Electrocardiogram based Meal Onset Detection for the Artificial Pancreas

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Background and Aims:

- Continuous glucose monitoring (CGM) is the only measured variable used to control insulin dosing in DM1 patients.
- The users must make manual meal announcements that are often forgotten or prone to miscalculation [1].
- A meal affects the electrocardiogram (ECG) parameters, like heart rate and QTc [2,3].
- We propose to exploit this non-invasive sensor modality for early detection of meal onset, to be included in the basis for insulin dosing (whether it's manual or automated).

Data Acquisition:

- ECG signal acquisition in three lead bipolar configuration with *ProComp Infinity* recorder and *BioGraph Infinity Software*.
- Two set of experiments were conducted:

Experiment I
No activities
22 meals for training
13 meals for testing

Experiment II
Activities of daily life (ADL)*
7 meals for training
4 meals for testing

- The protocol is shown in Fig. 1:

Pre-meal (15 min)	Meal (≤15 min)	Post-meal (20–25 min)

Fig 1: *Timeline of experiments.*

Methodology:

1. Segmentation of ECG signal into 10s frames with 50% overlap.
2. Obtention of time-domain, fiducial, and spectral features from each frame.
3. Creation of response vectors for different delay & duration combinations.
4. Construction of a SVM classifier with LOOCV for different delay & duration combination.
5. Application of the best classifier to the test set.
6. Fusion index N: Requiring N consecutive positive frames of response vectors, to reduce false positives (FP).
7. Obtention of fusion vector.
8. Calculation of detection delay: Delay between actual meal onset and time of detection.

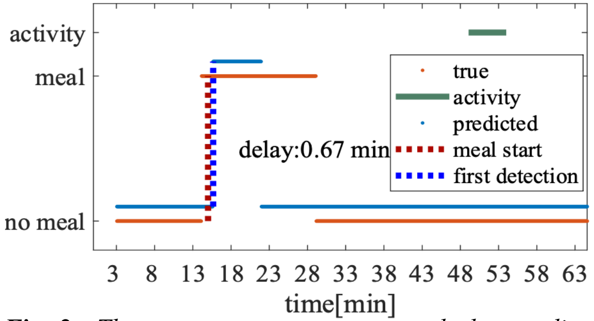

Fig 2: *The true response vector and the predicted response vector from the classifier for a particular meal in Exp II. The true response has 1 min advance** from meal start and 15 min duration based on selected parameter. No FP detected before meal or during the activity period.*

Results:

Exp. I (no ADLs)	True Positives	False Positives	Delay (min)
N = 1	11/13	7/13	1 ±1.73
N = 23	10/13	1/13	2.2 ± 1.7

Exp. II (w/ADLs)	True Positives	False Positives	Delay (min)
N = 1	4/4	1/4	1 ± 0.8
N = 8	4/4	1/4	2.7 ± 0.5

In Exp. 1, the number of FPs were reduced from 7 to 1 by fusing 23 segments. The detection delay time naturally increased with fusion.
In Exp. II, fusion did not remove any FPs, but the system was found to be robust to ADLs, as it did not predict any FPs during the activities. A true meal and the predicted response for a meal is illustrated in Fig. 2.

Our approach is faster than the existing CGM based meal detection systems which have a latency of 30–35 min. It also outperforms bowel sound-based meal detection method which has a delay of 10 min [4]. To our knowledge, this is the quickest meal detection method.

Conclusion:

The results confirm that ECG carries information for early detection of meal onset. Our ECG-based approach can detect meals with an average delay of less than 3 min after ingestion in both experiments, including activities of daily life.
Future work will investigate how to ensure sufficient robustness and reliability.

References:

1. Samadi, S. et al. "Automatic Detection and Estimation of Unannounced Meals for Multivariable Artificial Pancreas System". Diabetes Technology & Therapeutics. (2018).
2. Widerlöv, E., et al. "Influence of Food Intake on Electrocardiograms of Healthy Male Volunteers," European Journal of Clinical Pharmacology, (1999).
3. Hnatkova, K., et al. "QTc changes after meal intake: Sex differences and correlates," Journal of Electrocardiology, (2014).
4. Kölle, K., et al. "Feasibility of Early Meal Detection Based on Abdominal Sound," IEEE Journal of Translational Engineering in Health and Medicine, (2019).

Footnotes:

(*) ADLs included drinking water, talking and coughing. We randomized whether they would happen in the pre-meal or post-meal parts according to Fig. 1.

(**) We considered 9 advances/delays and 4 durations. Results for all 36 combinations were marked in a ROC plot for the training and validation sets. By looking for the shortest Euclidean distance to the ideal point (TPR=1, FPR=0), we selected a duration of 15 min and an advance of 1 min and applied this on the test set.