IMChew: Chewing Analysis using Earphone Inertial Measurement Units

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Background

According to World Health Organisation, in 2022, 1 in 8 people in worldwide population were living with obesity!

Background

- Increasing the number of chews per bite help reduce food intake and may aid in body-weight management [1].
- Eating at a slower pace aid in :
  - improved **digestion, nutrient absorption**
  - lower risk of **gastric cancer, tooth loss, and facial distortion** [2, 3]

[1] Yong Zhu and James H. Hollis. 2014. Increasing the Number of Chews before Swallowing Reduces Meal Size in Normal-Weight, Overweight, and Obese Adults. Journal of the Academy of Nutrition and Dietetics 114, 6 (2014), 926–931.
[2] Melissa Beitner and Subhash Kini. 2020. Postgastrectomy Syndromes. 129–135.
[3] Akihiro Nakamura, Takato Saito, Daizo Ikeda, Ken Ohta, Hiroshi Mineno, and Masafumi Nishimura. 2021. Automatic detection of chewing and swallowing. Sensors 21, 10 (2021), 3378.

Background

- Form factors
- Eating at a slower pace aid in :
  - improved **digestion, nutrient absorption**
  - lower risk of **gastric cancer, tooth loss, and facial distortion** [2, 3]

Chewing analysis is essential in helping users develop a healthier eating habit!

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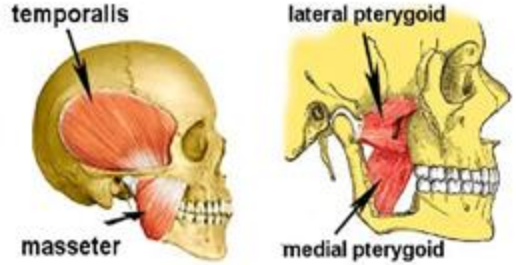
Our Work

IMChew: Chewing detection and counting using earphone IMUs

- Unobtrusive and socially accepted tool
- IMUs are available in smart earphones with open data access
- Position of earphone allows for accurate detection of jaw movements

eSense earbuds [4,5]



muscles of mastication [6]

[4] Fahim Kawsar, Chulhong Min, Akhil Mathur, and Alessandro Montanari. Earables for personal-scale behavior analytics. IEEE Pervasive Computing, 17:83–89, 07 2018.
[5] Chulhong Min, Akhil Mathur, and Fahim Kawsar. 2018. Exploring audio and kinetic sensing on earable devices. In Proceedings of the 4th ACM Workshop on Wearable Systems and Applications. 5–10.
[6] Hong, Kari Ann (2015): The Muscles of Mastication. Available online at http://www.thousandoaksfamilydentistry.com/blog/2014/12/22/the-muscles-of- mastication#.VVZIgTGUeSA.

Preliminary Analysis

eSense earphone is used to collect IMUs data during various head movement

- Chewing has a distinguishable pattern of regular small spikes which indicates to the regular motion of biting down.

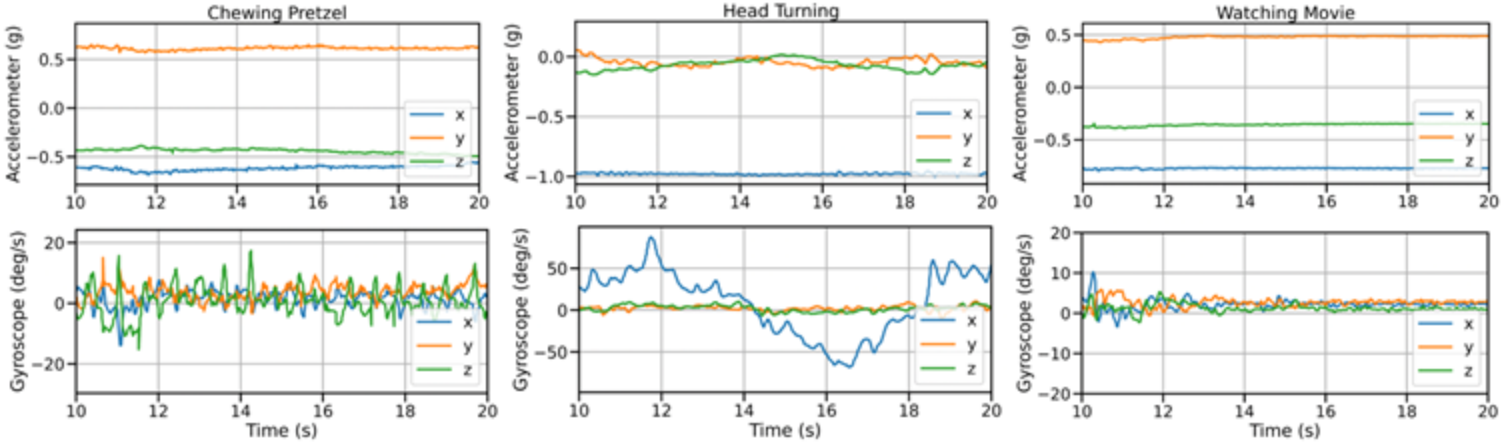
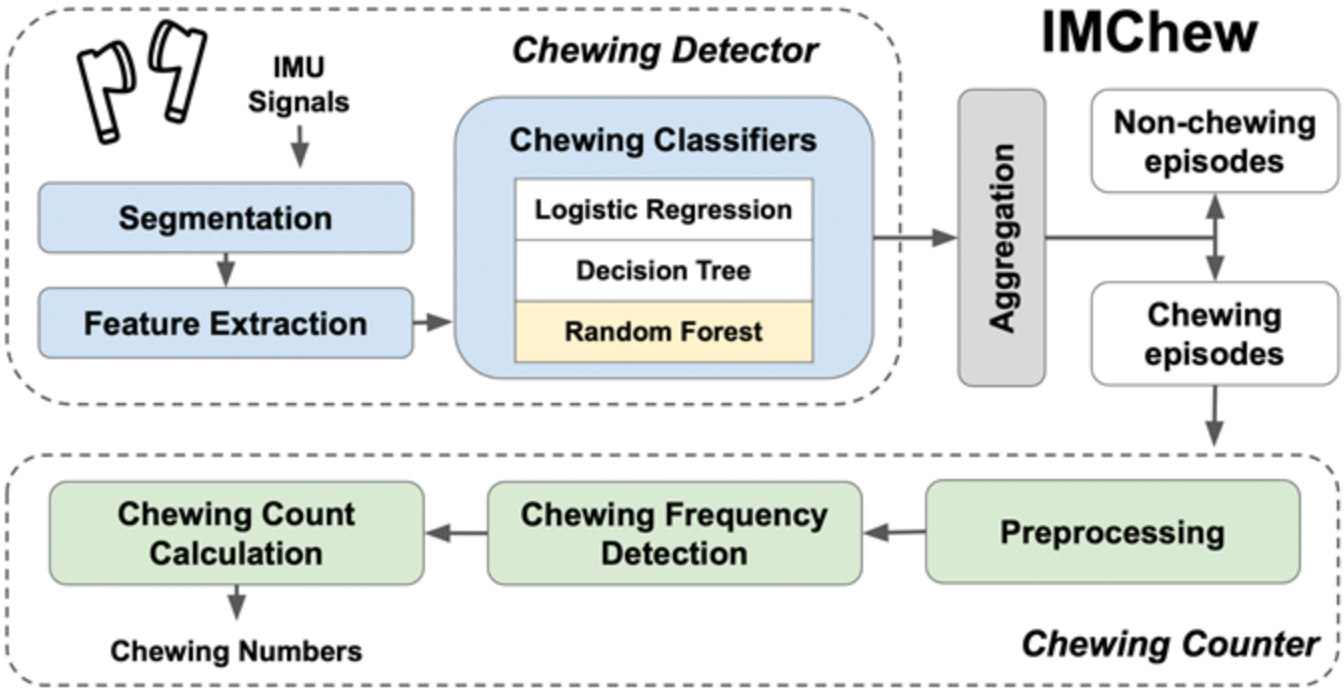


Figure 1: Samples of accelerometer and gyroscope data under various activities.

IMChew Pipeline

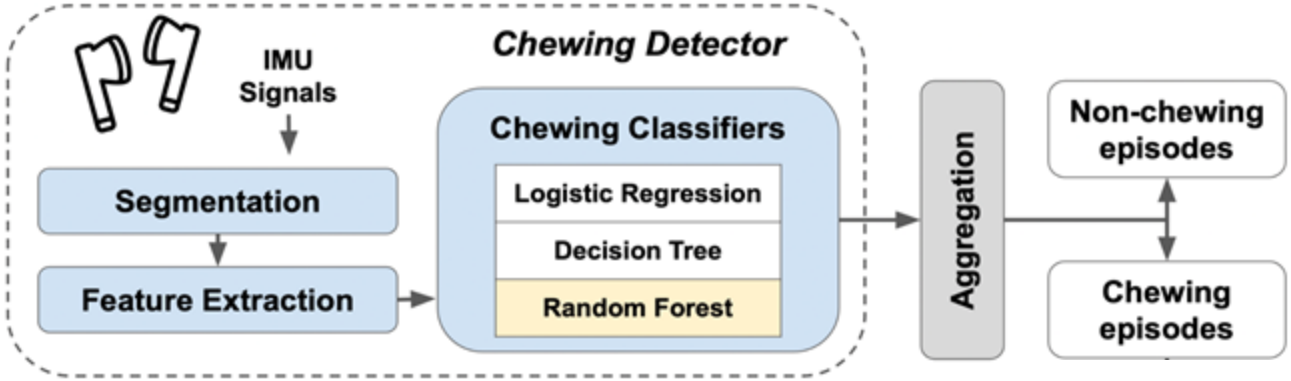


Pipeline: Chewing detector

Segmentation: 3 seconds of non-overlapped windows

Feature Extraction: Mean, Variance, Power, Spectral Centroid, MFCC

Aggregation: determine chewing episodes using majority voting



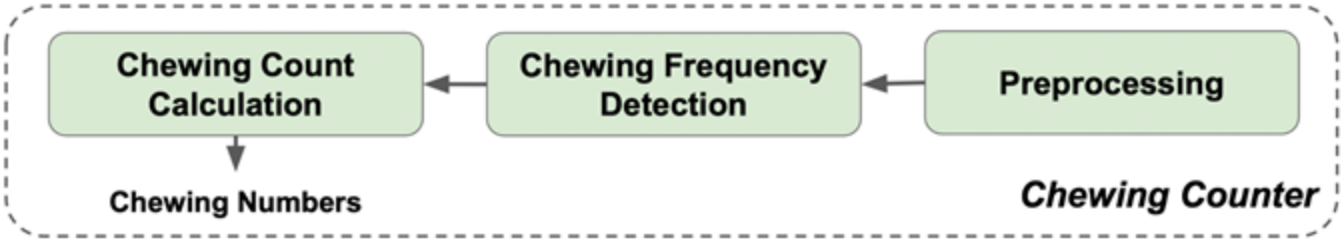
Pipeline: Chewing Counter

Preprocessing:

- Segment to 10s windows
- Butterworth bandpass filter, Moving Average Filter

Chewing Frequency Detection: select the frequency with highest intensity via FFT

Chewing Count Calculation: multiply the frequency with the size of each window



Data Collection

- 8 participants wearing eSense earphones while performing various activities
- Users manually annotating their chewing events
  - Wrote a script to record the timestamp each time the spacebar was pressed
  - Participants pressed the spacebar each time they chewed

Eating Activities	Duration
Chips	2 minutes
Pretzels	2 minutes
Apples	2 minutes
Mangoes	2 minutes
Breads	2 minutes

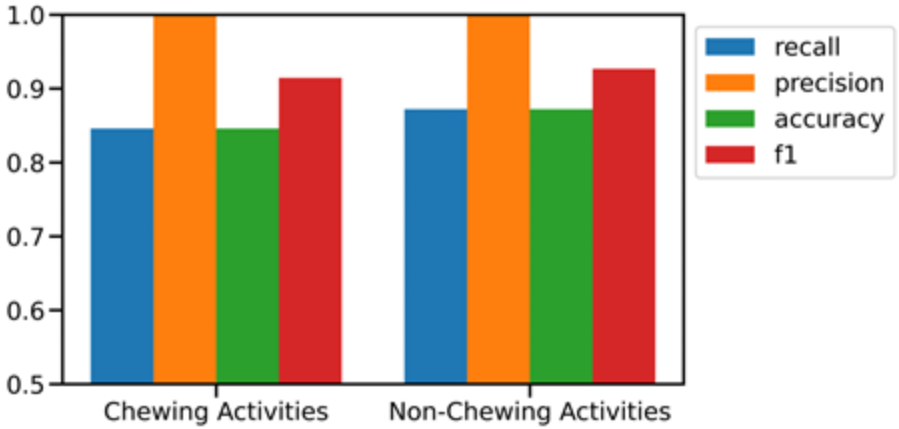
Non-eating Activities	Duration
Sitting Still	2 minutes
Moving Head from Side to Side	30 seconds
Making a Happy Face	30 seconds
Making a Sad Face	30 seconds
Making an Angry Face	30 seconds
Speaking	2 minutes
Drinking	1 minute
Watching a Movie	3 minutes

Result: Chewing detector

Random Forest had the best performance with **recall, precision, F1-score and accuracy of 0.91**.

Existing work [7] achieves accuracy of 0.94, precision of 0.87, recall of 0.92 and F1-score of 0.89.

	Recall	Precision	F1	Accuracy
Logistic Regression	0.83	0.86	0.84	0.86
Decision Tree	0.81	0.81	0.81	0.82
Random Forest	**0.91**	**0.91**	**0.91**	**0.91**



[7] Roya Lotfi, George Tzanetakis, Rasit Eskicioglu, and Pourang Irani. 2020. A comparison between audio and IMU data to detect chewing events based on an earable device. In Proceedings of the 11th Augmented Human International Conference. Article 11, 8 pages.

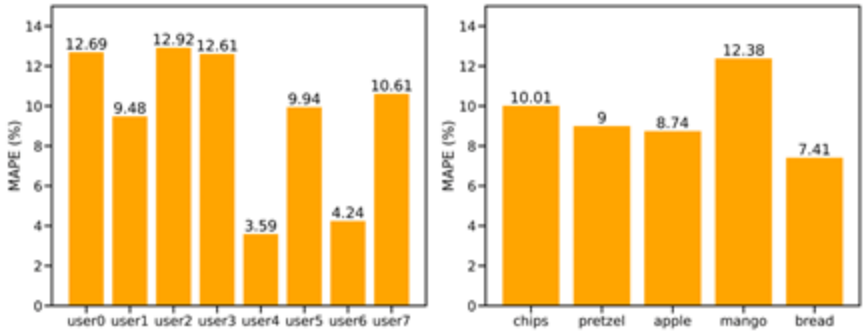
Result: Chewing Counter

Applying **Butterworth bandpass and moving average filters** results in the best performing model with a **MAPE of 9.51%.**

Better results observed for higher chewing rate and harder/chewier food.

Existing work on detecting chewing counting show results of MAPE in a similar range: 8.38% to 12.2% [8,9].

	MAPE (%)
Raw Signal	10.82
Butterworth Bandpass	9.60
Butterworth Bandpass & Moving Average	**9.51**



[8] Shuangquan Wang, Gang Zhou, Yongsen Ma, Lisha Hu, Zhenyu Chen, Yiqiang Chen, Hongyang Zhao, and Woosub Jung. 2018. Eating Detection and Chews Counting through Sensing Mastication Muscle Contraction. Smart Health 9-10 (07 2018).
[9] Abdelkareem Bedri, Gregory Abowd, Richard Li, Malcolm Haynes, Raj Prateek Kosaraju, Ishaan Grover, Temiloluwa Prioleau, Min Beh, Mayank Goel, and Thad Starner. 2017. EarBit: Using Wearable Sensors to Detect Eating Episodes in Unconstrained Environments. Proceedings

Discussion: Approach to Limitations

- **Noisy labelling:** inaccurate labelling because during sessions of eating activities, participants pause and stop chewing every now and then
- **Data collection bias:** range of chewing rate in our sample is only 0.79 to 1.16 chews per second, while the literature claims the range of 0.94 to 2.5 [10].
- **Simultaneous activities:** did not evaluate the chewing counting model's performance in complex free-living situations (e.g. when chewing is combined with other simultaneous activities)

[10] J.M.C. Po, Jules Kieser, Luigi Gallo, A.J. Tésenyi, P Herbison, and Mauro Farella. 2011. Time-Frequency Analysis of Chewing Activity in the Natural Environment. Journal of dental research 90 (08 2011), 1206–10.

Our Contribution

Chewing Detection: existing work explored many devices including earables

- Smart glasses [11]
- Novel head-mounted device [12]
- Earphones with embedded IMUs and microphones [13]

⇒ **We extend earable-based chewing analysis to include chewing counting**

Chewing Counting: existing work explored many devices but they are obtrusive

- Microphones on glasses [14]
- Throat Microphone [15]

⇒ **We investigate a more unobtrusive and socially acceptable device: earables**

[11] Vasileios Papapanagiotou, Anastasia Liapi, and Anastasios Delopoulos. 2022. Chewing Detection from Commercial Smart-glasses. In Proceedings of the 7th International Workshop on Multimedia Assisted Dietary Management. 11–16.
[12] Abdelkareem Bedri, Gregory Abowd, Richard Li, Malcolm Haynes, Raj Prateek Kosaraju, Ishaan Grover, Temiloluwa Prioleau, Min Beh, Mayank Goel, and Thad Starner. 2017. EarBit: Using Wearable Sensors to Detect Eating Episodes in Unconstrained Environments. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 1 (09 2017), 1–20.
[13] Mehrab Bin Morshed, Harish Kashyap Haresamudram, Dheeraj Bandaru, Gregory D. Abowd, and Thomas Ploetz. 2022. A Personalized Approach for Developing a Snacking Detection System using Earbuds in a Semi-Naturalistic Setting. 11–16.
[14] Nur Asmiza Selamat and Sawal Hamid Md. Ali. 2021. Analysis of Chewing Signals Based on Chewing Detection Using Proximity Sensor for Diet Monitoring. In Pattern Recognition. ICPR International Workshops and Challenges: Virtual Event, January 10–15, 2021, Proceedings, Part V. 599–616.
[15] Muhammad Mehedi Billah, Taiju Abe, Akihiro Nakamura, Hiroshi Meneno, Masafumi Nishimura, Takato Saito, and Daizo Ikeda. 2019. Estimation of Number of Chewing Strokes and Swallowing Events by Using LSTM-CTC and Throat Microphone. In 2019 IEEE 8th Global Conference on Consumer Electronics (GCCE). 920–921.

Conclusion

- To the best of our knowledge, IMChew is the first earable-based system for both chewing detection and counting using IMUs
- Proposed an efficient pipeline for chewing detection and counting using earphone IMU signals
- Demonstrated that earables are a viable platform for monitoring chewing activities via comprehensive evaluations of IMChew

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