IMChew: Chewing Analysis using Earphone Inertial Measurement Units

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According to World Health Organisation, in 2022, 1 in 8 people in worldwide population were living with obesity. Additionally, adult obesity has more than doubled since 1990. Studies on eating behaviour suggests that increasing the number of chews per bite is a potential strategy to reduce food intake and may aid in body-weight management [15]. Eating at a slower pace has also been found to aid in improved digestion, nutrient absorption and further contributes to a lower risk of gastric cancer, tooth loss, and facial distortion [5, 12]. Hence, chewing analysis is essential to assisting users in developing a healthier eating habit.

A variety of devices, in particular wearables, have been investigated for conducting chewing analysis. Microphones are of the most popular and effective sensors for chewing detection, embedded in various kinds of devices ranging from smartglasses [13] to a novel head-mounted device [4]. However, these wearables are obtrusive and not socially accepted for daily-life uses, limiting their usefulness for chewing analysis. Consequently, more recent studies [7, 10] have leveraged earphones for chewing analysis, enabling unobtrusive, convenient, and widely adopted solutions for daily uses. These works have achieved initial success with [10] using microphones and IMUs on earphones for chewing detecting and [7] using only IMUs for snacking detection.

Our work aims to take a step further in earable-based chewing analysis. We extend the applications to include chewing counting, a critical step towards detecting chewing rates and ultimately analysis of users' eating habits. Current works on chewing counting have explored a range of devices including microphones on glasses [14] and on user's neck [6], which are obtrusive. In contrast, our study introduces a non-invasive and user-friendly solution for both chewing detection and counting using earphones.

Specifically, we utilize IMUs in earphones, which are standard and low-cost sensors in commercial earbuds (e.g., Apple Airpods [1], Google Pixel Buds [2] and Samsung Galaxy Buds [3]), and show promise in capturing the jaw movements [8] induced by chewing [10]. We propose a system, IMChew, comprising two main components receiving IMU signals from earphones: chewing detector and chewing counter. Employing three machine learning models (Logistic Regression, Decision Tree, and Random Forest) with exploring various time and frequency domain features, the chewing detector is implemented to recognize chewing activities from various non-chewing activities. For the chewing counter, we develop a signal processing pipeline to detect chewing frequency in the recognized chewing episodes from the chewing detector.

We implemented a prototype system of IMChew using the eSense platform [9, 11], equipped with a 6-axis IMU (i.e., a 3-axis accelerometer and a 3-axis gyroscope). We collected data from 8 participants aged 20-60 years, encompassing both chewing activities with various foods and a broad range of non-chewing activities. We evaluated the system's performance across different participants and activities. Overall, the performance of our chewing detector using a LOSO approach achieved both accuracy and F1-score of 0.91, while our chewing counter attained a MAPE of 9.51%.

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