mOral:

An mHealth Model for inferring Oral Hygiene Behaviors in-the-wild Using Wrist-worn Inertial Sensors

Source: md2k.org

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Introduction

- HealthCare spending projected to draw 20% of the US Economy by 2026 (2018 study)
- Being reactive -> Being proactive and preventive
- 50% of US adults with periodontal diseases
- 53+ mil. American with untreated tooth decay
- Poor OH linked to heart disease, Alzheimer, etc.
- Dental diseases: eliminated by tooth brushing and flossing.

Introduction

- ADA: Brushing x 2 and flossing x 1, brushing 2”, cover all tooth area using optimal pressure
- 33% of men brush only once/day and 59% of women skip brushing at bedtime
- Smart tooth brushes, track duration, not pressure
- 80% of people use manual toothbrushes and will not benefit from the smart toothbrushes

Related Works

- Wrist-worn sensors can detect walking, sleeping, and eating, can also detect tooth brushing. FP rate for tooth brushing is more than 15%

False positive rate	15%	10%	5%	1%	0.1%	0.01%
False positives per day	72	48	24	4	$\frac{1}{2}$	$\frac{1}{20}$

- Different daily behaviors require different models
- Smart toothbrushes, Instrumented Manuals rely on user activating a button to indicate start and end

Oral Health

- Solution: mOral
  - Use wrist worn inertial sensors to detect Oral Health Behaviors(OHB)
  - Detects brushing and flossing without the use of instrumented toothbrushes
  - Can be used with manual toothbrushes and regular dental floss string
  - Possible detecting of mouth rinsing

Contribution - Proposal

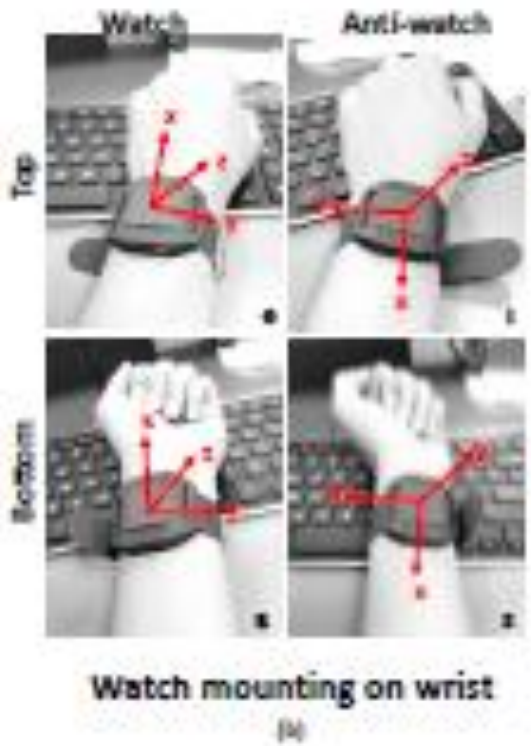
- Solution to the sensor mounting problem
- Highly accurate method for detecting rare daily activities: brushing, flossing, etc..
- Metrics for reporting error in estimating start/end times of detected events

mOral Devices

What? How?

Challenges

- Variability in Sensor Mounting



Watch mounting on wrist

- Reliable Detection of Rare Daily Behaviors: 4 minutes out of 960 minutes awake.

- Labelling the data: precise markings of start brushing -> end brushing

Who? How long??

- 25 participants: 12 M, 13F
- Avg. Age: 28.5
- Duration: 192 days; 2,797 hours
- Duration of interest: 8” per day (4” each OHB)

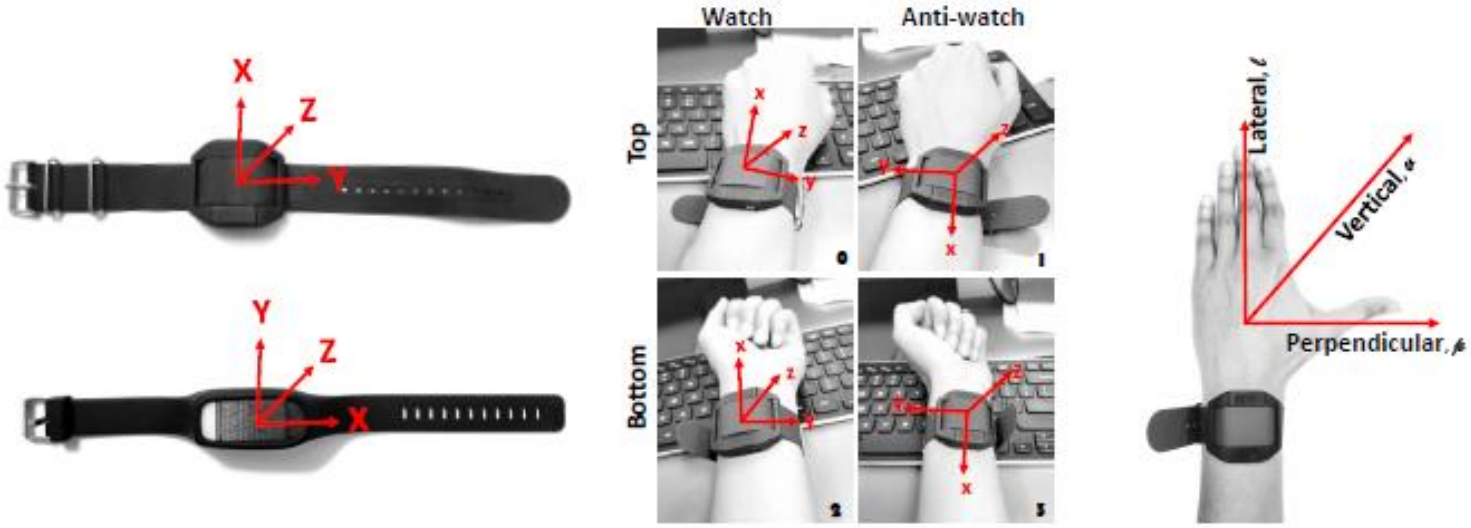
Participants

What? When?

- Wear 2 sensors, each one a hand, while awake
- Brush at least twice daily
- Floss at least once a day
- Record themselves when performing oral health activities

Sensor Wearing

How?



Sensor mounting on devices (a)

Watch mounting on wrist (b)

Wrist coordinate system (c)

Fig. 3. (a) Lateral (l), perpendicular (p), and vertical (v) axes of wrist coordinate system; (b) Variation in sensor mounting on the wrist-worn devices (c) Four sensor positions on the wrist, referred to as Configuration c (for $c \in \{0, 1, 2, 3\}$)

mOral – In Action

How?

(a) Brushing video data collection setup

(b) Dental Flossing

mOral – Software for Data Collection

How? mCerebrum:

- Open source, provides support for reliable real-time data collection
- Store sensor data
- Initiate video recording by participants
- Handles time synchronization between devices

Video Collection

Why?

- Provides ground truth labels for tooth brushing and flossing
- Data stored encrypted on a SD card
- Data uploaded to secure server using Cerebral-Cortex Software

Annotation from Video Data

- Data annotation for timing of each oral health activity
- Average duration of each video is 3.12”
- Annotated tooth brushing as normal or smart brush, flossing as string or picks, and their begin and end time

Data Annotation from Video

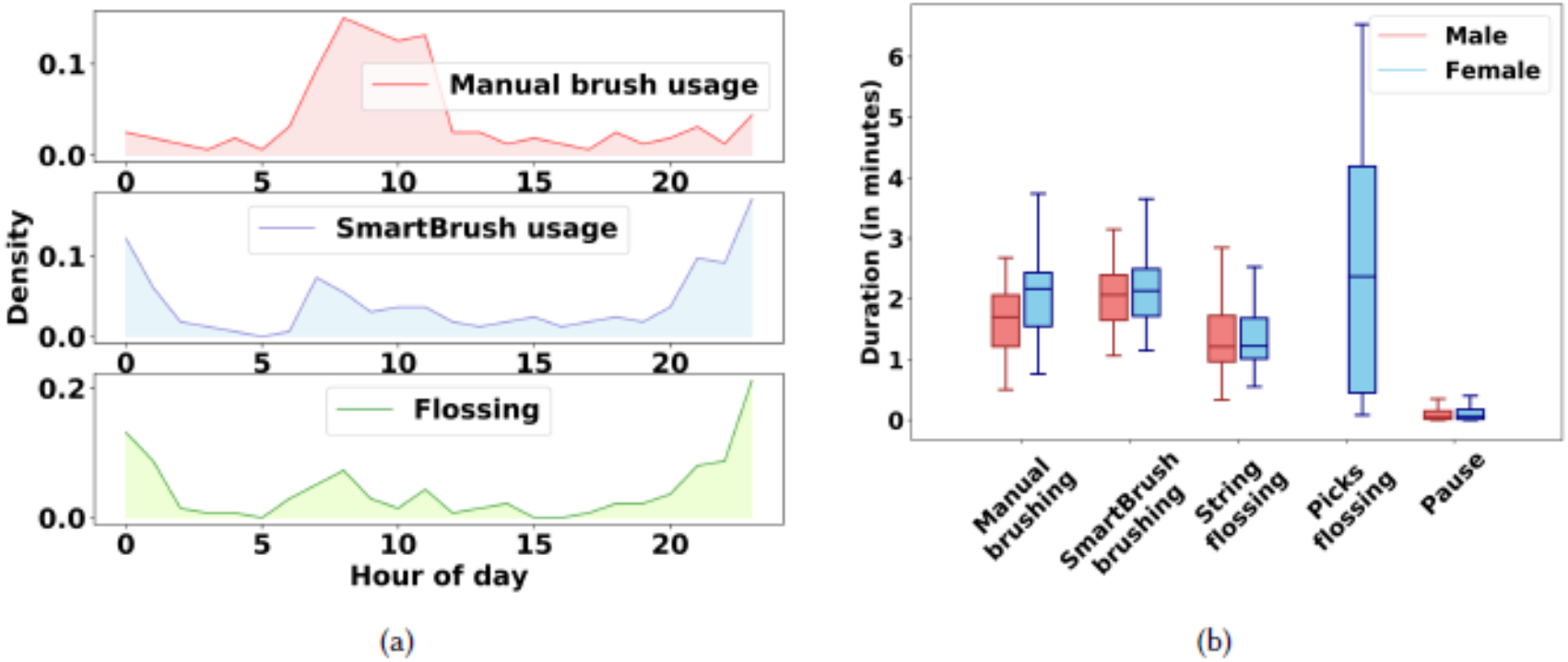


Fig. 2. (a) Time of day distribution for brushing and flossing events. Participants usually brushed their teeth with manual toothbrush in the morning and with SmartBrush at night; (b) Duration of oral hygiene events obtained from video annotations.

Observations

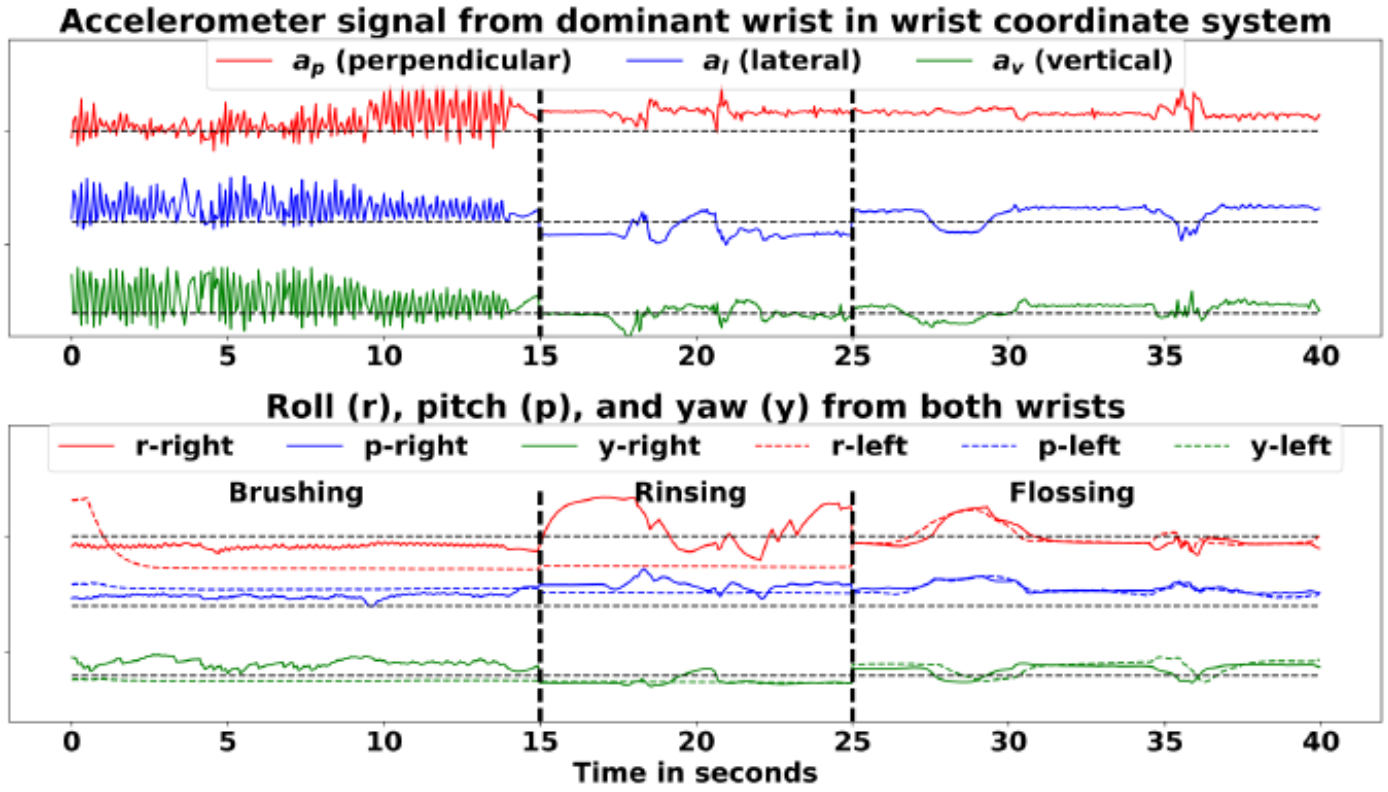


Fig. 4. Wristband signals during brushing, rinsing and flossing with string. During brushing, the brushing hand moves continuously either up-down or left-right. Therefore, we observe periodicity in accelerometer signals (see the left segment in the top figure). On the other hand, during flossing with string, there is a synchronized motion of both wrists (see the right segment in the bottom figure).

Candidate Data Identification

- Goal: a detection model that mines the continuous stream of sensor data to identify brushing and flossing events automatically.

Window Based:

- Divide time into equal intervals
- Identify OHB features

Event Based:

- Brushing: wrist above elbow, hand moves continuously
- Flossing: wrists are upward

Feature Computation and Selection

- Initially: 100 features
- To avoid overfitting, remove non informative features using Correlation-based Feature Selection
- Goal: Subset of features
  - Mutually not correlated
  - Highly correlated to OHB

Model Selection and Training

- Naïve Bayes Classifier
- Random Forest Classifier
- Ensemble Method (Decision tree, KNN, and NB, Ada-Boosting)

Model Implementation

Data Processing Steps

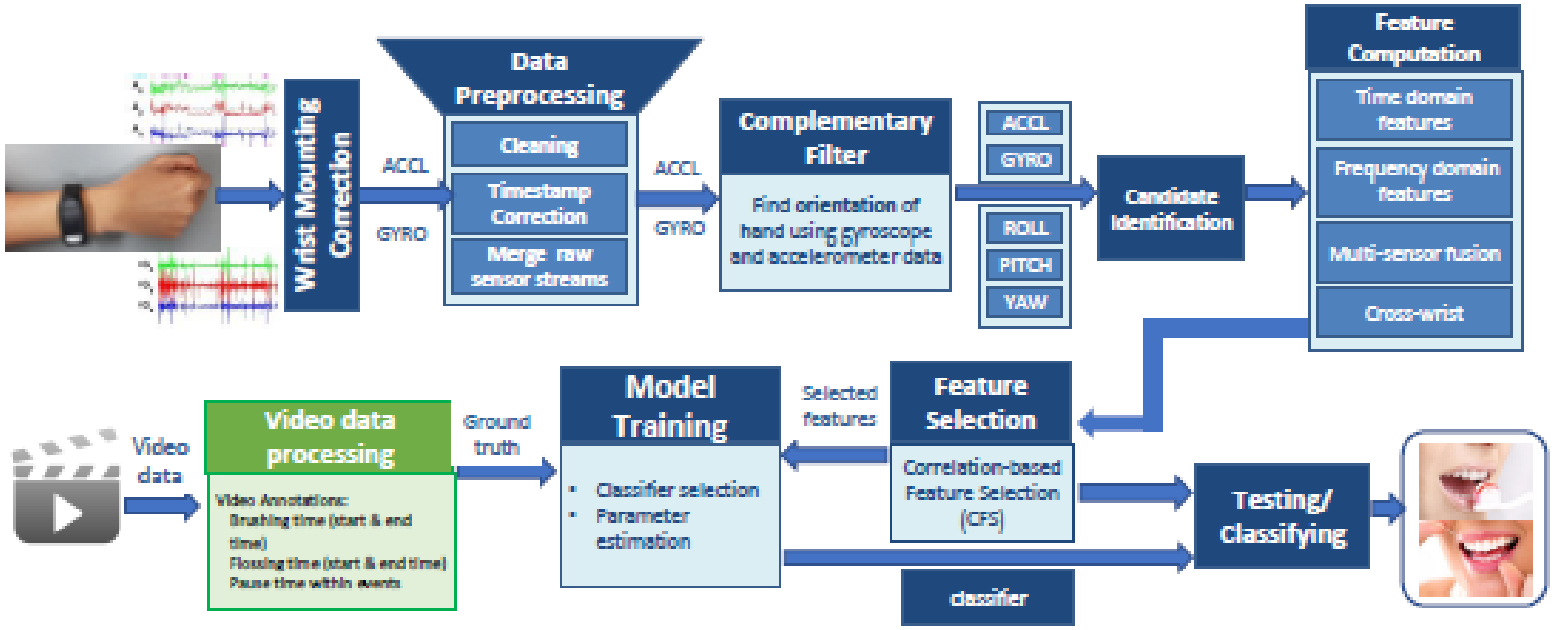
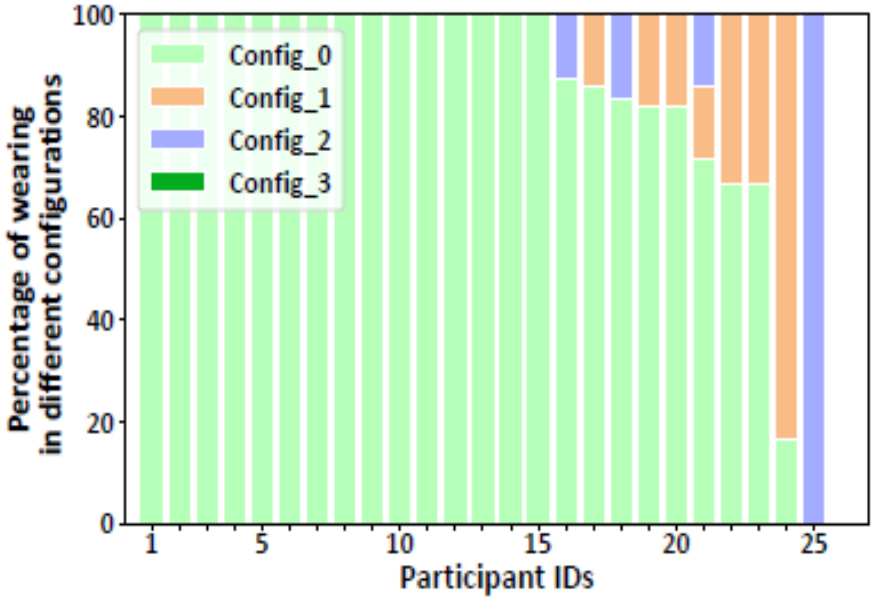


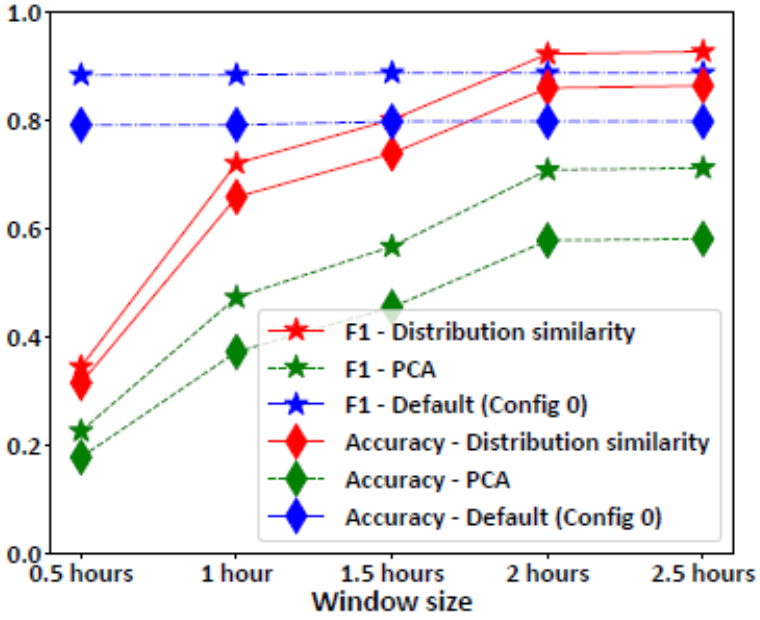
Fig. 7. Data processing stages for training and testing models for brushing and flossing detection.

Model Evaluation

Compare Performance of Methods to identify the correct configuration of wrist sensors



(a) Use of different configurations by participants

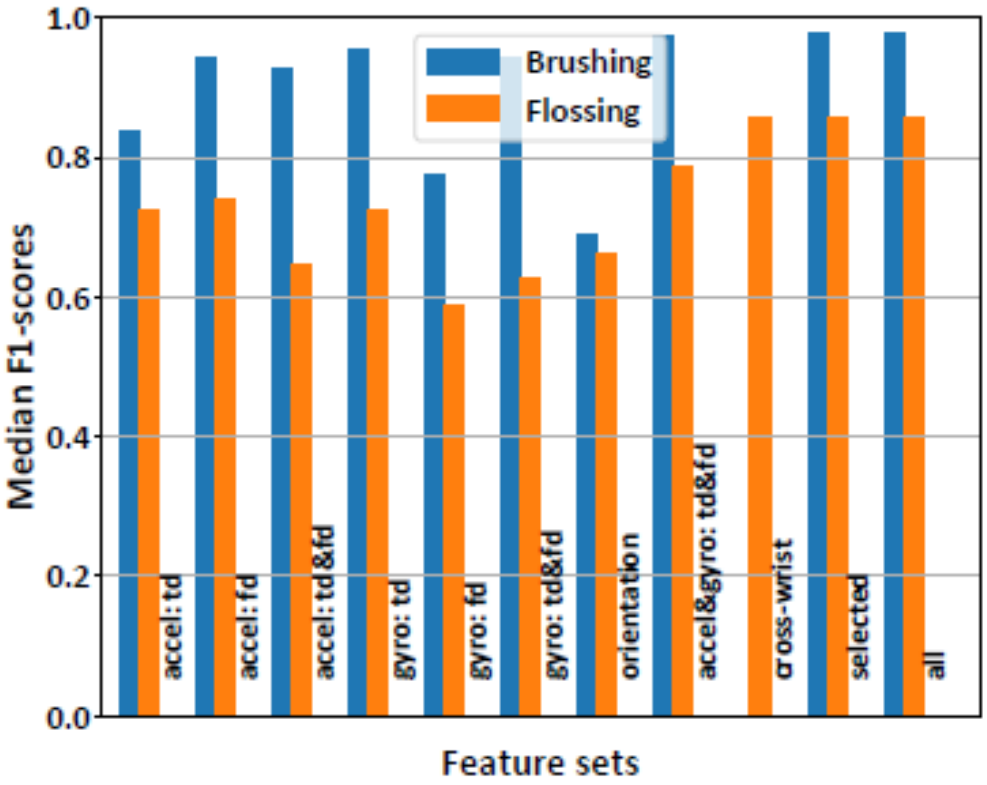


(a) F1-score and accuracy for virtual orientation

Model Evaluation

- Observe the performance of selected features for detecting OHB events
- Compare Performance of different models for detecting brushing and flossing events
- Analyze the error in duration and start/end times of OHB

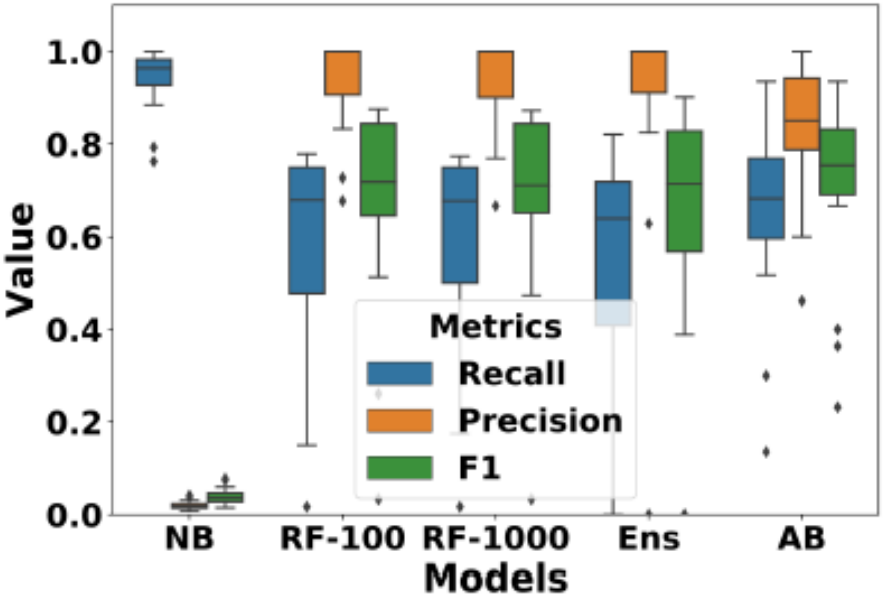
Model Evaluation



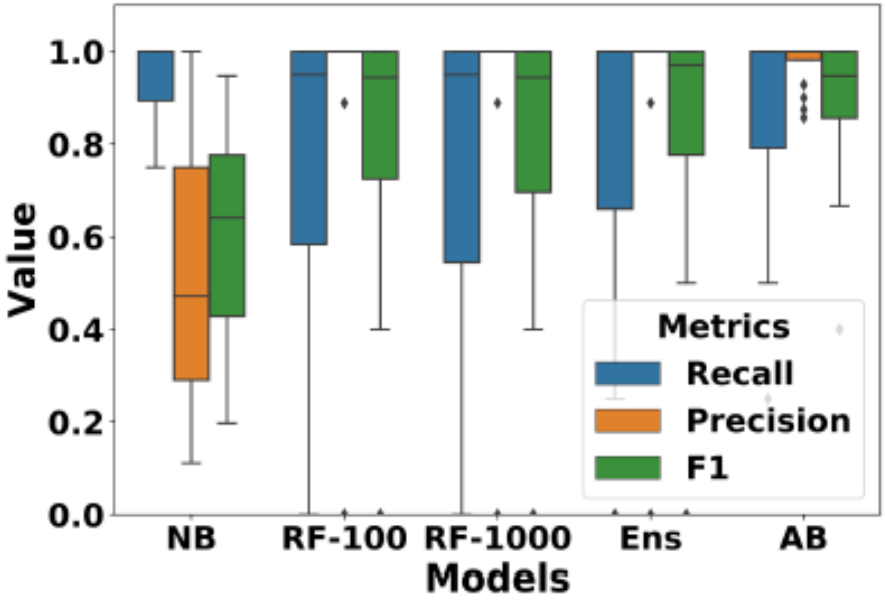
(b) F1-scores for brushing and flossing detection using different feature sets using LOSOCV evaluation

Model Evaluation

Brushing



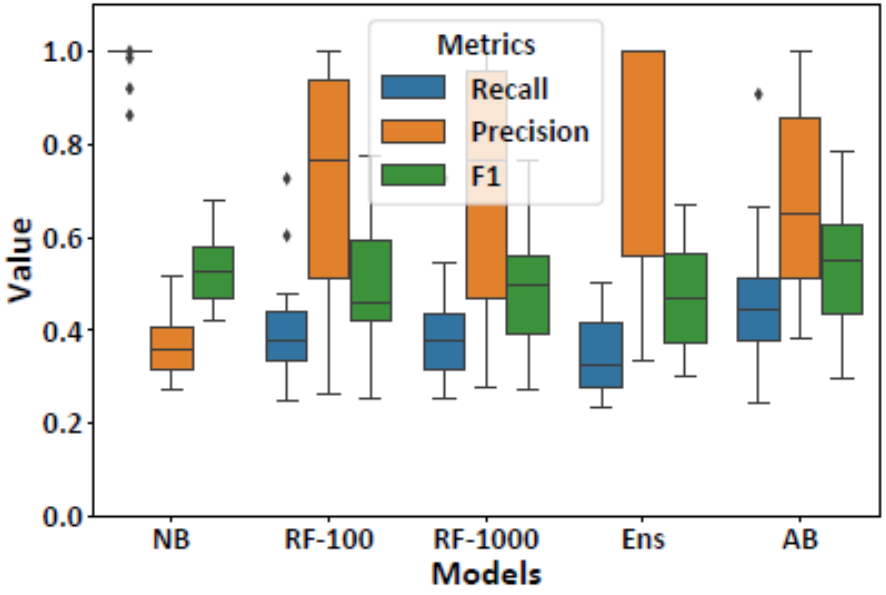
(a) Performance of brushing detection with a (15 seconds) window-based approach for candidate identification.



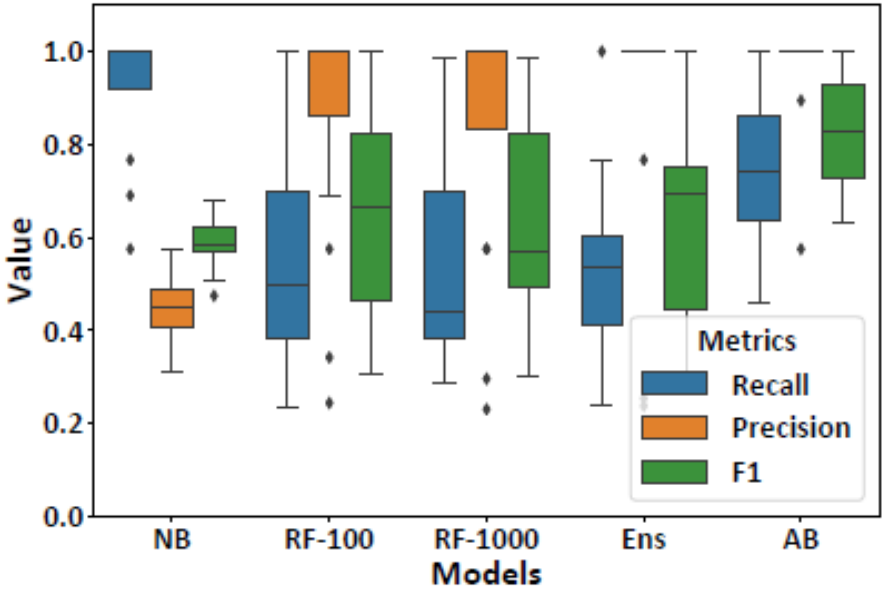
(b) Performance of brushing detection with an event-based approach for candidate identification.

Model Evaluation

Flossing

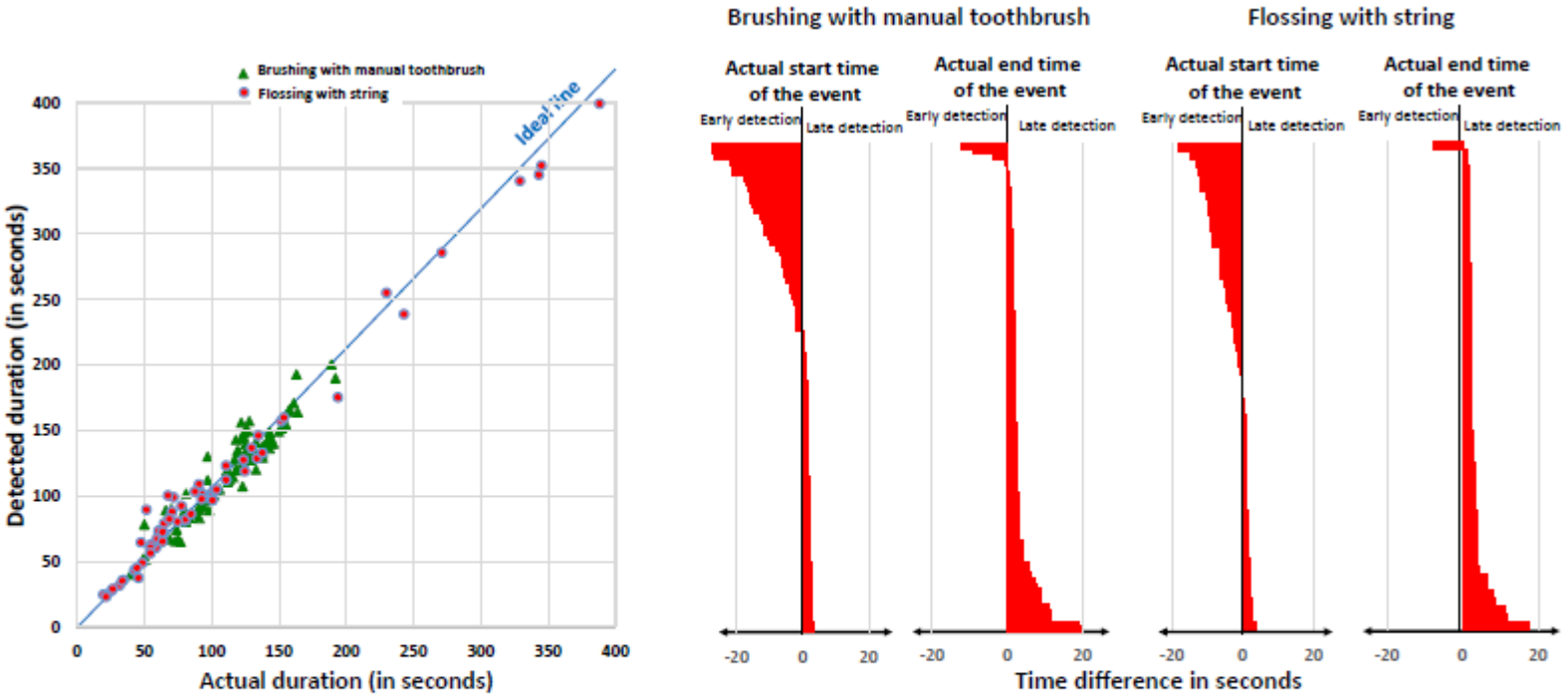


(a) Performance of flossing detection with a (15 seconds) window-based approach for candidate identification.



(b) Performance of flossing detection with an event-based approach for candidate identification.

Detecting Duration and Start/End Times



(a) Scatter plot of actual duration vs. detected du-(b) Error in start/end times, $err_{boundary} = 4.1\%$ for brushing and ration, $err_{dur} = 7.2\%$ for brushing and $err_{dur} = err_{boundary} = 3.5\%$ for flossing.
6.2% for flossing.

Fig. 13. Performance for detecting the duration and start/end times for brushing and flossing.

mOral Limitations

- Model:
  - Median recall rate 100%
  - FP 1 event every 9 days
- Flossing:
  - Median recall rate 75%
  - FP 1 event every 25 days
- Improvement:
  - Detect Oral Rinsing
  - Detect pick flossing, through deep learning
  - Use 1 wristband instead of 2
  - Detecting pressure applied on tooth surface area

mOral

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