# Estimating Caloric Intake in Bedridden Hospital Patients with Audio and Neck-worn Sensors

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## Introduction

- 1/3 patients that arrive at a hospital in developed countries suffer from malnutrition, and another 1/3 become malnourished during their stay.
- Malnutrition leads to poor patient health outcomes, hospital-acquired conditions and longer length of hospital stays.

## Goal

Nutrition monitoring in a bedridden setting given a limited set of food items, in order to:
- Recognize consumed food type,
- Estimate consumed calories per second.

## System Evaluation

### Study Design

- 10 participants (22-25 years of age, 9 male).
- Participants wore the devices around the neck and ate while laying on a patient bed in a clinical setting.
- They each consumed one or more of these food items: traditional bagel (N=12), turkey chili soup (N=13), Fuji apple (N=13), and potato chips (N=13).


### Sensors

- A neck-worn sensor:
  a) Placed around each subjects neck.
  b) Comprising a proximity, ambient light, (oriented towards the chin of the subject to capture chewing) and an inertial motion sensor (measuring the lean forward angle).
- A lavalier microphone:

Placed on the collar of the subject.

## Methods

### Feature Extraction

- We extracted 34 features from audio for each second. Then we calculated the average and standard deviation of the 34 features across 5 seconds centered at each second, resulting in 68 audio features.
- We extracted 98 features from the proximity, ambient-light and LFA signal as shown in the table.

| Device | Domain | Features |
|---|---|---|
| Necklace | Stat. | Max, min, mean<br>median, variance, RMS<br>correlation, skewness, kurtosis<br>1st and 3rd quartile, interquartile range |
| | Freq. | Amplitude at 0.25 Hz, 0.5 Hz, 0.75 Hz, 1 Hz, 1.25 Hz, 1.5 Hz, 1.75 Hz, 2 Hz, 2.25 Hz, 2.5 Hz |
| | Stat. of Freq. | Skewness and kurtosis of spectrum from frequency features |
| Audio | Time | Zero Crossing Rate, Energy, Entropy of Energy |
| | Stat. of Freq. | Spectral Centroid, Spectral Spread, Spectral Entropy, Spectral Flux, Spectral Rolloff, MFCCs (13), Chroma Vector (12), Chroma Deviation |

### Food Type Identification

- Apply Random Forest Classifier (RFC) (n=100 trees) to classify food-type consumed by second based on the features extracted from audio and necklace sensors.
- Apply Leave One Food Out (LOFO) evaluation method to identify food-type.

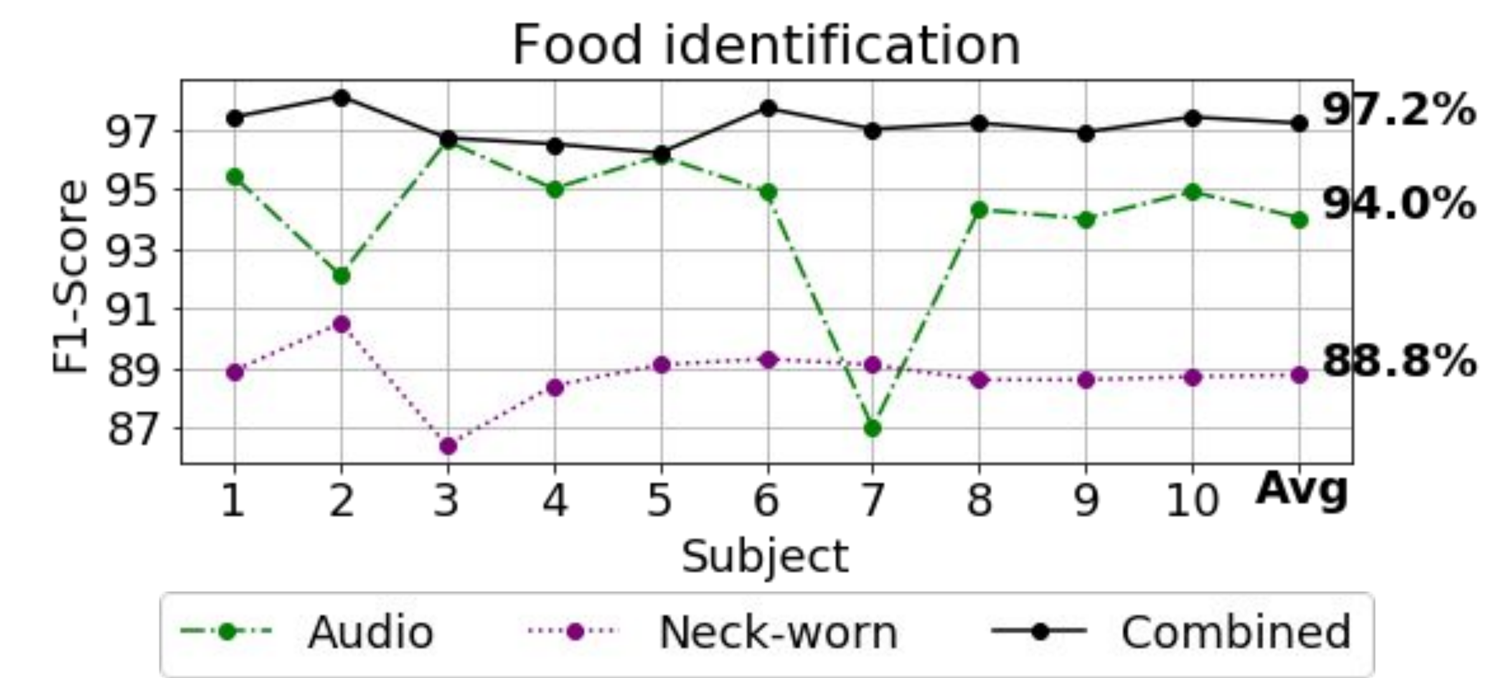
### Calorie Estimation

- Select the top 5 features using the forward feature selection algorithm out of the 166 combined features, for each food-type.
- Develop Multiple Linear Regression (MLR) model for each food-type to map second-level features to calories per second.
- Apply LOFO evaluation method to estimate kCals.

## Results

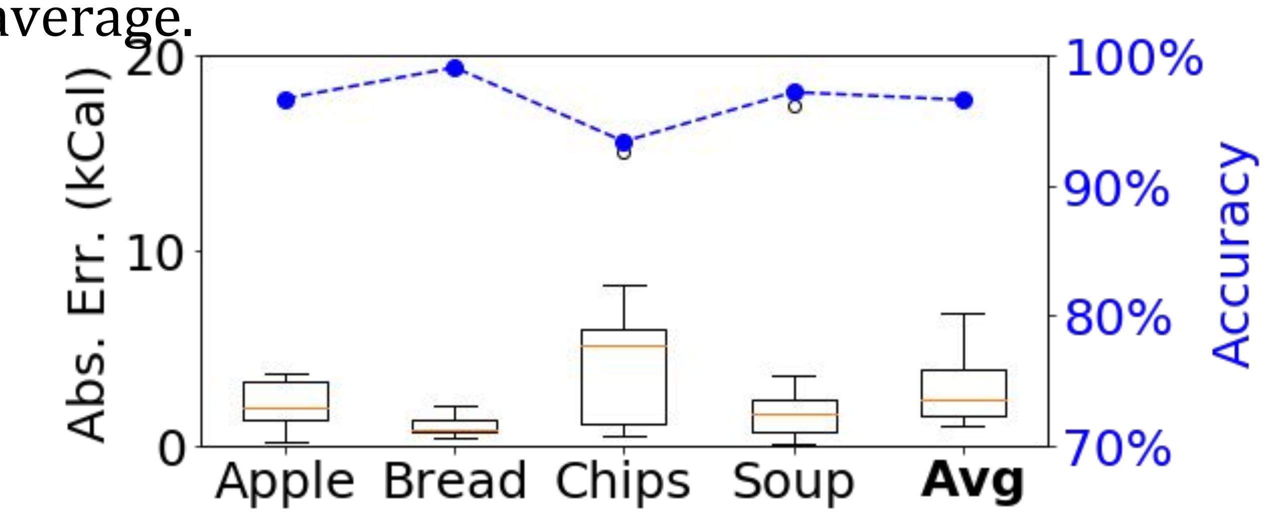
### Food Type Identification

The average F1-Score is
- 88.8% using the necklace-only model,
- 94.0% using the audio-only model,
- 97.2% using the combined model.




### Calorie Estimation

- For each second, we calculate the calorie using the corresponding regression model and achieve a 3.0 kCal Absolute Error, and a 96.6% accuracy on average.




## Conclusions

- We show, given a limited number of known food items provided to a bedridden participant the ability to identify food-type with 97.2% F1-Score, and estimate calories with a 96.6% accuracy using audio, proximity, IMU, and ambient-light sensors around the neck.
- Future work will incorporate testing in real patients in a hospital setting while consuming a greater variety of food items.