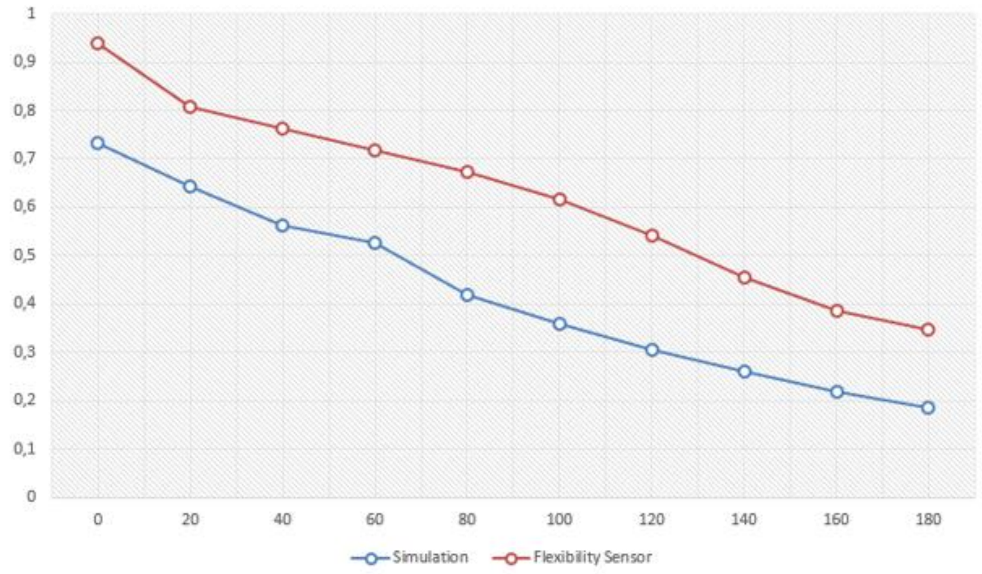


Fig. 5. Voltage vs. Bending Angle

The blue line graph in figure 5 shows the values obtained from the simulation, while the red line graph shows the flexibility sensor signal values taken from the actual prototype. The sensor resistance, which changes with the angle change of the flexibility sensor, affects the output voltage of the whole system. This output voltage data has been recorded over the simulation.

However, it is not correct to directly take the signal obtained from the circuit in terms of voltage. The reason for this is that the Arduino processor maps the analog voltage value received from the sensor in the range of 0-1023 and reflects it to the output as "sensor value". To get the actual output voltage value from here, the following formula specified by Arduino is used [19]:

$$V_{out} = Sensor\ Value\ x\ (\frac{V_{in}}{1023.0})$$

When the results are examined, the signal difference be- tween the simulation and the real circuit is in the range of0.16 volts minimum and 0.25 volts maximum.

4.3 Posture Monitoring

The purpose is to test the overall system operation on a real user. The success criterion of the system is that when the user shows a bad posture, the flexibility sensor stays below the threshold value for a certain period of time, thevibration motor is activated and at the same time the necessary warning is received through the mobile application. In order to get as many warnings as possible from the system during the test, the incorrect posture time for the vibration motor activation was determined as 5 seconds. For actual products this threshold time is considered to be 30 seconds.

Note that, the metric we call the "sensor value" is the analog voltage value that the Arduino processor maps between 0-1023 Volts. For this reason, calculations and threshold determinations were made on this metric. The reason why the threshold value was chosen as 250 sensor value depends on the medical studies in the literature. In studies on postural disorder, the negligible mean bending angle for spinal cord health has been observed to be between 10-20 degrees, while it has been concluded that an inclined posture of 30 degrees or more poses a danger to spinal cord health [20]. For this reason, in our study, the flexibility sensor was placed in the area between C7-T4 vertebra of the spinal cord and the threshold degree is determined as 250 sensor value (30-35 degrees inclination).

Figure 6 shows the posture change experienced every 5 seconds. While the sensor value is 320 on average, the user is in a completely upright posture, the tilt angle is 0 degrees. When the user is tilted at a 20 degree angle, the sensor averages 280. Finally, when the user stopped at an angle of 35 degrees, which is considered dangerous, the sensor value fell below the 250 threshold, and after 5 seconds the vibration motor was activated for warning. At the same time, the mobile device showed the "incorrect posture" screen.

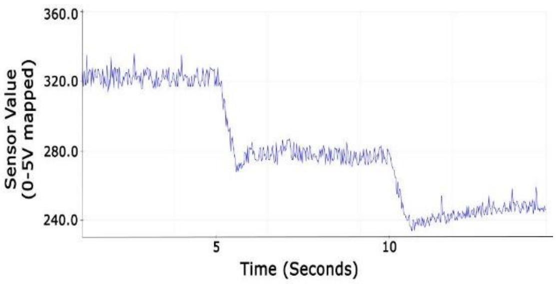
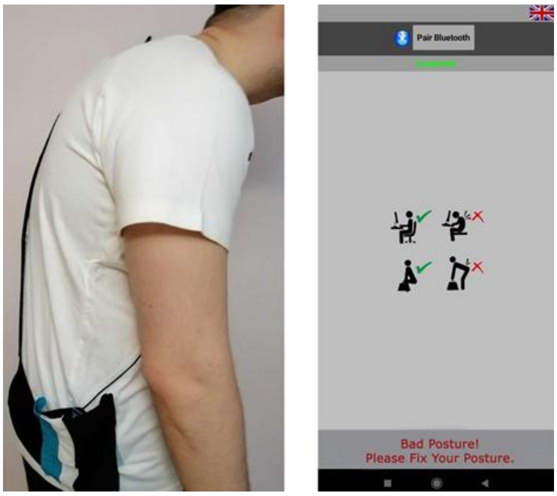


Fig. 6. Posture Signal Monitoring

Figure 7 shows the rear and side view of the prototype while the user is in the correct posture, respectively. The numbers1,2 and 3 appearing on figure 7 represent the fixed positions of the flexibility sensor, vibration motor and PCB board on the product, respectively. The placement of the flexibility sensor at number 1 is also based on spinal cord health studies referred to the experimental setup section. The reason why the PCB board is placed in position 3 is that it does not cause discomfort to the user while leaning. The colored part seen on the prototype contains all the electronic parts and can be easily detached during washing, drying and folding of the garment.

Fig.7. CorrectPosture(Back-Side)

Figure 8 shows the user incorrect posture and the warning screen from the activated mobile application, respectively. When the time, the user spends in the incorrect posture exceeds the threshold time value determined, the vibration motor starts to give physical warning to the user. Here, the reason why the vibration motor is activated after a certain period of time is to prevent false warnings during short-term bending movements (eg. reaching out, short unconscious movements etc.).



Bad Posture!
Please Fix Your Posture.

Fig.8. Incorrect Posture and App Warning

4.4 Communication Stability

This test was carried out to determine the uninterrupted communication distance of the system in environments with LoS and NLoS situations. Data was collected with the Arduino interface and the dependence of the RSSI values on the number of walls is taken into consideration. The communication module used, Bluetooth HC-06, is power class 2 device. Therefore, values between -46 dBm and -70 dBm in positions containing LoS indicate a strong connection, while an RSSI value between -70 dBm and -100 dBm in NLoS positions indicates a medium level connection [21][22]. The maximum distance recorded during this test are in line with previous studies with the same communication module [23][24].

Figure 9 shows the environment where the communication distance test is performed. "P0" in Figure 9 shows the location of the prototype. While the positions where the mobile device is positioned during the test are shown as P1-P8, the colors(green, yellow, red) indicates the signal transmission strength in these positions.

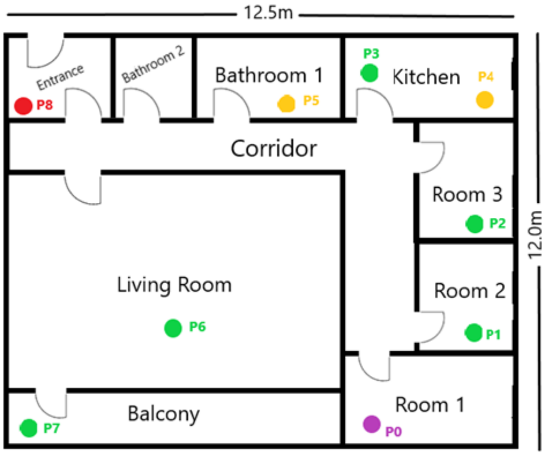


Fig. 9. Experiment Area

Table I shows the perpendicular distance from the P0 point to the other specified positions. Each wall of the house is 15cm thick. Looking at the results, only one position shows a disconnection, this is because the class 2 module wants to transmit to a point farther than the maximum signal transmission distance. The remaining positions are mostly strongly connected.

During the P4 position test, the in-between kitchen door and room1 door were kept closed. P3, the only position where the LoS is provided, showed value in the strong connection range even the maximum distance was more than 10 meters. All the remaining positions were considered NLoS.

Table 1: RSSI Measurement

Pos.	Dist. (m)	Wall	RSSI (dBm)	SNR (dB)	Connectivity
P1	5.1	1	-43.2	47.1	Strong
P2	6.7	2	-65.6	24.7	Strong
P3	11.1	0	-56.3	34.1	Strong
P4	11.4	3	-94.7	-4.4	Medium
P5	10.7	1	-86.2	4.1	Medium
P6	6.2	1	-62.3	27.9	Strong
P7	9.4	1	-68.1	22.2	Strong
P8	14.1	1	-101.2	-9.7	Disconnect

Table 2: PER Measurement

RSSI (dBm)	SNR (dB)	PER (%)	Interference Type
-43.5	46.2	0	Wi-Fi, Bluetooth
-92.9	-3.2	1,142	Wi-Fi, Bluetooth, Microwave
-61.9	21.3	0,012	Bluetooth
-69.3	18.4	0,071	Wi-Fi, Bluetooth
-52.6	37.1	0	Wi-Fi

Table II shows the Packet Error Rate measurements in environments where the communication module signal transmission is subject to different signal interference. Packet Error Rate (PER) is defined as the ratio of the number of packets received with errors to the total number of received packets. If a single bit in the packet is wrong, the packet is discarded. The PER expected value is defined in terms of packet error probability pp and packet length N as follows:

$$p_p = 1 - (1 - p_e) = 1 - e^{N * \ln(1 - p_e)}$$

Assuming that the bit errors are independent of each other, the approximate value for low bit error probability and large data packets is shown as follows;

$$p_p \approx p_e * N$$

When the above formulas are rearranged, the bit error rate (p_e), PER (p_p) and packet length (N) are calculated as follows;

$$p_e = 1 - \sqrt[N]{1 - p_p}$$

In total, 100 packages were sent for each position and the average values were recorded after the test was repeated 10 times. Each packet length is 100 bits.

Wi-Fi modem, wireless speaker, wireless TV receiver, mobile phone, laptop and microwave oven devices are operating full power to simulate possible signal interference in the ISM band.

Looking at the results in Table II, it can be seen that the RSSI values are in the range of -40 dBm to -60 dBm, which results in error free transmission. In locations where the RSSI value is between -60 dBm and -70 dBm, a very low PER value below %1 was observed. In the situation when the microwave, Bluetooth and Wi-Fi devices are simultaneously operating, the PER value exceeded %1. However, the recorded values are acceptable as specified in the IEEE standards and can be recovered through error correction mechanisms.

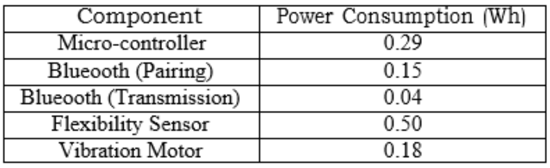
IEEE standards specify PER values in the range of 0-1% "good", 1-2.5% as "acceptable", 2-5% as "poor", 5-12% as "very poor", and "bad" for 12% and above [25][26]. Thus in our case the results are "good" in general, and "acceptable" in cases under the influence of high interference.

4.4 Power Consumption

The hourly power consumption of each piece used in the prototype is given in Table III. Micro-controller, Bluetooth module and flexibility sensor continuously transmit and process data during operation. However, during use, the Bluetooth module (unless the connection is disconnected) pairs the device once, and the vibration motor only activated when the person exhibits an incorrect posture.

The power consumption for this prototype varies depending on the user's action. Considering a scenario where the communication module makes a one-time pairing and the vibration motor runs for 5 seconds each time in case of 10 posture errors; the total hourly power consumption for all components is 0.83 Wh on average. A power source with a capacity of 3.33 Wh can run the system for approximately 3.9 hours in this scenario. The battery used for this study has a rechargeable feature. If desired, it can be replaced with a different battery.

Table 3: Power Consumption



Component	Power Consumption (Wh)
Micro-controller	0.29
Blueooth (Pairing)	0.15
Blueooth (Transmission)	0.04
Flexibility Sensor	0.50
Vibration Motor	0.18

V. CONCLUSION

The prototype proposed in this study aims to monitor the posture of people without requiring them to carry and additional devices. The designed electronic circuit is unobtrusive, neatly tucked up and includes effective wireless communication. The flexibility sensor, which is located on the textile product in the area between vertebra C7-T4, activates the vibration motor in case of inclination more than 20 degrees, which is considered dangerous, and sends a physical warning to the user to correct his posture.

The prototype, provides uninterrupted wireless communication for up to 14 meters in environments with LoS and NLoS. It also generally has a good packet loss rate and operates with low power consumption. Warning messages are sent, to a mobile device which can offers real-time posture tracking via the proposed mobile application. Thus, it is also possible to monitor the user by third parties such as parents, nurses, etc. In addition, since the textile part designed is removable, it completely protects the electronic components against washing and ironing. In addition, the proposed design is in the very low price range, less than about 50 USD, compared to its counter parts on the market.

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