Respiration Mode Detection Using A Wireless Instrumented Mouthguard[1]

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Many ongoing research and commercial efforts seek to develop head-mounted sensor systems primarily intended to measure the severity of impacts to the head and body. The majority of these systems incorporate computational and data acquisition electronics close to the mouth or ears. The prospect of utilizing such devices for health and safety assessment during athletic, occupational, and recreational activities presents a unique opportunity to use these systems for additional physiological monitoring and detection. In particular, instrumented mouthguards provide access to bone, mucosa, arteries, saliva, and inspirated and expirated air. We have developed an instrumented mouthguard with a primary function of inertial measurement of the skull, but present a secondary functionality of measuring respiration using a simple palate impedance measurement capable of identifying respiration rate and respiration mode.

The instrumented mouthguard system consists of a microcontroller, analog-digital converter, non-volatile FRAM memory and a radio for data transmission affixed to a rigid orthogonal bridge which is fused to a fitted retainer. Electrodes lay inside the fitted mouthguard in contact with the gum tissue near the 2nd molars. The system measures the impedance between the 2nd molar regions by measuring the time to charge a 5 nF capacitor to the logical signal threshold of an input pin on the microcontroller. The capacitor is charged using a 3.3 V supply voltage in series with the palate tissue. As the impedance of the tissue increases, the time to charge the capacitor correspondingly increases. An AC excitation is used in order to minimize galvanic disruptions.

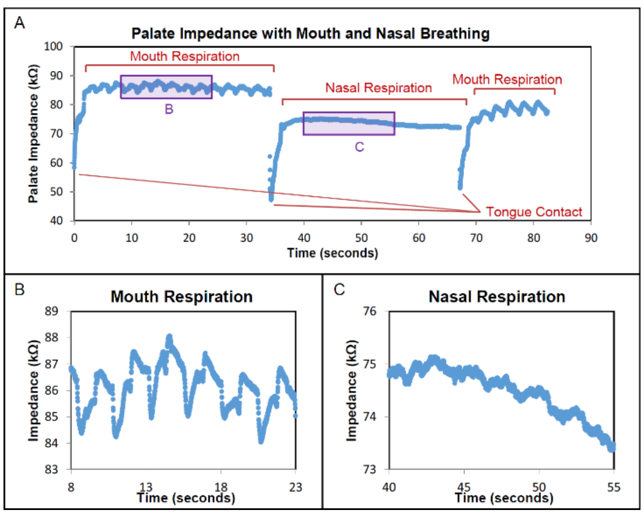
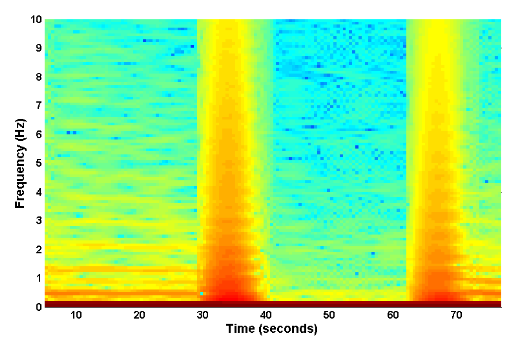


Figure 1: Measurements of palate impedance. Samples were collected at a 10 ms interval.

Measurements of palate impedance showed distinct impedance fluctuations resulting from respiration. These fluctuations are apparent not only when the subject is breathing through their mouth, but also during nasal respiration. As shown in Figure 1, the magnitude of the fluctuation during nasal respiration is substantially smaller. We developed a signal processing procedure for categorical identification of respiration mode. We focus our attention on respiration mode due to the historical challenge of measuring both nasal and mouth respiration and differentiating between the two.

Respiration palate impedance data was processed using a Short-Time Fourier Transform (STFT). As shown in Figure 2, spectral power in the range of respiration frequency can be used to differentiate between mouth and nasal respiration. To quantify this difference, we averaged spectral power between .4 and 1.4 Hz following the application of STFT, which we normalized to the 0 Hz power to compensate for drifting palate impedance.



The method described is susceptible to the behavior of the tongue. When the dorsal region of the tongue is pressed against the soft palate a substantial drop in measured impedance occurs during which no respiration detection is possible (contact of the tip of the tongue to the hard palate does not substantially change the measurement). This tongue contact anomaly requires a third categorization of respiration behavior. We developed a simple binning approach to categorizing respiration mode into the categories of tongue contact, mouth respiration, and nasal respiration based on impedance deviation from a low-pass filter of the incoming impedance signal (τ = 300 s) and averaged STFT spectral power between .4 and 1.4 Hz. The resulting classification had an accuracy of over 80% with accuracy of over 94% when discarding categorization within 5 seconds of a tongue contact transient event, indicating this is a promising approach to identify respiration rate and mode with minimal effort for health and safety assessment systems already employing an instrumented mouthguard.

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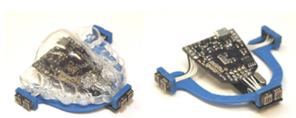
Abstract

- Evaluation of head impacts is leading to the expanded use of head-mounted sensing, computation, and communication systems.
- We present a method and device for using an existing instrumented mouthguard intended for measuring skull accelerations to perform secondary measurements of respiration rate and mode.
- Electrodes affixed to a rigid mouthguard contacting the 2nd molar gum tissue measure palate impedance, which fluctuates with respiration.
- Respiration rate and mode are identified via Fourier analysis and comparison of windowed average spectral power following Short-Time Fourier Transform.
- This approach results in a respiration mode detection accuracy of over 80%, and over 94% for analysis discarding tongue contact transient events.

Background

- Head-based wearable electronic devices are becoming more popular for detection and evaluation of head impacts, and are likely to be widely adopted for military and professional sports applications in the near future.
- Instrumented mouthguards provide access to bone, mucosa, arteries, saliva, and inspirated and expirated air, which are very useful for biological sensing.
- There is a good opportunity for the development of add-on sensors and detection mechanisms to add functionality to existing mouthguard-based sensor systems.
- Respiration rate is an important vital sign which is difficult to assess outside of a clinical setting without cumbersome wearable sensors (i.e. chest bands) or forced respiration mode devices (piezo strip sensors in breath analysis tests or spirometer devices) and rarely do these methods allow for both nasal and mouth respiration while also distinguishing between the two.

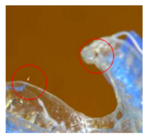
Existing Mouthguard Platform



- Microcontroller with external high-speed DAQ, large non-volatile memory buffer, wireless radio, and 6 high-speed linear accelerometers.
- Acrylic mouthguard fused to rigid orthogonal alignment plate offers a tight fit to teeth and gums.

Sensor Design

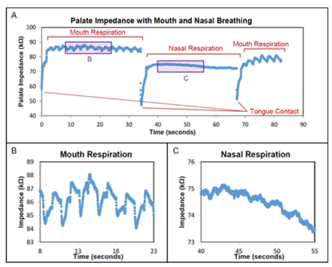
- Gold electrodes placed near the gum tissue adjacent the 2nd molars.
- We measured impedance between molars (through the palate) by using the palate as a resistive element in a simple RC circuit where the time to charge the capacitor to the logical input threshold of the microcontroller is proportional to the impedance of the tissue.
- Bi-directional charging allowed for AC current application to the tissue to avoid galvanic effects.
- Measurement time is variable using this measurement scheme, but still orders of magnitude smaller than the periodicity of respiration.



Electrodes place in contact with the gum tissue in the approximate location of the 2nd molars were used to measure soft palate impedance

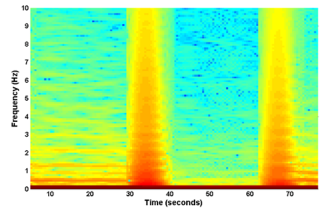
Measurement Results

- Test subject was asked to wear the mouthguard with electrode contact to gums and follow a respiration schedule of deliberate nasal and mouth respiration as well as intermittent contact between the tip of the tongue and the hard palate and the dorsal region of the tongue and the soft palate.
- Respiration periodicity is evident in the resulting signal (B), and substantially attenuated for nasal respiration (C).
- Tongue contact with hard palate results in no noticeable change in signal behavior, whereas dorsal contact with the soft palate results in a substantial reduction in impedance magnitude (A).



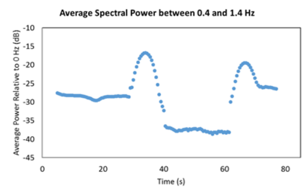
Spectral Analysis

- Signal processed using a Short-Time Fourier Transform with a 10 s window and 9 s overlap.

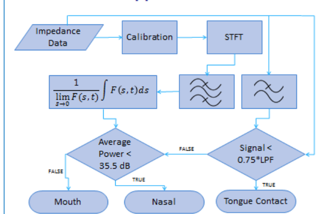


STFT measurement (10 s window) increased spectral power in the .4 Hz to 3 Hz range for mouth respiration.

- Averaging spectral power between 0.4 Hz and 1.4 Hz was used to quantify the magnitude of the respiration signal. Note: lower frequency windowing is required for non-athletic respiration monitoring where respiration frequencies of 0.2 Hz are common).
- Spectral power after averaging shows a 10 dB difference between mouth and nasal respiration when normalized to the 0 Hz power.



Classification Approach



Classification Outcome

- Accurate prediction of respiration state for at least 86% of instantaneous predictions for each respiration state.
- Tongue contact transients were the largest contributors to confusion.
- Identifying contact transients and ignoring predictions within 5 seconds of a transient contact event resulted in >94% accuracy for all predicted states.

Actual State \ Predicted State	Mouth	Nasal	Tongue
Mouth	92.2%	4.4%	3.2%
Nasal	1.9%	90.1%	8.0%
Tongue	6.2%	7.8%	86.0%

Confusion matrix for predicted state over a 25 minute respiration schedule sample collection.

Confusion matrix for predicted state over a 25 minute respiration schedule sample collection discarding predictions made within 5 seconds of an identified dorsal contact transient event.

Actual State \ Predicted State	Mouth	Nasal	Tongue
Mouth	98.4%	1.1%	0.5%
Nasal	0.2%	96.3%	3.5%
Tongue	1.3%	4.4%	94.3%

Summary

- As head-mounted instrumentation for health and safety assessment becomes more widespread, the need for and availability of supplemental sensory information will also increase.
- The prospect of data acquisition and computing electronics in the mouth present an interesting opportunity for novel sensor designs and applications.
- We have demonstrated the implementation of a supplemental sensor system which provides additional vital sign assessment to a system intended for measuring accelerations of the skull.
- We have implemented and verified the performance of this sensor system using a simple respiration mode identification algorithm.
- The system correctly categorized respiration mode with greater than 86% accuracy, and accuracy can be further improved.
- Additional sensor systems are possible with access to gasses, fluid, and tissue available inside the buccal cavity.

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