Biosensing Patch for Posture Correction

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***Abstract*— To address the widespread prevalence of lower back pain and excess curvature of the spine, a bioinstrument was created in order to encourage proper posture in daily life. The device uses a strain gauge component to measure curvature in the back and a hysteresis comparator to provide a steady voltage response to changes in posture. A low-pass filter creates a 3-minute minimum delay before a 555 timer is triggered, which activates a heating pad for a duration of 2 minutes. An SR memory latch is used to ensure the device continues heating if posture is not corrected.**

***Clinical relevance*— Back pain due to improper posture is a plaguing issue in an electronics-dependent society, especially among the youth. This proposed device, which has the potential to fit on a small patch, can serve as a constant reminder for patients to readjust their posture while delivering heat to relieve muscle tension. With the fast feedback response, this patch would be able to delay or even prevent the development of lower back pain caused by postural problems.**

I. INTRODUCTION

Nearly 10% of the global population suffers from lower back pain (LBP); while the proportion of people with LBP has decreased in recent years, the absolute number of people suffering from LBP has steadily increased, reaching 577 million in 2017 [1]. One of the leading causes of LBP, especially in younger patients, is improper posture, leading to the poor development of spine curvature [2, 3]. In a society gradually growing more sedentary, risks arising from constant sitting and improper posture are highly salient. Sitting for prolonged periods can lead to chronic muscle deconditioning and flatness of the lumbar-lordotic curve, which causes fatigue and discomfort [4]. Maintaining a slouched posture aggravates these problems, and recurrence within a year occurs in as much as 33% of the patients [5]. Among those with chronic LBP, 31.4% have reported seeking treatment from a doctor; 9.3% had LBP so severe it limited their mobility [5].

Given the prevalence of improper back posture, a biomedical device alerting the user when the back is overly slouched would be helpful to lower the rates of lower back pain. To do this, we propose an instrument that detects when slouching is occurring and provides feedback in the form of heat via a heating pad to remind the user to straighten their back. To accomplish this, a strain gauge, a hysteretic comparator, an RC circuit, a 555 timer, and digital logic using an SR latch are used.

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II. METHODS

A. Assumptions

We make the following assumptions for our circuit design.

- When the subject is not slouching, the strain gauge detects no strain ($\epsilon = 0$).
- When the subject is slouching, the strain measurement is about $\epsilon \approx 0.1$.
- The heating pad does not affect the temperature of the resistors; the temperature coefficient of the resistors can be ignored.
- Heat from the heating pad is dissipated immediately upon getting triggered—no feedback delay occurs here.

B. Design Aims

The circuit was designed with four aims in mind:

1) Quantify the posture by measuring the curvature of the back.
2) Create a 3-minute delay between the initial onset of slouching and the device response.
3) Activate a heating pad that warms for 2 minutes to relieve tension.
4) Implement memory in the circuit such that the heating pad can be activated longer than the 555 timer's output duration if the user is still slouching.

C. Overall Circuit

Figure 1 shows the circuit schematic. Two 3V batteries are utilized in the circuit: one at V_S, and another not shown connected to both the operational amplifier supply terminals and V_{CC} on the 555 timer.

D. Circuit Components

Table I shows the values of the components used in the circuit.

TABLE I
COMPONENT VALUES

Component		Value
V_S		3 V
R_0		1 kΩ
R_1		1.2 kΩ
R_2		100 Ω
R_3		1.4 kΩ
R_4		1.6 MΩ
R_5		1.1 MΩ
R_G	R_{nom}	1 kΩ
	G	8
C_1		100 μF
C_2		100 μF
C		10 nF

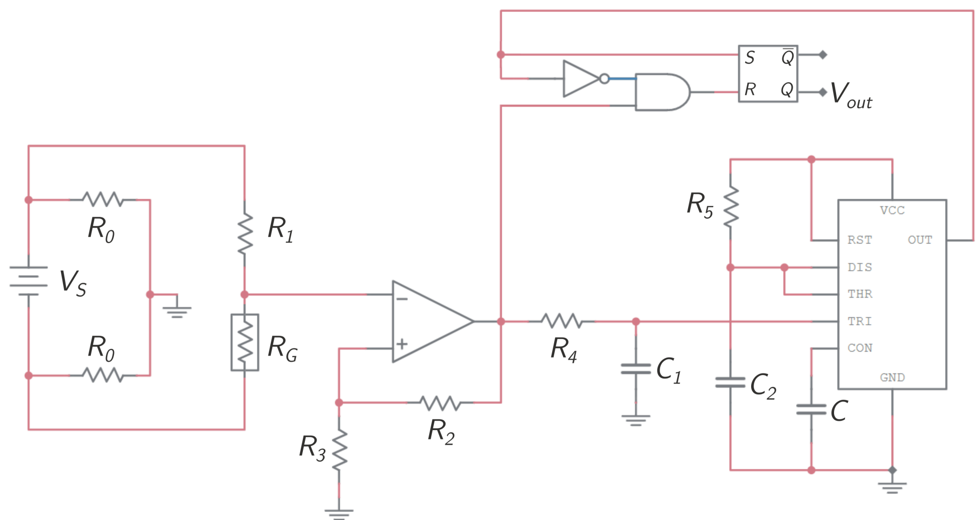

Fig. 1. Circuit schematic.

1) Posture Detection: Aim 1

In order to detect postural changes, the device measures changes in length with a strain gauge. By placing the patch on the lumbar spine, the strain gauge would stretch and compress along with the movement of the spine, affecting its overall resistance. Equation (1) provides the calculation for the resistance of the strain gauge.

$$R_G = R_{nom}(1 + G\epsilon + \alpha\Delta T) \tag{1}$$

R_G is the measured resistance of the strain gauge, and R_{nom} is its nominal resistance. As can be seen, the resistance depends on both the strain ϵ and the change in temperature ΔT. However, because we assume the temperature to remain constant, the $\alpha\Delta T$ term goes to 0, and we are left with only the strain term. The gauge factor G depends on the material, and we chose to set $G = 8$, which is a reasonable value if the gauge is made of silicon. Equation (2) shows how strain is calculated.

$$\epsilon = \frac{\Delta L}{L_0} \tag{2}$$

As the back slouches, the strain gauge stretches along with the spine, allowing for the detection of a positive ΔL, yielding a change in the strain gauge resistor. This affects the voltage divider on the strain gauge set-up, enabling this voltage V_A to be compared against designed thresholds.

Using V_A output from the strain gauge, a hysteretic comparator is used to detect whether the back is excessively slouched or if the back has been straightened. This comparator is connected to a 3V battery, enabling it to have two output modes: a "high" voltage output (3 V) when V_A is low, and a "low" voltage output (0 V) when V_A is high. This voltage output V_B is then fed into an RC filter.

2) Response Delay: Aim 2

Day-to-day movement may sometimes require the back to be arched for short periods of time (such as picking up a box, for example). To accommodate for these normal changes, a delay needs to be implemented such that the patch does not alert the user immediately after detecting a curved back. To do so, an RC circuit is used, and the output voltage V_C from the RC circuit is connected to the trigger terminal of a 555 timer. The supply voltage of the 555 timer is connected to a 3V battery, so $V_{CC} = 3$ V.

When the user has a straightened back, the hysteretic comparator outputs a high voltage (3 V), charging the capacitor in the RC circuit to 3 V. Once the device detects a slouched back, the comparator drops low (0 V), which begins to discharge the charge stored on the capacitor. Once the voltage V_C drops below $\frac{1}{3}V_{CC}$, or 1 V, the 555 timer is triggered, which activates the 555 timer output. Equation (3) relates the time required to reach the trigger voltage of 1 V to the time constant $\tau = R_4C_1$.

$$t_1 = \ln(3)R_4C_1 \tag{3}$$

We aim to create a delay of 3 minutes, so $t_1 = 180$ s, allowing us to derive the component values from Table I.

3) Heating Pad Activation: Aim 3

In order to output a 2-minute heating period, the 555 timer is configured in monostable mode. This enables the threshold pin to begin charging with another RC circuit defined by R_5 and C_2 immediately after the trigger pin is triggered. The output goes low after the threshold reaches $\frac{2}{3}V_{CC}$, or 2 V. Equation (4) finds the time needed to reach 2 V using the RC circuit on the 555 timer.

$$t_2 = \ln(3)R_5C_2 \tag{4}$$

To create a 2-minute output period, $t_2 = 120$ s; appropriate R_5 and C_2 values (located in Table I) were derived from Equation (4).

4) Circuit Memory: Aim 4

Regardless of whether the user is still slouching, the 555 timer's output will drop low after 2 minutes have elapsed.

The 555 timer would be unable to be triggered again since the trigger pin is negative-edge triggered. To fix this design flaw, memory is implemented with digital logic to keep the heating pad going if the user has not straightened their back yet.

An SR latch is used to retain memory about the state of the output. In particular, if the output went from high to low but the individual is still slouching, V_{out} would be set to high. We connect the output of the 555 timer and output of the hysteretic comparator to the Set and Reset pins of the SR latch, respectively. The output Q is connected to the heating pad, and $\overline{Q}$ is left disconnected. Table II summarizes the truth table for the SR latch.

TABLE II
SR LATCH TRUTH TABLE

S From 555 Timer	R From Comparator	Q To Heating Pad
0	0	Previous State
0	1	0
1	0	1
1	1	Invalid

To prevent an illegal case of $SR = 11$, logic NOT and AND gates are connected to the Reset pin. When both the 555 timer and the comparator are high (digital logic 1), the gates cause this input to be defaulted to $SR = 10$ to output $Q = 1$. Every other value of SR is unaffected.

III. RESULTS

A. Strain-Induced Voltages

With the component values for the resistors, the voltage V_A measured at the strain gauge can be found both for a straightened and slouched back. Equation (5) shows the voltage calculation for V_A with the current divider.

$$V_A = V_S\left(\frac{R_G}{R_G + R_1} - \frac{1}{2}\right) \quad (5)$$

When the back is straight, $\epsilon = 0$, so $R_G = R_{nom} = 1$ kΩ, yielding $V_A \approx -0.14$ V. When the back is slouched with $\epsilon \approx 0.1$, $R_G \approx 1.8$ kΩ, so $V_A \approx 0.3$ V.

B. Comparator Thresholds

Table III provides the thresholds for the hysteretic comparator.

TABLE III
COMPARATOR THRESHOLD AND OUTPUT VOLTAGES

Voltage		Value
Threshold	V_{in}^-	0.2 V
	V_{in}^+	0 V
Output	V_{out}^-	0 V
	V_{out}^+	3 V

To enable some flexibility, the thresholds were set below the maximum straightened and slouched back voltages; the comparator goes low when the strain-induced voltage is 0.2 V, and it returns to high when $V_A = 0$ V.

C. Simulation Graphs

With our bioinstrumentation design, the behavior can be modeled given a sample signal and looking at the voltage at different parts of the circuit. In the first sample signal, the patient starts upright, then slouches for about 5 minutes, sufficient to trigger the heating response (Figure 2).

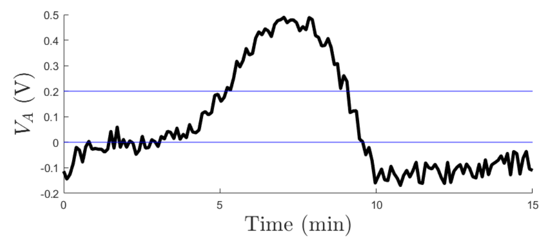

Fig. 2. Voltage measured at the strain gauge, V_A. Thresholds are shown in blue.

The resulting voltage V_A fluctuates around 0 V until slouching occurs and the voltage surpasses the 0.2V mark at 5 minutes. The user begins to stop slouching at around 7 minutes, with the 0V threshold being passed at 9.5 minutes. Therefore, the hysteretic comparator is triggered to go low at 5 minutes and does not return high until 9.5 minutes (Figure 3).

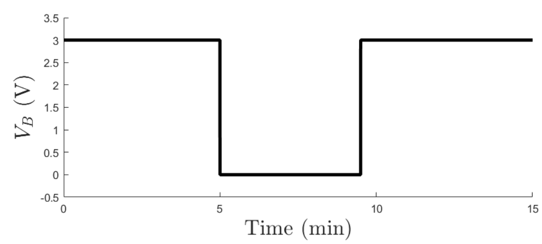

Fig. 3. Voltage measured at the output of the comparator, V_B.

As can be seen from the noise in the simulation, the hysteretic thresholds allow for a steady "bent" or "straight" status and avoids frequent fluctuations that could trigger the comparator voltage to go high and low repeatedly. This prevents damage to the device and helps form a predictable pattern of triggering for the heater.

When the comparator is low and outputting a voltage of 0 V, the capacitor C_1 begins to discharge from 3 V in the original state to 0 V from the output. By design, it will take 3 minutes to reach the 1V mark, at which the trigger voltage of the 555 timer will be activated (Figure 4).

Once the trigger voltage of the 555 timer is reached, the output will immediately change to 3 V. Since it is a monostable timer, the output will stay at 3 V for a duration of 2 minutes. This is known from the time constant of the 555 timer, and it is designed to be 2 minutes to provide an adequate amount of heating time to warm the back.

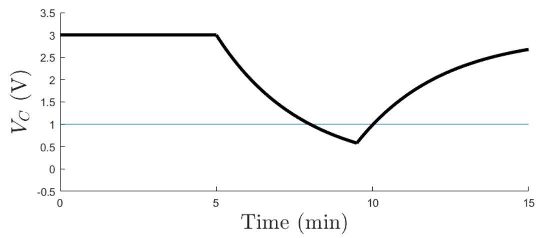

Fig. 4. Voltage measured at the output of the RC circuit, V_C. The threshold is shown in blue.

If the entire heating duration expires and the patient still does not adjust their posture to the "straight" position, the SR latch will be utilized to continue heating. Because the 555 timer is only triggered when the trigger voltage is negative-edge crossed, it will not activate if the patient does not readjust their posture. V_A would remain above 0.2 V, the comparator would still output 0 V, and V_C would remain below 1 V, causing the 555 timer not to be inactivate. The SR latch's logic continues heating for this duration while the back is still not adjusted.

Figure 5 demonstrates a full 45-minute simulation of the circuit.

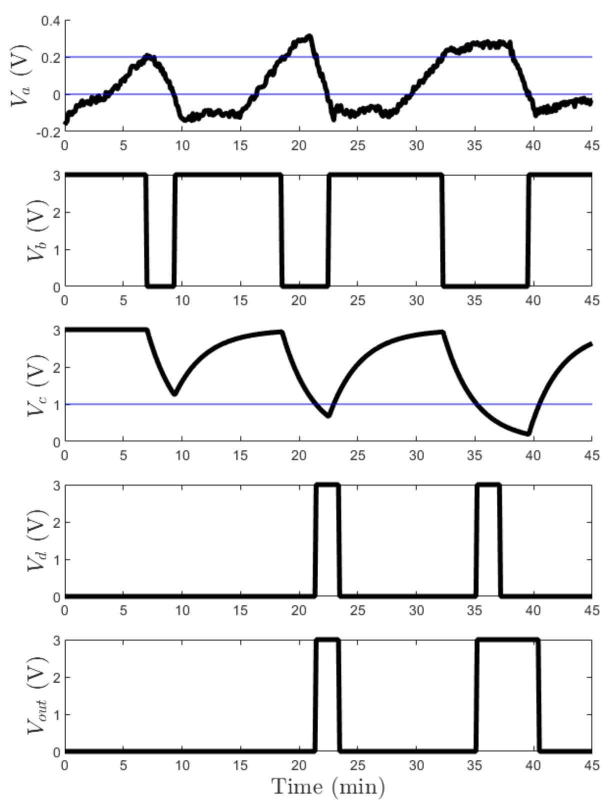

Fig. 5. Simulation of the circuit with V_A, V_B, V_C, V_D, and V_{out}. Thresholds are shown in blue.

IV. Discussion

A. Advantages

One of the main advantages of this bioinstrumentation design is that the circuit does not require signal processing or software. Additionally, the passive design is meant to make the device more user-friendly and the "gentle" heating mechanism should help reduce the likelihood of any induced stress or frustration. Lastly, the use of threshold voltages allows the circuit output to be steady and consistent.

B. Limitations

Some of the drawbacks of this design are that the device may not be comfortable on the body, and considering how individuals may perceive pain or heat to different degrees, there is no method to define an appropriate heating strength. Similarly, a method for user feedback or adjustable input is yet to be available. The circuit also requires large capacitance needed for a 3-minute charging time, which could make the patch larger than is convenient. Finally, the device does not have a "reset" button for the strain gauge, so it cannot be recalibrated.

C. Future Applications

Posture correction devices can act as a conservative treatment option for scoliosis patients (either those who cannot or do not desire to undergo surgical correction) or individuals with other spinal-related disorders that can cause pain and tension. These devices can also work well for individuals that have weak core muscles or have difficulty supporting a good posture while seated. We can also implement additional digital data processing techniques to monitor the users' health data for long-term considerations. In a future design, we could consider design factors such as comfort, the ability to readjust and recalibrate, and a friendly user interface.

V. Acknowledgements

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