Demo: HABits Necklace: A Neck-worn Sensor that Captures Eating Related Behavior and More

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Abstract
In this paper, we present the design and implementation of the HABits necklace, a neck-worn device that estimates behavior. This neck-worn device is continuously evolving to provide researchers with the ability to use it in multiple applications including eating, gesture, and activity recognition. Our proposed HABits necklace generates four signal streams using three embedded sensors including a proximity sensor, ambient light sensor, and a 9-axis inertial measurement unit (IMU). In this work, we highlight its ability to characterize eating episodes. We apply algorithms to estimate chew count, number of feeding gestures, posture, and activity intensity. Users will be able to visually see the necklace data and the result of the algorithms on the smartphone in real time.

Author Keywords
Neck-worn sensors; wearables; eating detection.

ACM Classification Keywords
H.1.2 [User/Machine Systems]: Human Factors; I.5.4 [Pattern Recognition]: Applications

Introduction
The ubiquity of wearable wrist-worn sensors has led other researchers to create more devices that are similar in form factor and design to worn accessories like rings, necklaces,

Figure 1: Necklace design and personalized casings.

and glasses. Several devices have been designed to detect and characterize eating behaviors. We present a device comprising a sensing suite that has been shown to be comfortable to wear. The necklace is equipped with an inertial measurement unit (IMU), proximity sensor, and an ambient light sensor. The IMU measures physical activity and posture, the position of the proximity sensor is ideal for tracking jaw movement, and the ambient light can aid in detecting feeding gestures.

Device Design

Figure 1 shows the construction of the necklace along with a few 3D printed casings to support personalization of the device. We designed leather-based neck bands (color options were brown and black) with velcro closures, and fashioned three 3D printed sensor casings to allow for personalization (clear green, white, and black). The leather-based bands ensured that the angle between the proximity sensor and the chin did not change significantly during wear time. Providing participants with the ability to select between different necklace designs increased their willingness to adhere to wearing the device [1].

A separate top piece was designed with a square opening at the top of the casing to provide a field of view for the proximity and ambient light sensor, and another opening from the bottom of the casing to charge the battery. The following describes each sensor and what it measures.

Proximity Sensing: A combination proximity and ambient light sensor (VCNL4010) is pointed towards the participant's chin; when the participant chews, the relative distance between the chin and the necklace changes, and this change is captured by the proximity sensor.

Ambient Light: Using the same sensor from the previous signal we also capture the ambient light. Although the sensor is pointed towards the chin it also picks up on when objects are near the face, this can be used to detect when a person touches their face, which can be useful in applications related to both smoking and eating detection.

Inertial Measurement Unit: An IMU (BNO055) calculates absolute rotations in the form of quaternions. The necklace records the calculated quaternions and linear acceleration from the IMU for further processing. Using this we can calculate the amount the user leans forward and back. This is helpful in eating detection as people tend to lean forward during a bite and lean back when drinking.

The necklace also comprises a real-time clock (RTC) to maintain absolute time when the necklace is turned off. A smartphone app transmits a BLE packet to the necklace once a day (around 3 am) to synchronize the clock of the necklace with the smartphone. Every few minutes, the clock cycles on the microprocessor and corrects for drift from the RTC.

The processor samples the sensors at 20Hz, and pools the absolute time from clock cycles. The proximity, ambient,

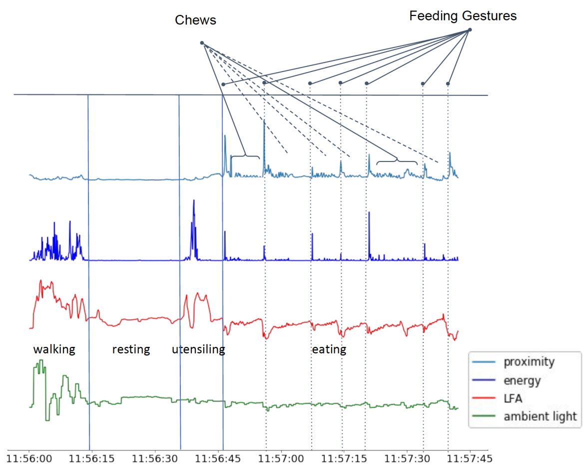


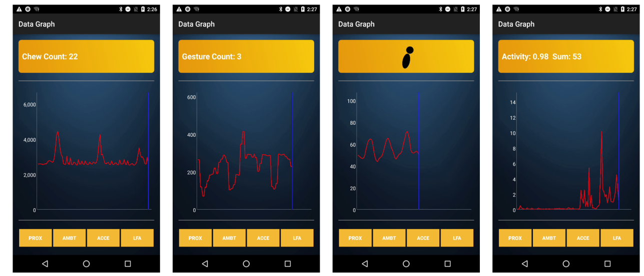
Figure 2: An example of signals obtained while a person is eating

and IMU sensors sequentially write to a buffer in memory. When this buffer reaches capacity, the data is written to a local microSD (uSD) card. The buffer helps increase writing throughput and reduces power consumption by writing every three minutes. The necklace can collect data continuously for 2 weeks with a single charge if the data is stored locally without Bluetooth transmission to a smartphone, otherwise, it lasts 24 hours.

We developed an Android application that connects to the necklace via Bluetooth which allows us to either stream the data continuously to the phone for visualization purposes and/or for online detection of events.

Applications

Our necklace supports multiple applications including chew count, feeding gesture count, activity intensity estimation, and posture recognition. Figure 2 is an example of signals obtained while a person is eating which shows the signals related to walking, resting, utensiling, and eating.



a) Proximity b) Ambient-Light c) Posture d) Activity Intensity

Figure 3: Android app captures four signals and performs real-time calculation of a) chew count, b) feeding gesture count, c) posture, and d) activity intensity estimation.

Chew Count Detection (Proximity Sensor)
Figure 3 shows different snapshots of the smartphone application visualizing the real-time data transmitted by the necklace. The screen shows the real-time signals in red, and the moving blue vertical line shows the most recent data value (which wraps around the screen once it reaches the end). Figure 3a shows 3 bites and 2 chewing sequences between the bites with a chew count of 22.

Feeding Gesture Count Detection (Ambient Light)
Figure 3b shows the data from the ambient light sensor. The three dips in the signal correspond to 3 feeding gestures as the participant places his/her hand close to the mouth.

Leaning Forward/Backward Detection (IMU)
Figure 3c shows the posture estimated from the IMU, with an animation on top moving forward and backward as the person leans forward and backward. The lean-forward motion often corresponds with a feeding activity, while the

lean-back motion corresponds with a drinking activity (unless a straw is used).

Activity Intensity Value (IMU)

Figure 3d shows an energy signal calculated from the 9-axis IMU, this can help inform us when participants are moving and at what intensity level, to offset calorie need. The app presents both the current activity intensity value and a cumulative sum for the day.

Necklace Use Cases

The necklace can potentially detect other activities as shown by the spectrogram in Figure 4. Visually inspecting the spectrogram, one can see clear differences in the patterns between chewing, talking, walking, and running activities. This device could aid in providing useful features for other applications related to activity recognition, particularly those that benefit from detection of head or chin motion.

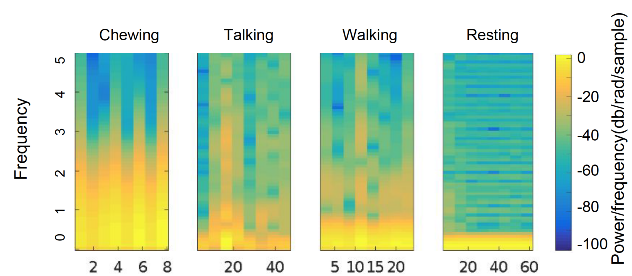


Figure 4: Spectrogram of proximity signal for four activities comparing chewing, talking, walking, and resting.

Related Works

Recent work has shown promise in using a proximity sensor around the ear [2] to detect chewing from talking through detection of movement by the mandible. More recently a proximity sensor has been tested around the neck combined with a threshold-based algorithm to detect chewing bouts and eating episodes [3]. Our method extends the inertial and proximity sensing modality by fusing the ambient light sensor with the proximity sensor, an IMU, and a novel algorithm for chewing sequence detection and eating episode identification. Moreover, our sensing suite is embedded in a fully enclosed stable sensor design for durability in the wild setting.

Conclusion

We present a demo of a necklace that is equipped with four sensing modalities (proximity, ambient, and inertial sensing). We show the feasibility of the necklace in characterizing chews, feeding gestures, posture, and activity during an eating episode. The necklace also streams data in real-time to an app for processing and visualization.

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