Monitor for Repetitve Wrist Strain

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***Abstract*— Repetitive strain injuries in the wrist tend to develop gradually through overuse of the hand and wrist, as swelling and irritation of the tendons increase over time. Numerous conditions such as tendinitis, tenosynovitis, and carpal tunnel syndrome can develop as a result. As the common use of keyboards in the workplace frequently puts the wrist and hand in compromising positions, it is important to develop a device that can effectively monitor deviations from healthy wrist posture and notify the user. This was achieved via a wearable flex sensor system on the hand and wrist consisting of a Wheatstone bridge and instrumentational amplifier that convert strain to voltage. Other circuit components determine the thresholds and bounds of movement and generate pulse waveforms as a response. LEDs are triggered to alert the wearer of strained hand positioning and a dangerous frequency of this motion over time. The design of the device allows for easy control over parameters. Simulations of the proposed device proved useful in modeling and verification. With the data collected from further experimentation, device constraints can be explicitly defined, and a setup can be engineered to reduce susceptibility to repetitive strain injury. Going forward, a wide range of conditions can be tested to fully optimize engagement with computer devices and minimize consequences to the wrist.**

I. Introduction

A. *Pathophysiology of Carpal Tunnel and Other Tendinopathies*

Overuse of the wrist can lead to severe physiological implications. The six tendons that control wrist movement through force from muscle contraction and external forces. When undergoing repetitive flexion or deviation, the collagen fibers that make up the tendon rub together creating friction. As a result, the fibers that constitute the tendon begin to degenerate and the parallel structure is lost [2]. The friction of the sliding fibers generates heat which can be detrimental to the cells in more ways than one. With constant stress and no relaxation, the tendon is subject to damage beyond the threshold for recovery.

Another impact of stress and strain on the wrist is compression of the carpal tunnel. The flexor muscles and the hand are connected through a passageway called the carpal tunnel. It is made up of ligaments and carpal bones and constricted under strenuous conditions. Repetition of this movement is a common cause of carpal tunnel syndrome as the median nerve, which lies in this passageway, is compressed. This reduces blood flow and causes irritation or damage to the median nerve. The median nerve supplies blood to the muscles that control the thumb and provides sensation to the thumb, and the index, middle, and ring fingers. Damage to this nerve leads to eventual wrist weakening, numbness, and pain.

The goal of the proposed device would be to monitor the strain on the wrist and prevent degradation.

B. *Device Motivation*

Factors such as forearm, wrist, and finger posture can cause the fluid pressure within the carpal tunnel to increase. Specifically, deviations from the neutral beyond 30° extension and 15° deviation can cause wrist strength to decline rapidly and can lead to significant tendon weakening [4]. Previous studies have shown that a pressure of 4 kPa applied to the medial nerve can cause significant damage to the nerve within 2 hours [4]. This is especially concerning, considering that many modern occupations demand extensive use of a computer to complete day-to-day tasks, which will frequently put the wrist into compromising positions, increasing the risk of a repetitive strain injury, as it was shown that the risk of carpal tunnel syndrome increases with the use of a keyboard for greater than 20 hours per week [4]. For this reason, it is important to create a device that can detect strain on the wrist and notify the user before repetitive strain injuries can develop.

Fig. 1. Sketch of device. Flex sensor placed could be placed at base of palm or side of thumb running down radius to measure flexion-extension or radial-ulnar deviations, respectively.

II. Model

The goal of the device is to take in hand position, determine if the hand position is in bad posture, and provide the user with feedback. Additionally, to provide a longer-term metric of hand position and strain, the circuit was also designed to provide feedback based on the frequency of deviations over time. This design implements three main stages to accomplish these goals: (1) Wheatstone bridge and instrumentation amplifier, (2) a comparator and 555 timer, and (3) low-pass filter and a second comparator.

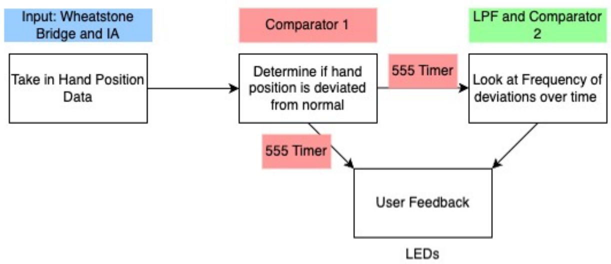

Fig. 2. Flowchart of device goals and implementation.

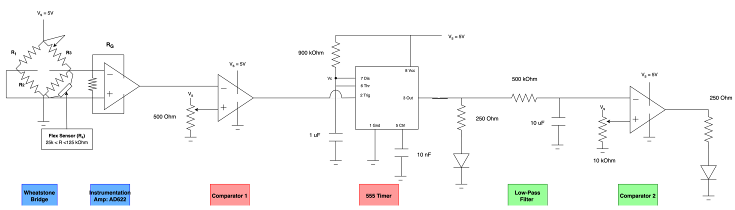

Fig. 3. Circuit diagram of device.

A. Circuit: Wheatstone Bridge and Instrumentation Amplifier

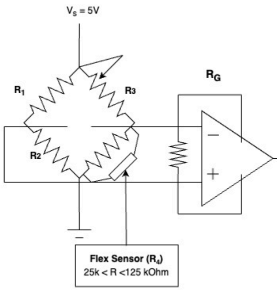

Fig. 4. Circuit diagram of Wheatstone bridge to instrumentation amplifier.

The flex sensor changes resistance as it bends with hand position, and the Wheatstone bridge allows this unknown resistance of the flex sensor to be determined. The Wheatstone bridge is balanced at the voltage associated with a critical hand position and flex resistance, meaning that the voltage output is zero. When the hand is past the critical position, the voltage output of the bridge will be positive, and below the threshold, the voltage is negative. This proportional relationship between voltage output and resistance change is achieved with a potentiometer and the flex sensor in series for one branch of the bridge. The resistor relationships were established based on this goal and maximizing the sensitivity. From these principles, we find the following:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} = 1$$

$$\frac{R_4(1+\Delta R)}{R_3 + R_4(1+\Delta R)} - \frac{R_2}{R_2 + R_1} = 0$$

$$\frac{R_4(1+\Delta R)}{R_3+R_4(1+\Delta R)} = \frac{1}{2} \rightarrow R_3 = R_4(1+\Delta R),$$

where R3 is the value of the potentiometer, R4 is the nominal value of the flex sensor, and delta R is the change in resistance of the flex sensor when it is bent. The potentiometer allows for easy adjustment of the critical resistance, which should be determined with actual experimentation.

Next, this voltage could be connected to an AD622 instrumentation amplifier to amplify the signal. This amplification would be necessary if the flex sensor had low sensitivity. The gain of the AD622 can be adjusted using a single resistor. The gain is determined by the following equation:

$$G = 1 + \frac{50.5k\Omega}{R_G}.$$

B. Circuit: Comparator 1 to 555 Timer

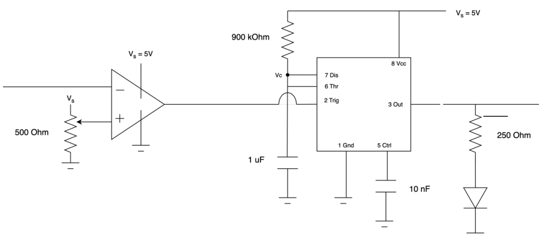

Fig. 5. Circuit diagram using a comparator and 555 timer to trigger the first LED.

The voltage from the first stage is connected to an inverting comparator. The comparator determines if the input voltage is above or below a threshold of comparison, and outputs the high or low power rail in response. In this design, the comparator outputs high when the voltage input is low, and vice versa. The reference voltage is set by a potentiometer connected to the non-inverting input and tunes the reference voltage to the desired value. High output is the positive power rail, 5V, and low output is ground. When the voltage from the input stage is higher than the reference voltage, the comparator outputs 0V, corresponding to a flex resistance above a safe angle. Conversely, when the input stage voltage is below that of the reference, the comparator outputs 5V. The comparator output feeds into the trigger pin of the monostable 555 timer. The inverting comparator properties are leveraged to control the 555 timer. A low comparator output, which corresponds to a flex resistance greater than the critical value, triggers the timer to output a pulse. The pulse width is controlled by the resistor and capacitor values of the timer. A 900 kOhm and 1 uF capacitor were chosen to produce a pulse lasting about 1 second:

$$T = RC * \ln(3) = (900 * 10^3 \Omega) * \left(1 * 10^{(-6)} F\right) * \ln(3) \\ = 0.99\ s$$

The pulse is sent to the next circuit stage and an LED. The LED pulses in accordance with the 555 timer output to notify the user each time they deviate past an acceptable hand position.

C. Circuit: Comparator 2

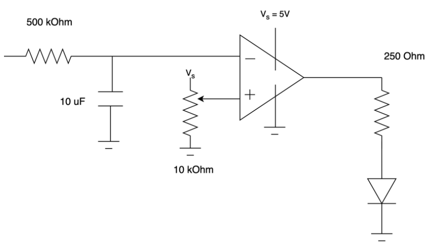

Fig. 6. Low pass filtering of signal as input into comparator to trigger the second LED.

The low pass filter receives a square wave output from the 555 timer pulse when a deviation from the critical angle is detected. The capacitor charges when the 555 output is high and discharges when the output is low. Therefore, when deviations are detected at a high enough frequency, the output voltage of the low pass filter will be high enough to cause the comparator to go high, triggering the second LED output.

The sensitivity of this component can be adjusted by changing the cutoff frequency of the low pass filter, which will determine the rate at which the capacitor will charge. Changing the threshold of the comparator allows for manipulation of the point at which the second LED is lit up. The threshold voltage of the comparator can easily be manipulated, as a potentiometer is connected to the reference voltage of the comparator. The variable resistance of the potentiometer can then be used to adjust the threshold value.

III. Results and Simulation

For preliminary verification, the circuit was simulated on National Instruments (NI) Multisim. To simulate the signal from the Wheatstone bridge, a sine wave of 0.5 Hz frequency with a DC offset was used. This mimics the effect of the wrist bending and straightening, consequently increasing and decreasing the resistance of the flex sensor. In practice, the signal would not have a consistent frequency as the wrist moves at an inconsistent pace. For the purposes of this simulation, different frequencies of signals were tested to see the effects of faster and repetitive motion.

A. Comparator 1 and 555 Timer (first LED trigger)

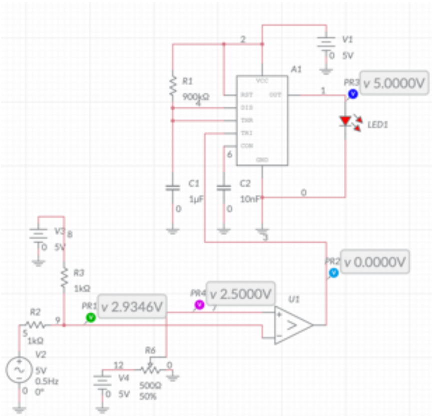

Fig. 7. Simulated circuit to trigger the first LED.

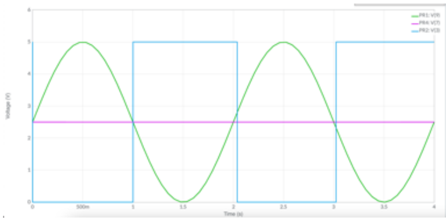
Fig. 8. Flex sensor signal (green) through compared against reference voltage (magenta) to generate output from comparator (light blue).

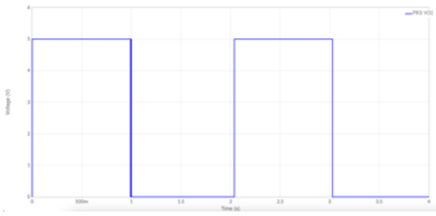
Fig. 9. Output from 555 timer (dark blue).

The output voltage of the Wheatstone bridge is increased when the resistance of the flex sensor increased. In the simulation, it is deemed that voltage due to the resistance at the critical angle would be 2.5 volts. This value is set as the reference voltage of the comparator.

This can easily be manipulated by tuning the potentiometer. When the sensor is bent, the voltage increases going higher than the reference voltage. Since the comparator is inverting, the output goes low when the input voltage is higher than the reference.

The signal is then fed to the 555 timer which produces pulse waveforms in response shown in figure 9. The monostable 555 timer generates a pulse waveform in which the width of the period when the output is high is given by:

$$T = RC\ln(3) = 0.99\ s$$

When the signal from the comparator goes low, the 555 timer triggers a pulse of 5 volts which turns on the LED. Comprehensively, the response when the wrist goes beyond the critical angle is an LED is pulsed for 0.99 seconds.

B. Low Pass Filter and Comparator 2

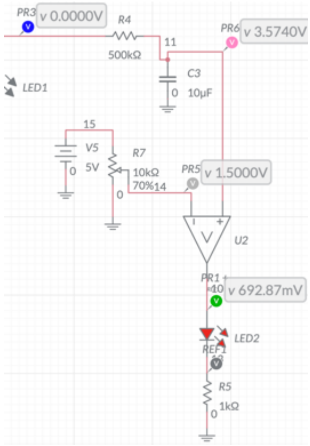

Fig. 10. Simulated circuit diagram to trigger the second LED.

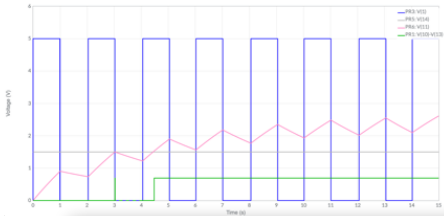
Fig. 11. Response after a 0.5 Hz input signal. 555 timer signal (dark blue) filtered by the low pass filter. Capacitor voltage in low pass filter (pink) compared against reference voltage (grey). Comparator output (green) fed to second LED.

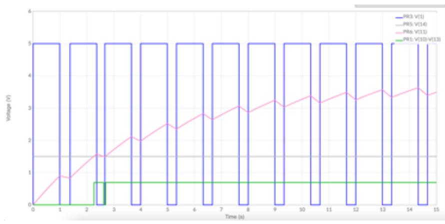
Fig. 12. Response after a 0.75 Hz input signal. 555 timer signal (dark blue) filtered by the low pass filter. Capacitor voltage in low pass filter (pink) compared against reference voltage (grey). Comparator output (green) fed to second LED.

To highlight the purpose of the second LED, the simulation is run at two different frequencies. The reference voltage of the comparator is again adjustable using the potentiometer and, in this simulation, is set at 1.5 volts. The low pass filter has a time constant calculated below:

$$\tau = RC = 5\ s$$

The capacitor will take 25 seconds to fully charge.

In the simulation at higher frequency (figure 12), the capacitor charges faster as it has less time to discharge. The comparator output goes high, and the LED is turned on sooner than in the simulation at a lower frequency (figure 11). This yields the overall desired result of the second LED acting as a warning for repetitive motion. When the second LED is lit up, this corresponds to a high frequency of repetitive strain movement.

IV. Discussion

A. Design and Simulation Improvements

While this device holds potential, constraints in the simulation restrict proper testing of the device. Ideally, the output signal from the Wheatstone bridge should be one of irregular frequency. Without a change in signal frequency, the discharging of the capacitor and as a result, the LED turning off, is not able to be simulated. This is difficult to generate on the platform chosen for this simulation and alternatively, more complex processing could be done using MATLAB and Simulink software.

The simulator assumes ideal components but in practice, real components would prove to have certain inconsistencies that may need to be accounted for. As a preemptive measure, a hysteretic component can be added to both comparators using a resistance to couple the non-inverting input of the comparator to its output. This would create positive feedback, and employing potentiometers once again would allow for control over the degree of hysteresis and for optimization of the device. The use of potentiometers can be extended further to adjust the time constant of the 555 timer pulse. Although the parameters of the device have not been explicitly chosen, this allows for experimentation to define the values of the components and have potential in individual configuration. Variability in individual movement can drive a need for different threshold values and the potentiometers would enable easy manipulation. Overall, only further research and testing would resolve the aforementioned issues and solidify the design of the device.

B. Conclusion

Repetitive strain injuries in the wrist, such as tendinitis, tenosynovitis, and carpal tunnel syndrome, can result from hand and wrist overuse. Given the prevalent use of keyboards in the workplace, it is crucial to monitor and notify users of deviations from healthy wrist posture. This is where the project developing a wearable flex sensor system can use the keyboards as a jumping of point. Applications of this project can hopefully extend to monioting all aspects of a workplaece setup to optimize ergonomics.

The wrist strain monitoring system developed in this project uses a Wheatstone Bridge + Instrumentation Amp, Comparator 1 + 555 Timer, and LPF + Comparator 2 to detect wrist strain and send an alert to the user in real time. The potential real-world applications of this wrist strain monitoring system are significant, particularly in helping individuals reduce their risk of further injury or even prevent it altogether. By warning users of deviations from healthy wrist posture, the device may be able to improve workplace safety and reduce the incidence of repetitive strain injuries.

To better the functionality of the wrist strain monitoring system, future work should focus on fine-tuning parameters after experimentation and improving the design to alert in both directions of strain. Additionally, it may be helpful to design a window of angles that are considered in range of safe movement. Further development could be achieved through the use of an Arduino and simple code to track how much wrist straining is related to a higher risk of developing carpal tunnel. Overall, this project presents an innovative and practical solution to a common problem, and it has the potential to significantly improve the lives of those affected by wrist strain.

Acknowledgment

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References

[1] G. Cauwenberghs (2023). BENG 186B Lecture Notes [Online]. Available: https://isn.ucsd.edu/courses/beng186b/lectures/

[2] Loiacono, C., Palermi, S., Massa, B., Belviso, I., Romano, V., Gregorio, A. D., Sirico, F., & Sacco, A. M. (2019). Tendinopathy: Pathophysiology, Therapeutic Options, and Role of Nutraceutics. A Narrative Literature Review. Medicina (Kaunas, Lithuania), 55(8), 447. https://doi.org/10.3390/medicina55080447

[3] M. Mack and C. -H. Min, "Design of a Wearable Carpal Tunnel Syndrome Monitoring Device," 2019 IEEE 62nd International Midwest Symposium on Circuits and Systems (MWSCAS), Dallas, TX, USA, 2019, pp. 1195-1198, doi: 10.1109/MWSCAS.2019.8884804.

[4] Rempel, D. M., Keir, P. J., & Bach, J. M. (2008). Effect of wrist posture on carpal tunnel pressure while typing. Journal of orthopaedic research : official publication of the Orthopaedic Research Society, 26(9), 1269–1273. https://doi.org/10.1002/jor.20599

[5] Spectra Symbol, “Flex Sensor,” FS7548 datasheet, 2010. https://www.sparkfun.com/datasheets/Sensors/Flex/flex22.pdf

[6] Thomsen, J. F., Gerr, F., & Atroshi, I. (2008). Carpal tunnel syndrome and the use of computer mouse and keyboard: a systematic review. BMC musculoskeletal disorders, 9, 134. https://doi.org/10.1186/1471-2474-9-134