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PosturePerfect: Smart T-Shirt for Real-Time Posture Correction and Monitoring

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ABSTRACT

Posture-related back pain degrades mobility and quality of life for many who experience it. Building a healthy posture can reduce strain on the spine and help avoid these back problems. However, recognizing and correcting one's posture can be difficult to accomplish on one's own. In this work, a wearable technology solution is presented. Using a T-shirt with embedded flexural strain sensors, this work enables users to recognize when they have bad posture and correct it in real time. To extract useful information from the flexural strain sensors, a machine learning algorithm was trained to utilize the flexural strain sensor output to predict whether the user had good posture, leveraging existing vision-based algorithms to extract human pose. The model demonstrated high accuracy, showing the viability of this technology. Overall, this work presents a reliable, non-intrusive solution for monitoring and correcting bad posture, which can provide valuable feedback and reduce overall back-related problems.

Background

Research indicates that a staggering 80% of Americans encounter back problems at least once per year, and poor posture is a significant contributor to these issues (Devon & Rubin, 2007). Neglecting posture issues can escalate the problem, potentially leading to more severe complications. Approximately 16 million adults, or 8 percent of all adults in the U.S., experience persistent or chronic back pain, which limits them in certain everyday activities (Druss et al., 2002). Back pain is the sixth most costly condition in the United States, with health care costs and indirect costs over $12 billion per year (Druss et al., 2002).

The repercussions of bad posture extend beyond mere discomfort and encompass a range of serious effects. Poor posture causes strain on your upper and lower back, and affects the backbone disks and muscles (Meziat et al., 2015). Moreover, poor posture causes neck pain and headaches as it puts pressure on your spine. The neck is strained when shoulders are hunched forward or when the head is aimed downward (Rani et al., 2023). Poor posture can also cause digestive issues. The compression of organs resulting from slouched postures can impede the digestive process, potentially leading to stomach issues (Harvard Health, 2023). Placing undue stress diminishes the spine's ability to effectively absorb shock, increasing the risk of more serious spinal injury in the future. Fortunately, prioritizing good posture can mitigate the adverse effects of poor posture and foster optimal health and wellbeing.

Upper or lower back pain often arises from repetitive tasks at home or work, such as prolonged periods of sitting on a couch or at a computer or frequent lifting and carrying. These activities can lead to muscle tightness and strain, resulting in discomfort and backache. One simple strategy to protect your back involves paying attention to your posture and developing the habit of maintaining a healthy posture. Poor posture not only promotes back pain but also affects the position and function of your abdominal organs, leading to various health issues. As people age, perpetuating these bad habits such as slouching or hunching can lead to back pain. In contrast, good posture not only protects against back pain, but it also improves overall health and appearance.

The current solution to this problem is to wear a brace, physical therapy, or wear posture monitoring devices. Braces can be worn to keep the back straight, but they only help while they are in use and are not comfortable to wear. An example of a brace available in the market is shown in Figure 1A. Physical therapy is expensive and requires regular follow-up, which can result in noncompliance. While there are several products available on the market to monitor posture, they don't seamlessly integrate in user's daily activities, and only capture data from a small surface area. For example, one such product, the Upright Go2 shown in Figure 1B, needs to be attached to the skin with adhesive and captures posture data from a small surface area.

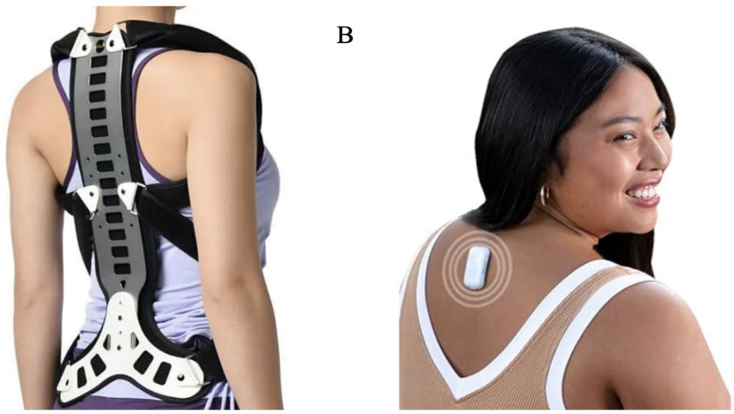
A B


Figure 1. Products in the market. Figure 1A shows a tight brace worn to improve the user's posture. Figure 1B shows a product called Upright Go2, which can be attached to the skin using adhesive to monitor posture.

All people, and especially the elderly population, prefer devices with seamless technology integration into their daily lives (Lewis & Neider, 2017). Specifically, they prefer devices that are more discreet, lightweight, and flexible (Stansfield et al., 2023). This project involves an embedded smart T-shirt with an electronic circuit designed to correct posture by alerting users and monitoring their posture improvements. This integrated T-shirt is easy to wear, very comfortable and can be seamlessly integrated in daily life. It measures curvature from a wider surface area as it is equipped with four flex sensors. When a user slouches, an alarm and a gentle pull on the back reminds the user to straighten their back. This device not only helps users build healthy posture habits but also trains the right muscles to strengthen the back and monitors improvements in posture over time.

Methods

There were four steps to this project: electromechanical design of the circuit, data collection, statistical modeling, and utilization for correcting back posture.

Electromechanical Design

Using the materials listed in Table 1, I created an electrical circuit to read flexural strain sensor values and a mechanical system to pull the back lightly.

Table 1. Bill of Materials to build the smart T-shirt

Item	Item Description	Quantity

1	Sports T-shirt	1
2	Raspberry Pi 4B 4 Gb Model	1
3	Flexural strain sensors	4
4	Analog-to-Digital converter	1
5	Servo motor	1
6	Alarm	1
7	Camera	1
8	Breadboard kit and jumper wires	1

The smart T-shirt and Raspberry Pi electromechanical circuit was designed through several iterations of mechanical and electrical sketches, with one design being finalized after preliminary testing. Flexural strain sensors were attached to the T-shirt to measure changes in spine curvature. As the spine bends, it also curves the flexural strain sensors, which results in higher resistance and, in turn, a higher voltage reading across the component. The analog to digital converter converts the analog voltage signal to an 8-bit unsigned binary value which is communicated to the Raspberry Pi over the I2C bus. Finally, the change in voltage is processed through the Raspberry Pi to identify instances of incorrect back posture. The servo motor and the alarm notifies the user in real-time when the posture is incorrect.

Initially, one flexural strain sensor was considered for the design. This initial design proved inadequate because it was unable to capture differences between users stretching as opposed to users that were hunched over due to collecting data at only one location. Thus, additional sensors were placed to collect data throughout the user's back. The final prototype incorporated four flexural strain sensors, which were directly installed on the T-shirt using sewing tape. These sensors were placed at locations that have the most sensitivity to movements of the back muscles and for symmetry. The location that resulted was a few inches from the backbone. A servo motor and an alarm were installed near the base of the T-shirt to provide user feedback. The data from the flexural strain sensors indicated whether the back is bent; and in such instances, the alarm sounded and the servo motor gently pulled the back into alignment using fishing wires.

The final design as a concept drawing is shown in Figure 2A. The various components mentioned are detailed in this figure along with rough placements of the flexural strain sensors. Figure 2B shows the final project prototype worn by a user. Because the sensor placement is integrated into the shirt and the size of the control device can be further refined through custom circuit boards, the design shown is more seamless than its market competition.

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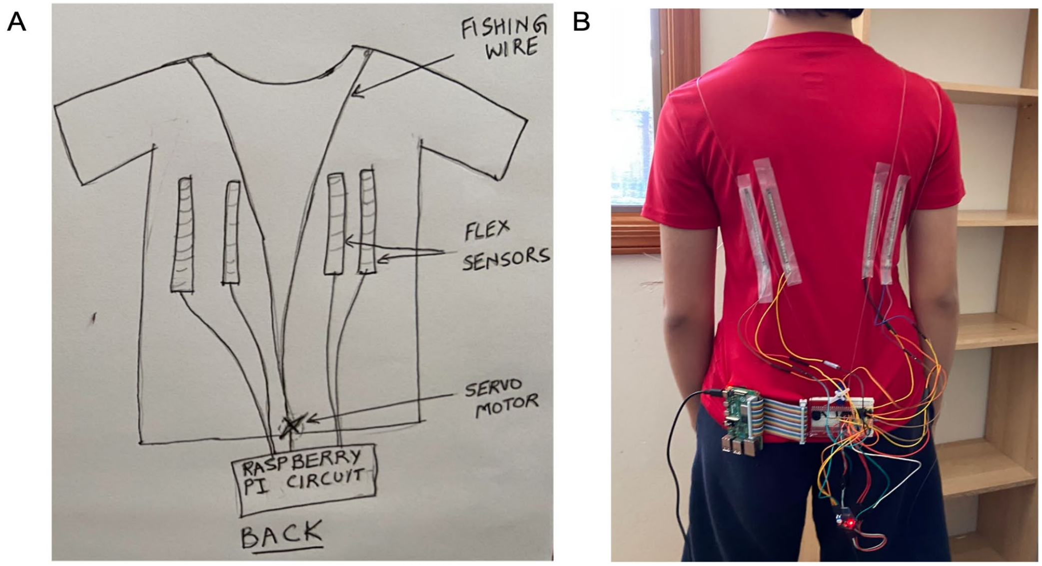

Figure 2. Design of the T-shirt: Conceptual design illustrated in figure 2A. Figure 2B shows the final project prototype worn by a user.

Data Collection

Data was collected from two individuals to determine incorrect back postures, using readings from four flex sensors. A total of 1,000 data points were collected from each individual. Since each user's normal back curvature differs, the first 100 readings were used to calculate the user's baseline, during which the user was asked to stand still. The remaining 900 readings were then adjusted based on this baseline and used to create the model. Python code was developed to capture data from the sensors and take posture pictures simultaneously with each reading.

In addition, synchronous images were taken using a Raspberry Pi camera to capture the observed posture. Each image was processed through OpenPose (Cao et al., 2021) to determine the key points of the human body as x and y pixel locations in the image. The image in figure 3 shows the key points predicted by the OpenPose model.

$$Tan\ \theta\ = \frac{x1 - x2}{y1 - y2}$$

Equation 1. Equation to calculate the angle of the back.

The angle of the back was calculated using Equation 1, where (x1, y1) are the coordinates of the shoulder and (x2, y2) are the coordinates of the hip. This angle served as the ground truth for whether the back was actually bent. Figure 3 shows the positions of shoulder and hip coordinates, and the angle θ that was calculated.

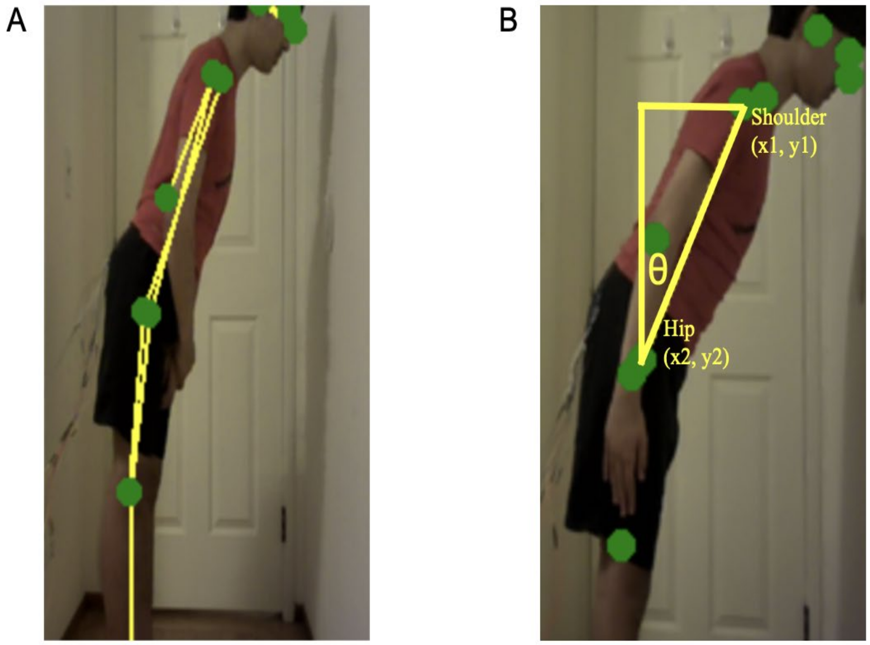

Figure 3. OpenPose model result. Figure 3A shows the position of posture key points from the OpenPose model. Figure 3B shows the angle of the back as θ, which is calculated using the shoulder coordinates(x1,y1) and and hip coordinates (y1, y2).

Based on existing research (Etra et al., 2015), if the back angle is bent 10 degrees or more, it places undue pressure on the discs. Therefore, such readings were classified as 'back bent', while others were classified as 'back not bent'.

Statistical Modeling

Statistical models were built to address sensitivity of the flex sensors and their variability with every movement. The input variables were the flex sensor reading sets, and the output variable was the calculation of whether the back is bent. The dataset was split into training and testing datasets, with 80% allocated for training and 20% for testing. Various data models were trained on the training dataset, and the results from the testing dataset were compared to determine which model best predicts if the back is actually bent. Models compared were logistic regression, decision tree, random forest and MLP neural network models.

Correction for Back Posture

The MLP neural network model with 93% accuracy was implemented in the Python code. The flex sensors in the T-shirt continuously collected data which was passed through the data model to predict if the back was bent. When the data model predicted that the back was bent, the alarm sound notified the user and the servo motor lightly pulled the back to correct the posture.

Results

Several data models like logistic regression, decision tree, random forest and MLP neural network models were trained on the training data set, and their performance was compared using the testing data set.

Table 2. Comparison of the data model's performance.

	Accuracy	**Precision**	**Recall**	**F1 score**
Logistic Regression	88%	70%	89%	78%
Decision Tree	85%	82%	73%	77%
Random Forest	89%	92%	77%	84%
MLP Neural Network	**93%**	**91%**	**88%**	**89%**

From Table 2, it can be seen that the MLP had the highest performance in terms of accuracy, precision, recall, and F1 score. Thus, this model was utilized in the final design. It should be noted that the precision is higher than the recall indicating that the model is more likely to predict false negatives rather than false positives. Due to this device correcting for posture, this is ideal as it would not be desirable for users to receive correction when it is unnecessary because this could increase the rate of noncompliance.

Table 3. Confusion matrix for the MLP Neural Network model

	Predicted "Back not bent"	Predicted "Back bent"
Actual "Back not bent"	**100**	14
Actual "Back bent"	10	**236**

In Table 3, the predictions are shown as a confusion matrix. It can be seen that there are minimal cases where the prediction deviates from the actual.

Conclusion

Back pain, a common problem that worsens with poor back posture, is addressed by the smart T-shirt designed in this project. This ailment affects 80% of adults and can lead to chronic pain and mobility issues. Recognizing the importance of this issue, the easily wearable T-shirt uses embedded flex sensors to measure spinal curvature. When poor posture is detected, the T-shirt provides immediate feedback through an alarm and a gentle mechanical pull using a servo motor, guiding the user to correct their posture. I further enhanced it with data-driven predictions, using a neural network to learn from past behavior and classify good and bad postures. Continuous usage of this product will improve users' posture habits.

This project offers a proactive solution to a common health problem, potentially reducing the long-term health impacts associated with poor posture. It appeals to anyone from office workers to students who may not be aware of their posture throughout the day. With the increasing adoption of comfortable wearable technology, this smart T-shirt explores the space of measuring and improving posture problems with a smart embedded system.

Future work in this area should consider variations in body type, ethnicity, gender, positions, and environment as this would increase the generalization of the model and likely reduce cases of false prediction. To enhance wearability, the circuit can be printed on a chip, and conductive threads in T-shirts can function as flex sensors for increased user-friendliness.

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