Demo: Accurate Eating Detection on a Daily Wearable Necklace

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ABSTRACT

While there are many research proposals for wearable Automatic Dietary Monitoring (ADM) systems that detect eating of a user, it is difficult to notice real-world users wearing such devices in public. We propose a new wearable ADM system that could be used daily by real-world users. It is designed in a form of necklace, providing natural and firm contact of sensor on user's skin to accurately capture eating activities. At our preliminary experiments, our wearable ADM system detected eating of a user with 86.1% accuracy.

CCS CONCEPTS

• Human-centered computing → Ubiquitous and mobile computing; **• Applied computing** → *Health informatics.*

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1 INTRODUCTION

Food journaling is an effective method to monitor eating habits. Daily recording of food journal provides consciousness on the food intake, which leads to healthy food choices. Maintaining daily food journal is well-known to be effective in losing weight and managing chronic diseases. Because of these benefits, food journaling is widely recommended by doctors and nutritionists.

As there is no widely used autonomous eating detection system, a typical choice for journalers is to manually record the food journal. However, manual food journal often results in inaccurately recording every food intake. Journalers often forget to write the journal or write erroneous self-recording. With frequent missing entries and inaccurate food intake estimation, many people abandon food journaling and fail to consistently maintain food journaling.

To address such challenges, wearable Automatic Dietary Monitoring (ADM) systems that automatically detect eating of a user on wearable devices with various sensors have been proposed. Despite the significant amount of research on wearable ADM systems, we rarely witness adoption by real-world users in public. We believe that the following two conditions must be met for wearable ADM systems to be adopted by real-world users:

- It should be designed in a form factor that is suitable to be daily worn at real-world (i.e., it should be (i) comfortable for users to wear and (ii) socially acceptable.).
- It should accurately detect eating episodes at outside-the-lab environments.

We found that no existing wearable ADM systems satisfy both conditions.

We propose and demonstrate a new wearable ADM system that could be used daily by real-world users. Our wearable ADM system design satisfies both conditions above. It is designed as a necklace, which is a form factor that is widely regarded as daily wearable. A contact microphone sensor is placed at the back of the necklace, directly on human's back of the neck (Figure 1b). The sensor is firmly contacted on human skin by the gravity induced from the weight of the front side of the necklace, thereby accurately capturing human eating activities. At our preliminary studies, our wearable ADM system achieved 86.1% accuracy in detecting eating episodes of a user.

2 SYSTEM DESIGN

2.1 Design Choices

Prior works on wearable ADM systems have leveraged various types of sensors; acoustic sensing with microphones, inertial sensing with IMU sensors, physiological sensing with EEG and EMG, camera-based image sensing, and capacitive sensing.

Our goal is designing a wearable device with sensing method that achieves both accuracy and "wearability" conditions discussed in Section 1, which are necessary for mainstream adoption. However, except for acoustic sensing with contact microphone, no sensing method achieves both conditions. While traditional acoustic sensing with condenser microphones are very susceptible to ambient noise, acoustic sensing with contact microphone provides reliable sensing of eating by minimizing the effect of ambient noise [2]. Inertial sensing on its own rarely overcomes accurate sensing of eating as it commonly suffers from a high rate of false positives in uncontrolled environments. Equipments for physiological sensing and capacitive sensing (e.g., EEG headset and neckband with conductive pads) are difficult, if not impossible to pass the wearability in real-world condition due to their large form factor. Camera-based image sensing poses serious privacy challenges.

We hence use acoustic sensing with contact microphone on our wearable ADM system to detect eating of a user. We believe that acoustic sensing can achieve both conditions. Since microphone sensors are made in small size (diameter < 20mm), it could be easily embedded in any form factor of devices that is widely regarded as daily wearable. Moreover, acoustic sensing can accurately detect eating of a user by capturing unique audio signals from eating-related activities (e.g., chewing, swallowing, etc.). We implemented eating detection on the microcontroller board to protect the privacy

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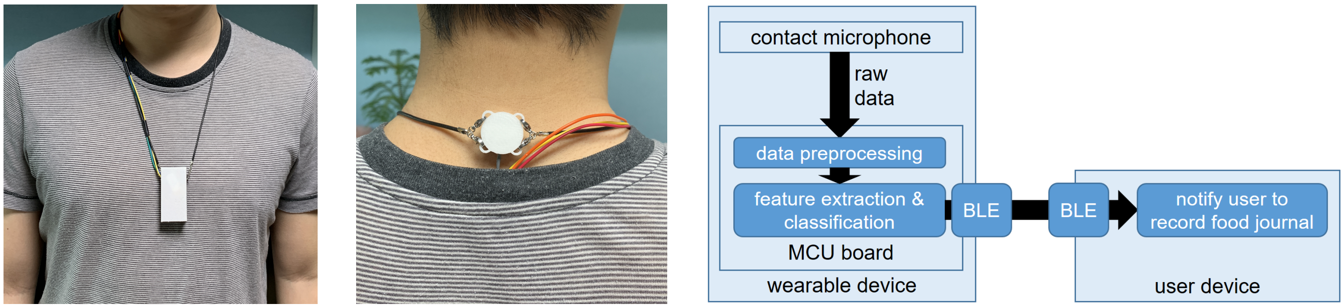

(a) Front side. (b) Back side. (c) System architecture.

Figure 1: Our wearable system prototype.

of a user (i.e., no communication with cloud) in various real-world situations.

2.2 Hardware Design

Prior studies on eating detection that utilize acoustic sensing with contact microphones leveraged large, obtrusive form factors (e.g. neckbands and headgear) to firmly contact microphone sensor on human skin [1, 2]. While the firm contact of sensor is necessary to properly capture body activities, the form factors of these studies make them unwearable (i.e., uncomfortable to wear and socially awkward), thereby limiting real-world adoption. To address this issue, our system design is in a form of daily wearable necklace that provides reliable contact of a sensor on human skin. The microphone sensor on the back of the necklace is firmly contacted on the neck by the gravity induced from the front side of the necklace.

Figure 1a and 1b illustrate our wearable device design. On the front side, there is an nRF52840 Miniboard from SparkFun that has ARM Cortex M4F microcontroller with BLE and a 110mAh LiPo battery, which are covered by 3D-printed housing. On the back side, there is a contact microphone CM-01B placed on the user's back neck. The sensor is attached to a 3D-printed cover, which is designed to equally distribute the effect of gravity on the sensor. We plan to minimize the size of both sides of the necklace by using a custom PCB board and a custom-built contact microphone sensor.

2.3 Eating Detection Procedures

Figure 1c describes the overall functionality of our system. For eating detection, our wearable device collects audio signal with the contact microphone at a sampling frequency of 500 Hz. The collected raw audio signal data is then standardized to remove sensor-specific characteristics. From the raw data of each non-overlapping window of 3-seconds, 23 features are extracted. Those features are applied to a single layer, fully-connected DNN model to classify between "eating" and "non-eating". When the classifier outputs eating, the wearable device sends a signal to the user device via BLE, to notify the user to record food journal on time.

To train the classifier model and assess the performance of our system, we conducted a preliminary study with two people. Participants wore our wearable device during three meals at places with ambient noise (e.g. other people having a conversation), and 90 minutes of data were collected in total. During the data collection, participants were freely allowed to do other activities such as talking, laughing, and drinking. For the ground-truth collection of eating and non-eating state of a user, the participants were video recorded during the data collection. From the collected data, we extracted over 900 features and further selected 23 features considering the limited computational resource of our wearable device. With the 23 features, the fully-connected DNN model with single layer showed 86.1% accuracy in classifying between eating and non-eating state of a user. As our system proposes a new way of natural contact of sensor with gravity, we expect the performance of our system to be lower than the state-of-the-art eating detection with contact microphone and headgear (92.8% accuracy) [1]. We further plan to explore the accuracy and wearability on different weight of front side of our wearable necklace to look for optimal setting that achieves both high accuracy and wearability.

3 DEMONSTRATION

In this demonstration, we will show a accurate eating detection on a daily wearable necklace that we designed. We will bring our wearable prototypes to let attendees wear the device and test the eating detection of our system, by providing them snacks to eat and showing the classification results real-time.

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