Yawning Detection using Earphone Inertial Measurement Units

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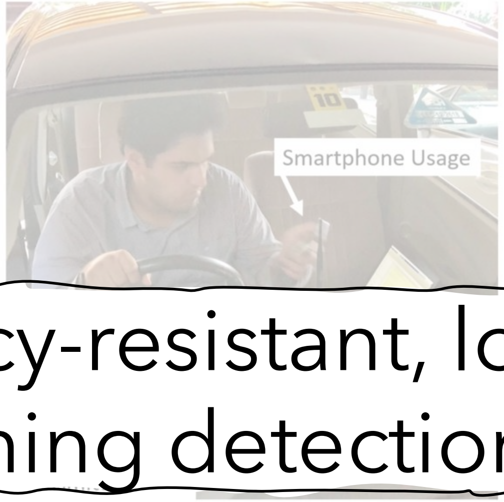
Background

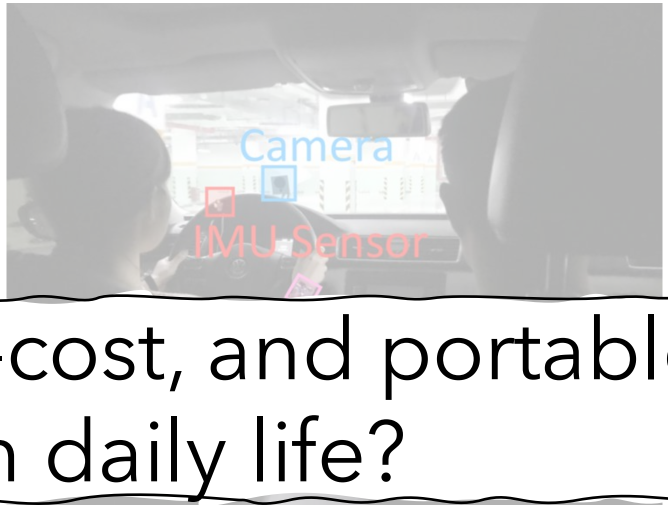
- Why detect yawns?
  - Drowsiness; People are less alert when drowsy[1]
  - Failure to be alerted during safety-critical tasks is dangerous
    - NHTSA: 91,000 crashes in 2017 due to drowsy driving[2]
  - Yawning is a reliable indicator of drowsiness; one of key components

[1]: G Daquin, J Micallef, and O Blin. 2001. Sleep Medicine Reviews [2]: NHTSA. 2017. Drowsy Driving: nhtsa.gov/risky-driving/drowsy-driving

Background

Existing yawning detection solutions fall into 3 categories:





Can we explore a privacy-resistant, low-cost, and portable solution of yawning detection in daily life?

[3] Vision	[4] Wireless	[5] Wearable
Privacy concerns High computation cost	Requires infrastructure/not portable Sensitive to environment/motions	Hand movements Driving scenarios

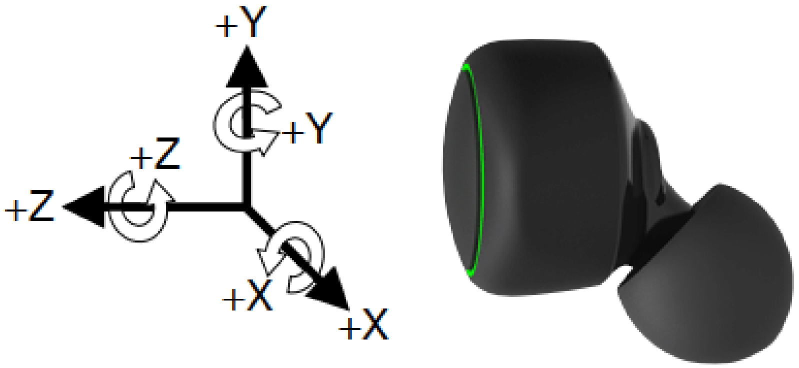
[3]: Belhassen Akrout, Walid Mahdi. Yawning detection by the analysis of variational descriptor for monitoring driver drowsiness. 2016. IPAS
[4]: Hashim Saeed, Tabish Saeed, Muhammad Tahir, Momin Uppal. Risky driving behavior detection using in-vehicle WiFi signals. 2018. VTC-Fall
[5]: Yetong Cao, Fan Li, Xiaochen Liu, Song Yang, Yu Wang. Towards reliable driver drowsiness detection leveraging wearables. 2023. TOSN

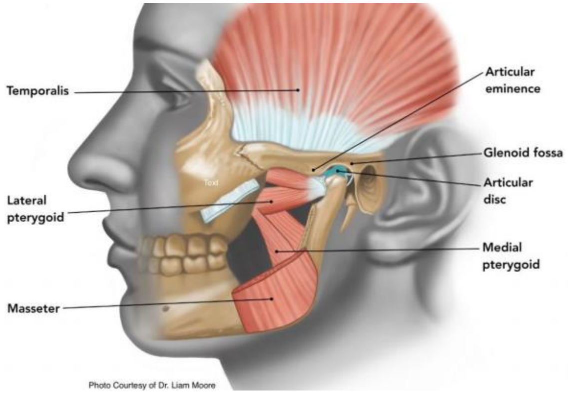
Our work: a feasibility study

Yawning detection using earphone IMUs

- Widespread and high user acceptance
- Proximity to the jaw allows capture of yawning-incurred movements
- Isolated from complex and frequent hand movements

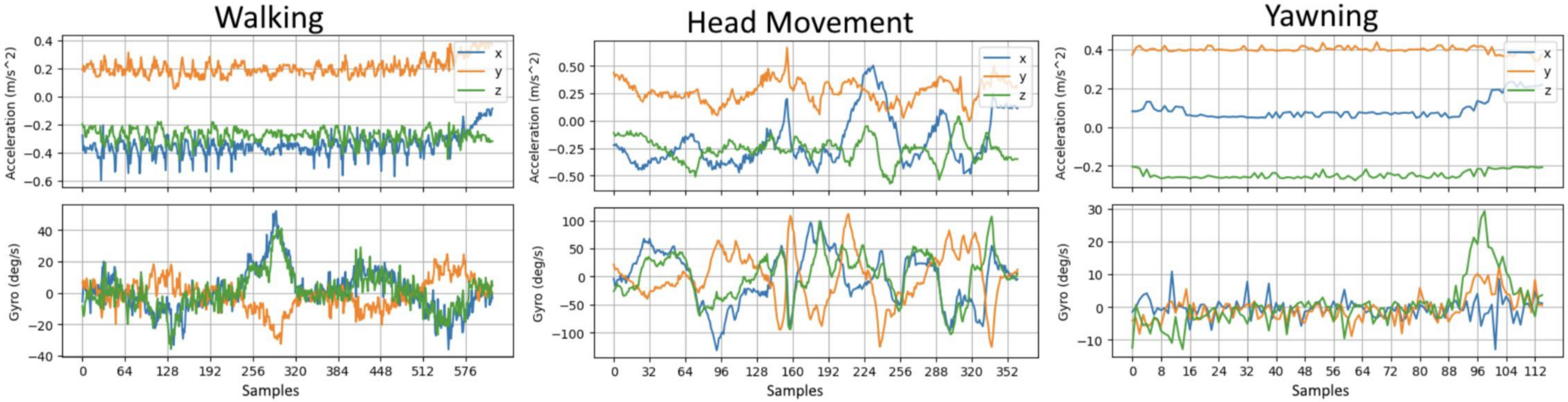
Privacy-resistant, low-cost, portable, long-term usage





Preliminary analysis

- We use eSense[6] headphones to collect IMUs data:



(recorded at 32Hz)

- Yawning has a unique pattern on three axis of accelerometer and gyroscope data.

[6]: https://www.esense.io/

Methods: study objectives

1. **Data collection and preprocessing:** to collect data and find initial features of interest

2. **Model constructions:** to use these findings to guide the construction range of neural network models

3. **Feasibility analysis:** to ultimately determine the feasibility of yawning detection using earphone IMUs

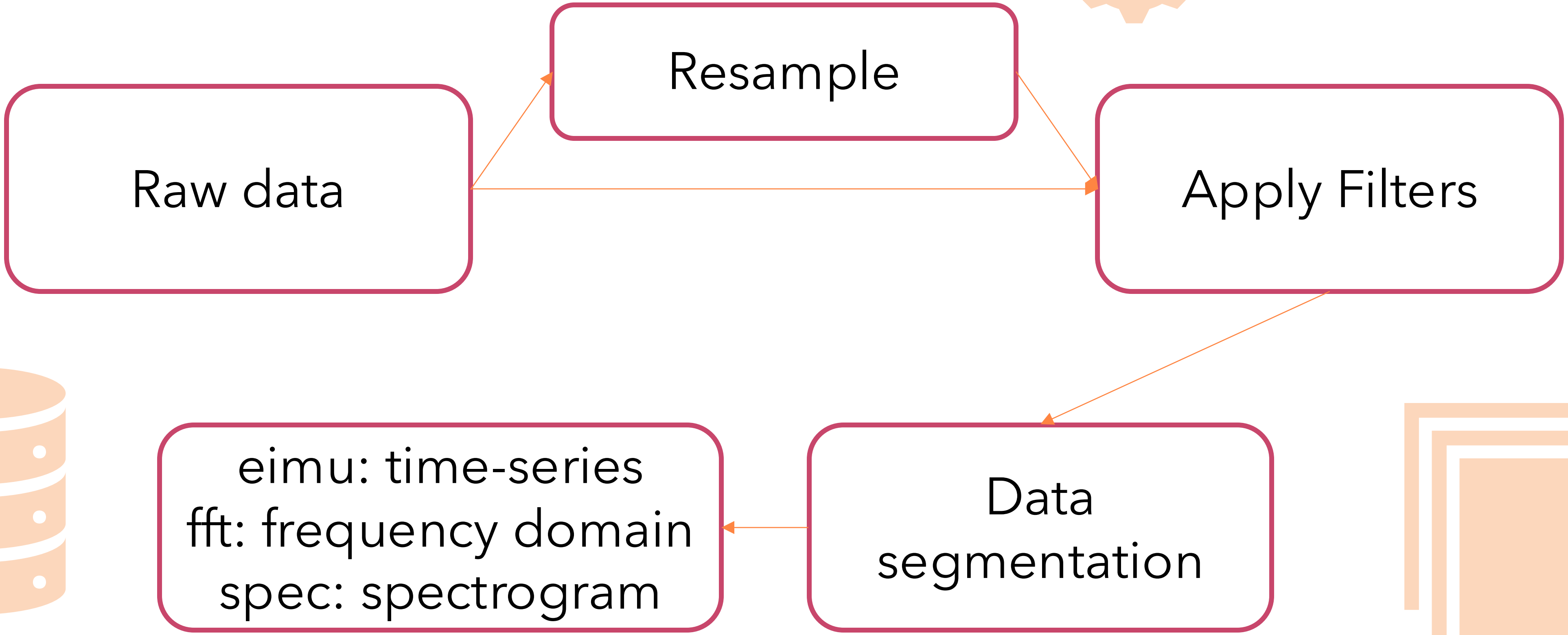
Data collection

Two datasets:

- **Dataset A**, collected by ourselves
  - 10 participants wearing eSense earphones and performing various activities
  - Develop an Android app to collect and label data
  - Yawn (100 times), rest (5 minutes), walk (5 minutes), talk (3 minutes), move head (30 times), eat and drink, three facial expressions (30 seconds each)
- **Dataset B**, a subset of the HAFAR[7] dataset
  - Headphone IMUs data under different facial expressions, including yawning
  - Subset chosen to prevent class imbalance

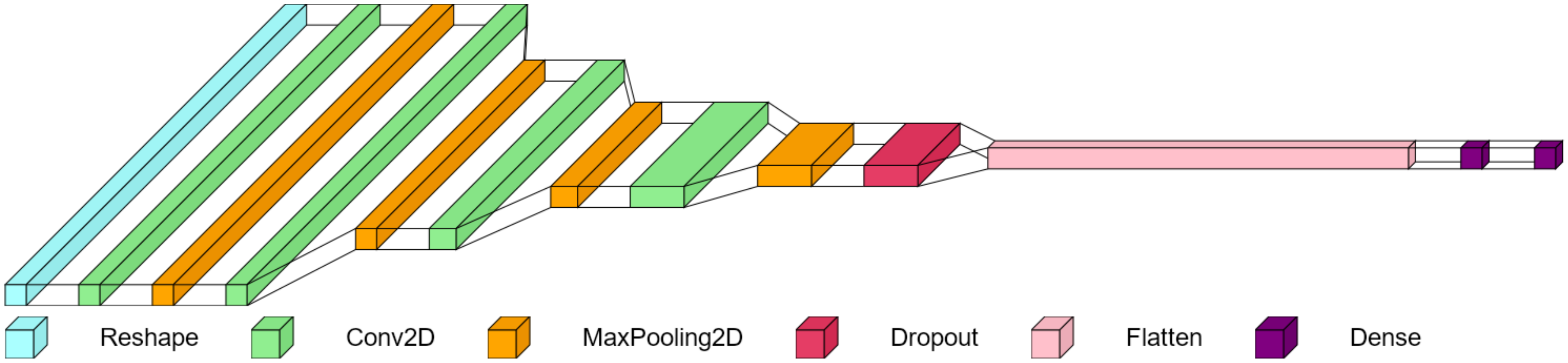
[7]: Shkurta Gashi, Aaqib Saeed, Alessandra Vicini, Elena Di Lascio, and Silvia Santini. Hierarchical Classification and Transfer Learning to Recognize Head Gestures and Facial Expressions Using Earbuds. 2021. ICMI

Methods: preprocessing



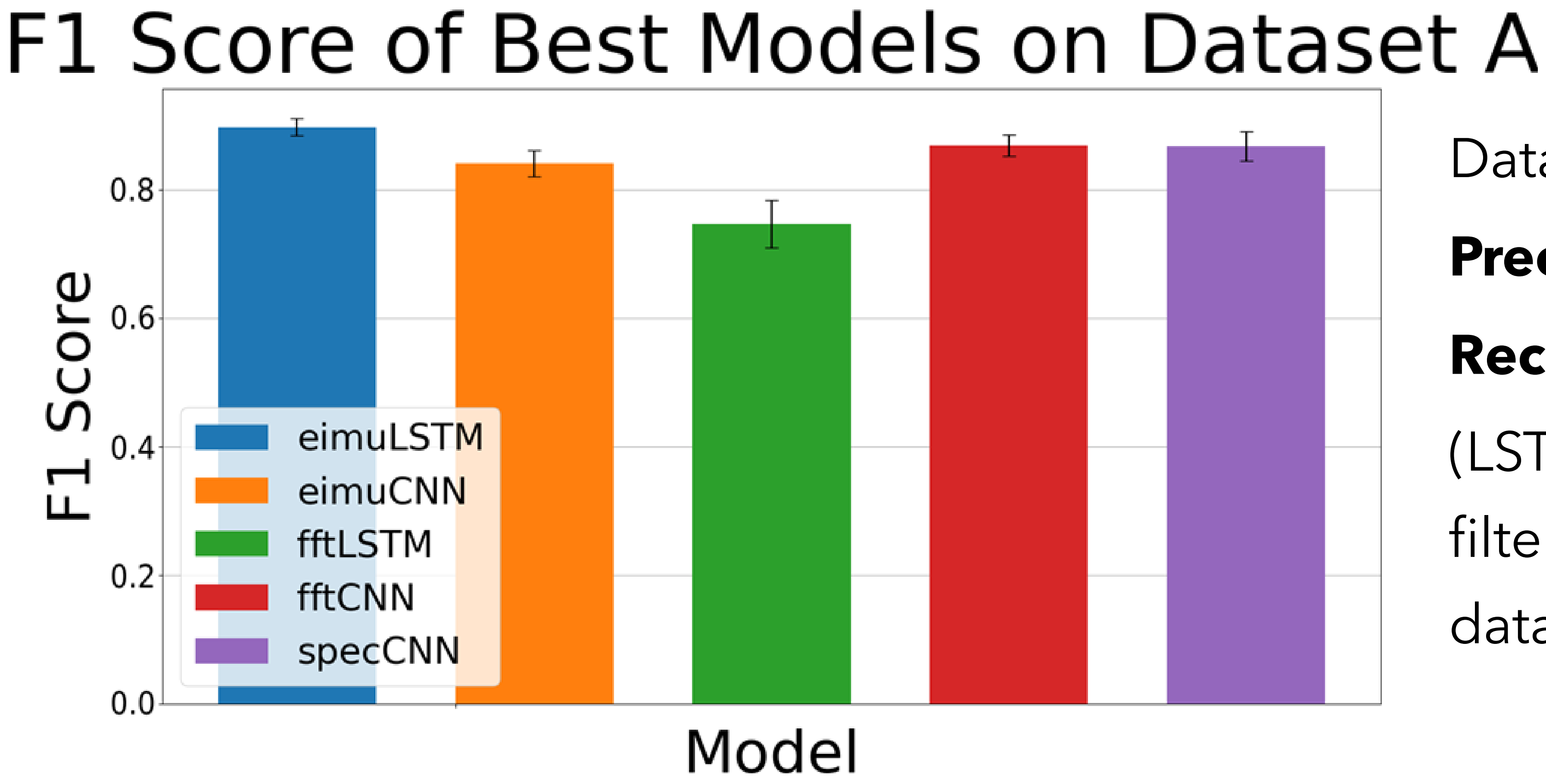
Methods: model constructions

- Two LSTM and CNN models, for raw and FFT data, respectively
- One further CNN model for spectrogram data



Example breakdown of the layers within a CNN model

Results: Dataset A



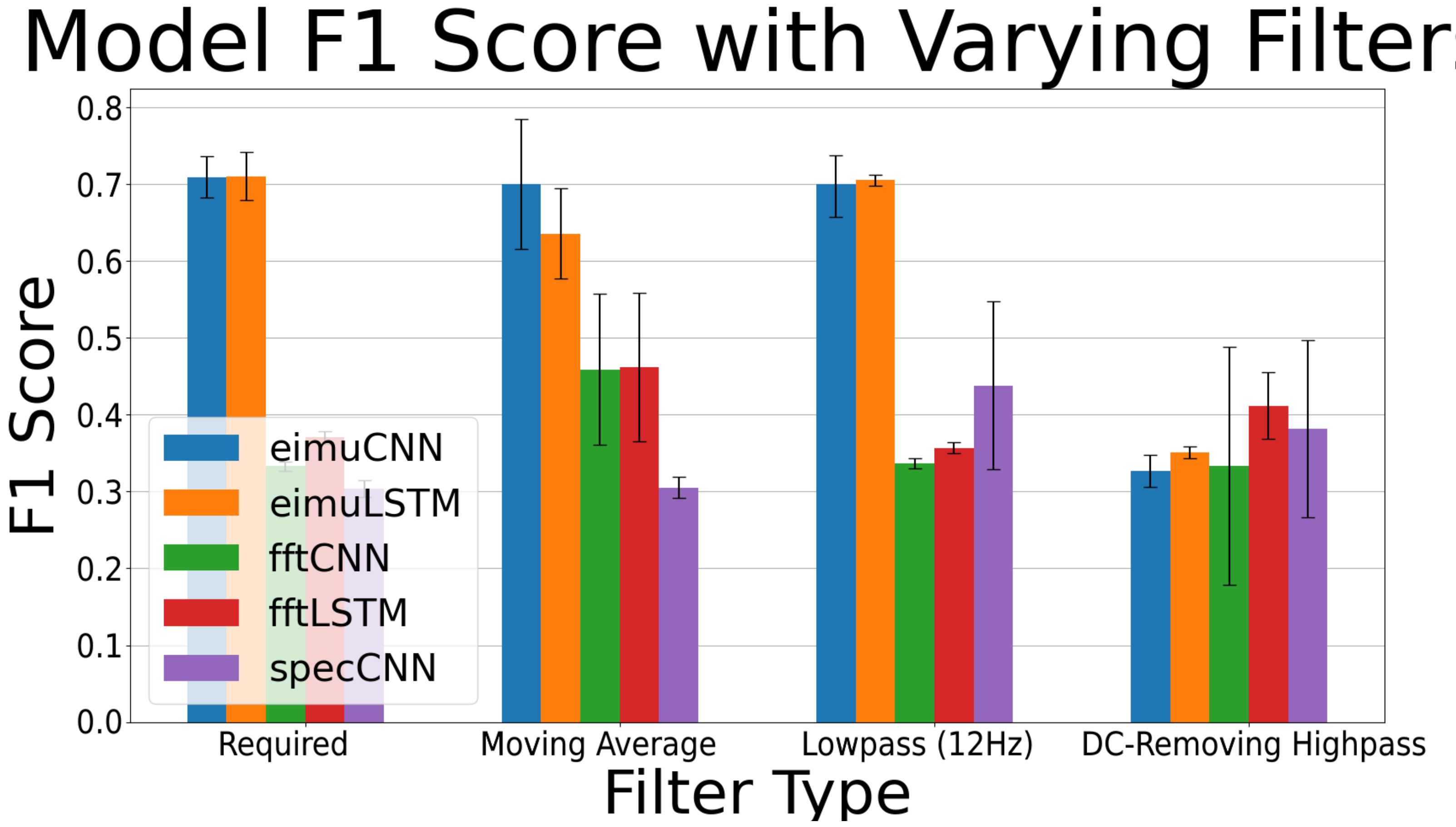
Dataset A: **F_1 = 0.90**

Precision = 0.94

Recall = 0.86

(LSTM, 12Hz lowpass filter, over time-series data)

Results: Dataset B



Dataset A: $\mathbf{F_1 = 0.72}$

Precision = 0.83

Recall = 0.61

(LSTM, no filter, over time-series data)

Conclusions

- We propose to conduct yawning detection using earphone IMUs
- Our study indicates the feasibility
- Successful proof-of-concept, need to improve accuracy
  - CNN+LSTM
  - Larger dataset
  - Class imbalance problem

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