Neck Movement Sensor

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The basic principle of the sensor is to record the number of times a device connected to the user's ear touches its neck. The evolution of this number over time could indicate that the user is engaged in different activities that involve back-and-forth head moving (i.e. head-banging).

Components and functioning

To build this sensor the following components were used:

- Arduino UNO board
- ATtiny85-20S Microcontroller
- LED
- Resistance 300 Ohms
- Resistance 10 MegaOhms
- 3D printed earpiece
- Chain

The Arduino UNO board was used to program the ATtiny85-20S Microcontroller. The system works by setting the ground signal to the skin of the user's ear. The PCB is positioned inside a 3D-printed earpiece with a small chain of a conductive material, this design is inspired by a high-quality jewelry product. Using a voltage divider it will be able to detect when the chain touches the user's neck. The chain is wired in series with a 10M resistance and the circuit is aligned with 5V. The microcontroller analog-to-digital converter measures the voltage divider output voltage. Finally, these values are used to compute the sensor resistance (See Equation 1).

$$V_{out} = \frac{Z_2}{Z_1 + Z_2} * V_{in} \quad (1)$$

When the chain touches the skin (ground) it adds resistance to the circuit, thus we set a threshold value that will be compared to the sensor output and if the value is lower than the threshold the LED is turned on. In the next section, the signal-to-noise ratio metric is reported to evaluate signal reliability.

Sensor signal evaluation

In Figure 1, three series are presented, the raw signal (blue), the threshold (orange), and the binarized signal (green). The signal-to-noise ratio (SNR) was calculated using these values in two scenarios: when the signal is 1 (Touch) and when it is 0 (No touch).

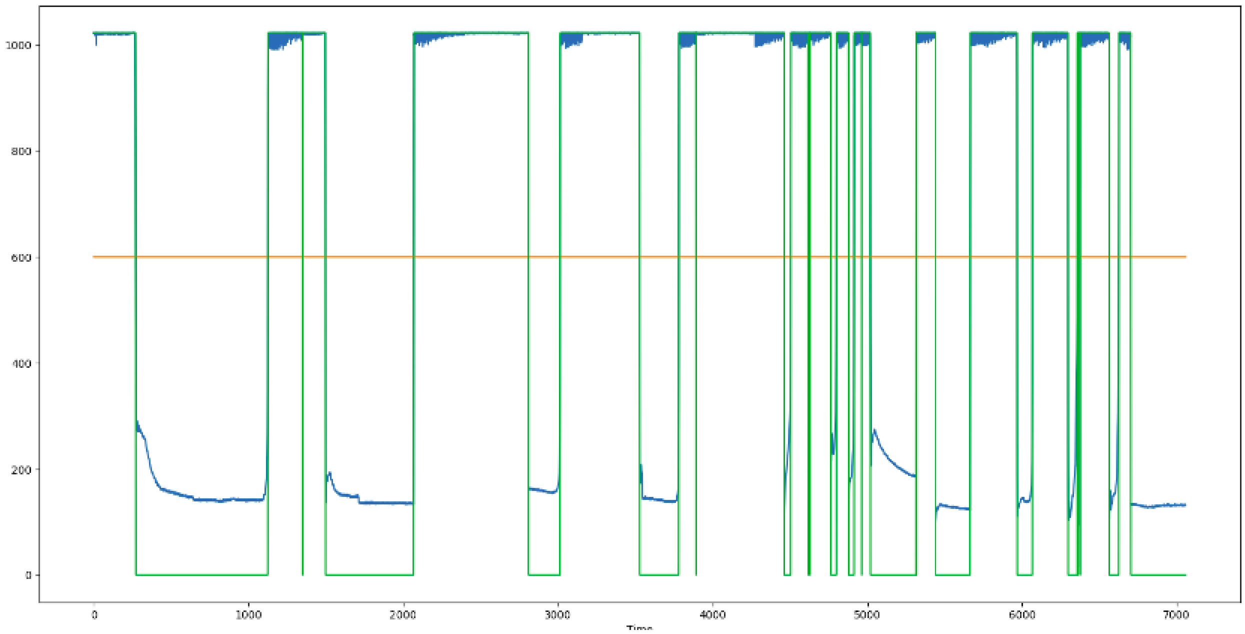


Figure 1. Time Series of recorded raw signal values (blue) and binarized values signal (green). The threshold is indicated in orange.

We use the raw signal mean and standard deviation in each scenario and apply them to the normal distribution formula with a confidence interval of 95% to obtain the volts (V) of signal and the V of background noise.

$$V_{(signal|noise)} = \left(\frac{\bar{X}}{1.96 * \sigma_x}\right)^2 \quad (2)$$

Finally, we obtained an **SNR of 12.9457 dB** using Equation 3, which is higher than 10 dB and indicates a signal measurement error lower 5%. For additional details and evaluations please refer to the project's GitHub repository.

$$SNR_{dB} = 2(10log_{10}(V_{signal}) - 10log_{10}(V_{noise})) \quad (3)$$

Applications

There is research on head-banging behavior in toddlers with autism [1]. For example, studies are measuring if head banging is more frequent in subjects with autism than subjects without autism. Other studies investigate the potential risk of self-injuring while head-banging. The proposed sensor could aid the remote monitoring and self-awareness of the initial stages of head-banging behaviors to prevent or stop them before it becomes a safety risk.

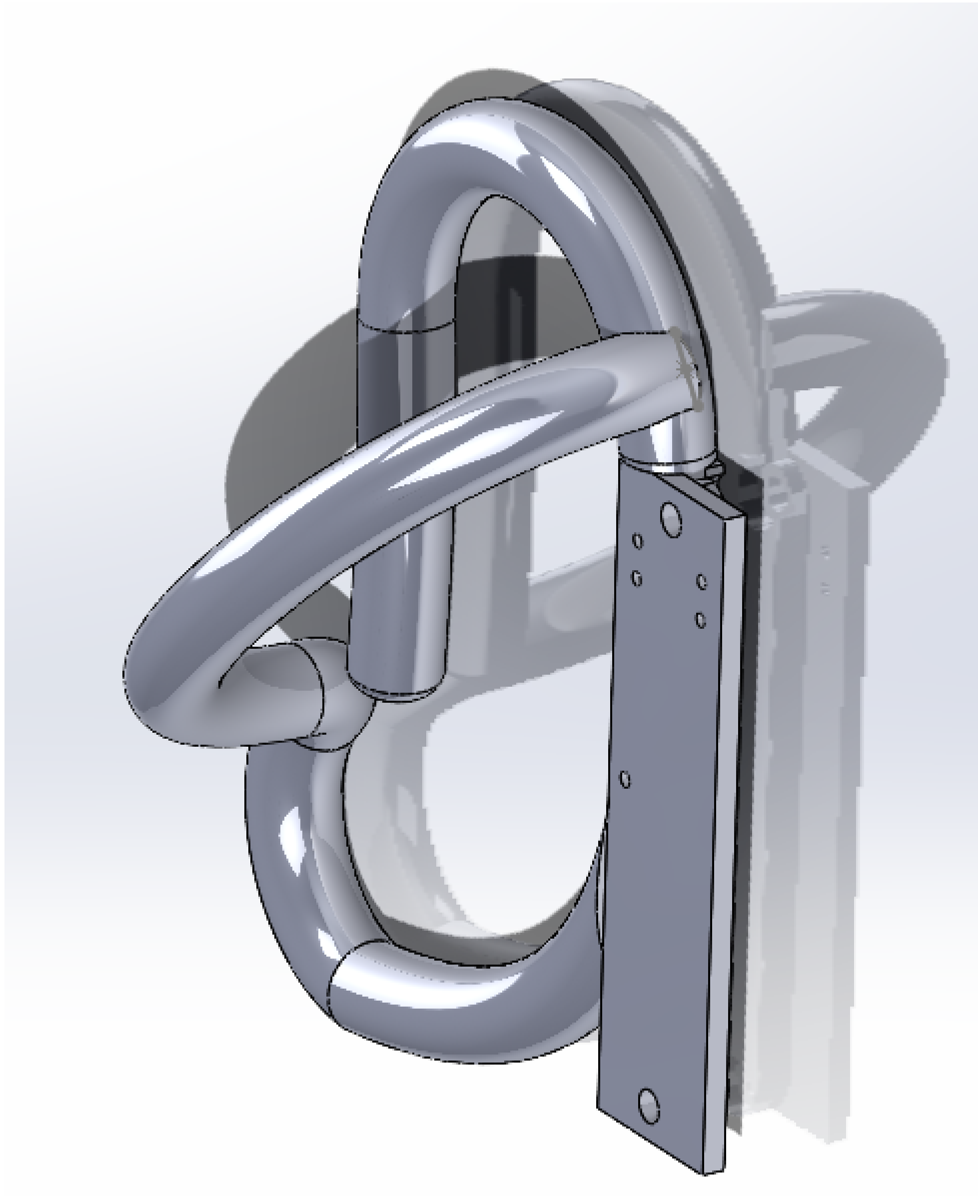
On the other side of the age pyramid, the elderly population (over 65 years old) has a high prevalence of head tremors. This condition can be related to several causes such as cervical dystonia or essential tremors. To accurately identify and diagnose the cause of tremors some studies propose gyroscope sensors attached to the user's head to generate statistical models that can classify the cause of the head movements [2]. Nevertheless, this approach involves having a heavy sensor attached to the user’s head for an extended period. Our sensor can be a more subtle alternative that is less intrusive and allows us to record the number of times the user engages in mid to high tremors during a prolonged period. Thus, health professionals could compare patients, and determine how frequently this condition affects the user's normal behavior.

Also, this behavior is related to activities such as hard impacts inside a vehicle (automobile, motorcycle, bicycle, among others). In this case, our sensor monitors how frequently the user's neck is involved in the middle to high impacts while the user is driving or being inside the vehicle. Our device is less intrusive than other alternatives to measure the movement while it is still low-cost and easy to manufacture [3].

References

1. Martin, K.B., Hammal, Z., Ren, G., *et al.* Objective measurement of head movement differences in children with and without autism spectrum disorder. *Molecular Autism* 9, 14 (2018). https://doi.org/10.1186/s13229-018-0198-4
2. Berbakov, L., Jovanović, Č., Svetel, M., Vasiljević, J., Dimić, G., & Radulović, N. (2019). Quantitative Assessment of Head Tremor in Patients with Essential Tremor and Cervical Dystonia by Using Inertial Sensors. *Sensors (Basel, Switzerland)*, *19*(19), 4246. https://doi.org/10.3390/s19194246
3. Dsouza, H., Pastrana, J., Figueroa, J., *et al.* Flexible, self-powered sensors for estimating human head kinematics relevant to concussions. *Sci Rep* 12, 8567 (2022). https://doi.org/10.1038/s41598-022-12266-6

Appendix A. 3D-printed earpiece that holds the PCB.



Appendix 2. Circuit diagram.