Improvement in Automated STEMI Detection by Modeling and Classification of the ST Segment

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Abstract

Accurate analysis of the ST segment is critical in diagnosis of the ST segment elevation myocardial infarction (STEMI). Negligible to high levels of artifact from different sources may be present throughout the ST segment and could either mimic a nonexistent ST elevation (false STEMI), or change the actual ST level and negatively impact the precise diagnosis of the underlying disease. Filtering and averaging the beats in an ECG interval reduces the artifact level on the ST segment, but does not eliminate it completely.

We studied two approaches for improving the ST segment analysis, a short-duration smoothing filter and an ST segment curve-fitting model, and compared them to the raw ECG average beats. The smoothing approach used polynomial least-squares approximation of the average beat ST segment in a 20 msec window. The curve-fitting method modelled the ST segment by a section of a fitted parabola using a quadratic polynomial equation.

The 12-lead 10-second records from a test database collected in a single medical center and annotated by the experts were analyzed for STEMI detection. Smoothing or curve-fitting the ST segment reduces the number of false STEMI detections significantly compared to the raw ECG average beats.

1. Introduction

ST segment deviation (elevation or depression) is a major feature in identification of a series of cardiac diseases such as STEMI, pericarditis, early repolarization, LBBB, and LVH [1]. In a previous study, we investigated the discrimination of the STEMI from its confounder using the ST segment morphology [2]. We also studied an algorithm to suppress the false STEMI detection in a very noisy records [3].

In this work, we specifically study the improvement of the STEMI detection performance by modeling the ST segment and elimination of the moderate and artifact to achieve more accurate ST levels. According to the ACC/AHA guidelines, STEMI is defined by ST elevation in at least two contiguous leads (typically convex or straight), where other morphological features such as ST depression in reciprocal leads, Q-waves, and wide upright or inverted T may also be present- [4],[5].

We presented two models to improve the ST segment measurements: a short-duration smoothing filter which uses polynomial least-squares approximation of the average beat ST segments in a short window, and an ST segment curve-fitting model which models the ST segments by a quadratic polynomial equation fitted to them.

The rest of this paper is organized as follows. Section 2 describes the method and material including the algorithm and the database. Section 3 provides the results. Discussion and conclusions are presented in Section 4.

2. Method and Material

2.1. Algorithm

Our algorithm aims to improve the detection of STEMI in non-overlapping 10-second segments of 12-lead ECG records, by smoothing or curve-fitting of the ST segments. The following criteria should be met for STEMI:

- ST elevation: According to ACC/AHA guidelines [4], ST elevation should be present in at least 2 contiguous leads with typically convex or straight shape. ST elevation threshold in leads V2 and V3 is 200µV in men and 150µV in women. The suggested ST elevation threshold in other leads is 100µV in both men and women.
- ST depression in reciprocal leads
- Wide upright or inverted T-wave
- Presence of Q-waves
- Reduced R-wave

First, the ECG record is filtered using a bandpass filter and the average beats are generated in each ECG interval using a template-matching method. The average beats show reduced ST segment artifact compared to the individual ECG beats, but do not remove the artifact completely. To eliminate the impact of the artifact on the ST segment, we modeled the ST segments in the average beats with two different models: a short-duration smoothing filter and an ST segment curve-fitting model. Philips DXL$^{(TM)}$ diagnostic algorithm was used to analyze the 12-lead 10-second ECG records in each model to identify STEMI, compared to the raw ECG average beats.

In a previous work, we introduced an algorithm to identify the suspicious STEMI records where the high noise level exists in at least two contiguous leads which contribute to STEMI diagnosis. Using this algorithm, the STEMI records with high noise levels were eliminated.

In the remaining records with moderate or low noise levels, the STEMI detection performance is studied for raw average beats, average beats with short-window filtered ST segments, and the average beats with curve-fitted ST segments. Figure 1 shows the block diagram of the algorithm.

The short-window filtering approach used a 20-msec least-squares smoothing filter throughout the average beat ST segments. The curve-fitting method modelled the entire ST segment by a section of a parabola using a quadratic polynomial equation. Figure 2 displays an example of applying smoothing and curve-fitting models to an ECG lead with moderate level of artifact.

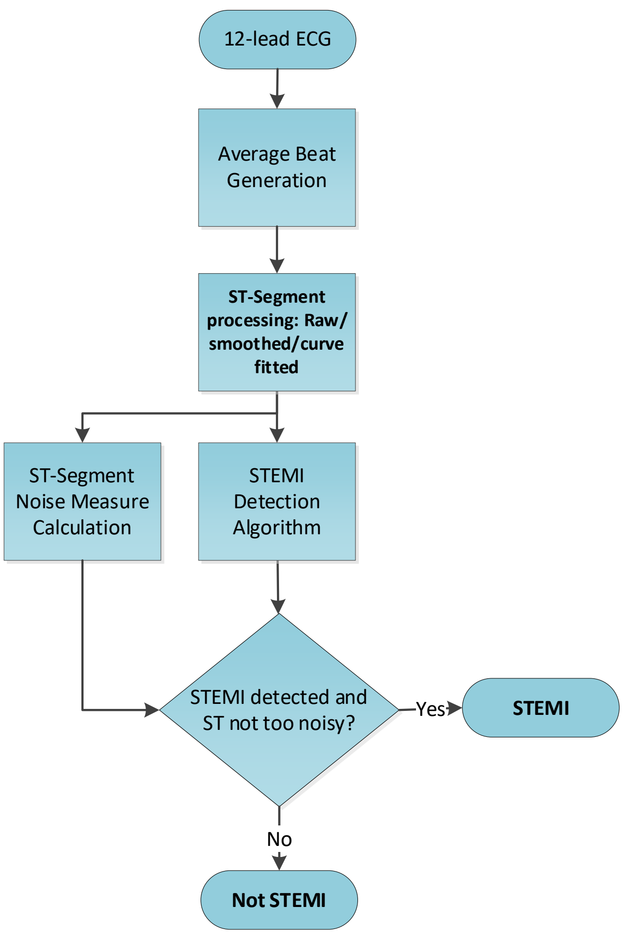


Figure 1. Block diagram of the algorithm. The raw or modelled ST levels and the noise measure on the ST segments were used to detect STEMI. The STEMI records with high levels of artifact on contiguous leads contributing to the STEMI diagnosis were suspicious and diagnosed as 'Not STEMI'.

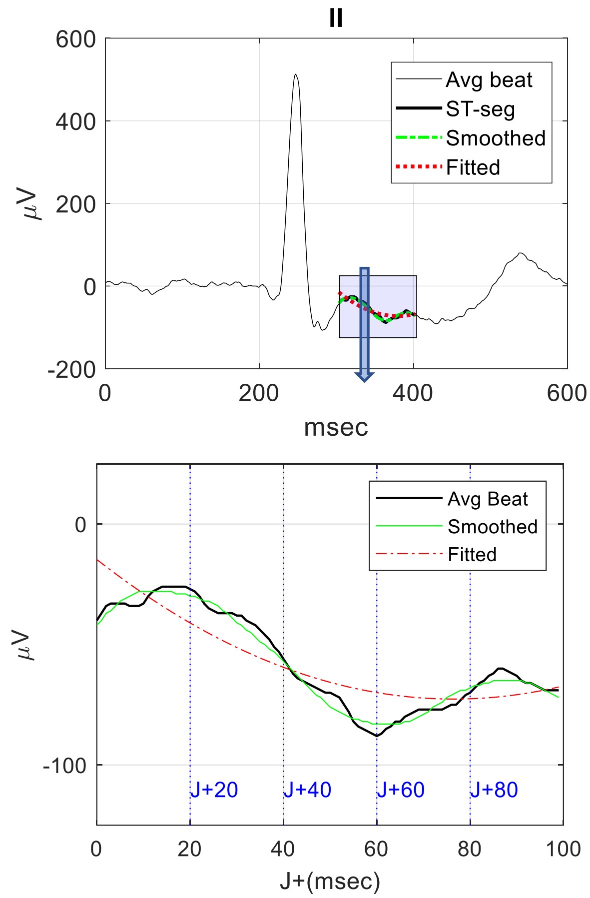
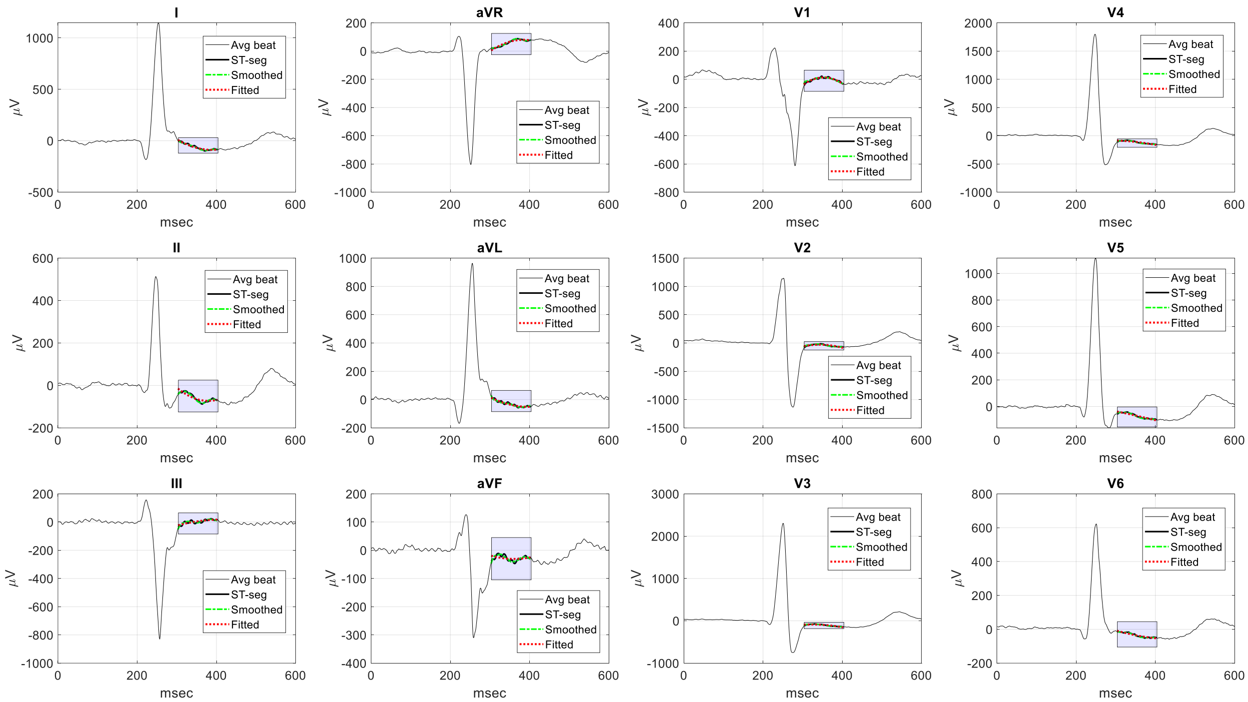


Figure 2. An example of applying smoothing and curve-fitting models to an ECG lead with moderate level of artifact. The ST segment is magnified to illustrate the difference between the raw ST segment and the smoothed or curve-fitted models. Vertical lines are plotted at J+20, J+40, J+60, and J+80 to compare the ST-segment levels at these locations.

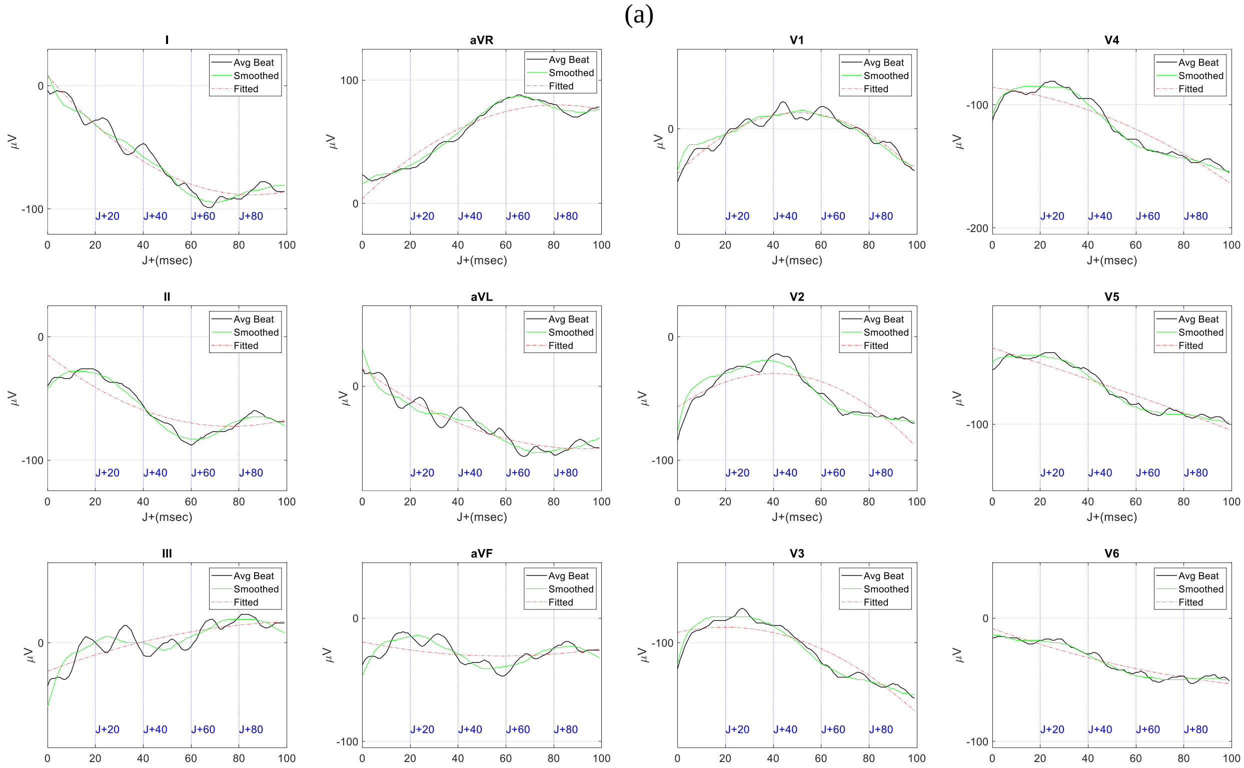
An example of modeling ST-segment in a 12-lead ECG record with moderate artifact is shown in Figure 3. The average beats are plotted in the top panel and the ST segment is magnified in the bottom panel.

2.2. Database

We tested our algorithm on a large database (HCMed2016) consisting of 146,349 de-identified 12-lead ECG records collected in a single hospital during a 3-year period. The database was annotated for a series of cardiac diseases and arrhythmias of which a total of 2,524 records (1.7% of all records) were labelled STEMI by experts.



(a)



(b)

Figure 3. Example of modeling ST-segment in a 12-lead ECG record with moderate artifact. (a) The 12-lead average beats are plotted and ST segment is highlighted and modelled by short-duration smoothing and curve-fitting. (b) The ST segments highlighted in the average beats are magnified. The difference between various methods in ST-levels at J+20, J+40, J+60, and J+80 is noticeable.

3. Results

We modified and executed three different versions of our diagnostic algorithm, DXL(TM) on the 10-sec intervals of all 12-lead ECG records in the database. These versions include the raw ECG average beats without more ST segment processing, the average beats with smoothed ST segments using the short-duration filter, and the average beats with curve-fitted ST segments.

The results were analyzed to detect the number of false positive (FP) and false negative (FN) STEMI records for each model. These measures are summarized in Table 1.

A 20-fold decrease in number of false positives is observed after smoothing or curve-fitting the ST segment in average beats. This is the result of removing the artifact in the ECG records where it causes false ST elevation which in turn is labeled as STEMI. However, the number of false negative STEMI records is lower in raw ECG average beats which is due to the increased ST levels added by artifact in borderline STEMI records.

Table 1. Regression algorithm performance compared to a simple method

	FP	FN
Raw Average Waveform	27,645	1,071
Smoothed ST segment	1,368	1,745
Curve-Fitted ST segment	1,247	1,775

4. Discussion and Conclusions

We observed that smoothing or curve-fitting of the ST segment in average beats is critical in reducing the number of false positive STEMI detections significantly. However, the artifact increasing the ST level helps to label the borderline STEMI records correctly in raw records.

On the other hand, the number of false positives is lower in curve-fitted ST segments than the smoothed ones. The reason is that the former generates a monotonic ST segment model and eliminates the artifact completely, while the latter may follow the trend of a slow-varying or high amplitude artifact as observed in Figure 2. The lower number of false negatives in smoothed ST segments compared to the curve-fitted one can also be justified by the added artifact mimicking the ST elevation in borderline STEMI records.

References

[1] Nichole Bosson, et al, “Causes of Prehospital Misinterpretations of ST Elevation Myocardial Infarction,” Prehospital Emergency Care, 2016 Nov 18: 1-8.

[2] Reza Firoozabadi, Richard E. Gregg and Saeed Babaeizadeh, "Modeling and Classification of the ST Segment Morphology for Enhanced Detection of Acute Myocardial Infarction," Computing in Cardiology (CinC), IEEE, 2019.

[3] Reza Firoozabadi, Richard E. Gregg and Saeed Babaeizadeh, “Suppression of False Automated STEMI Detections in Low-Quality ECG Recordings,” J of Electrocardiol, Vol 57, Page S107, 2019.

[4] O’Gara PT, Kushner FG, Ascheim DD, et al. 2013 ACCF/AHA Guideline for the management of ST-elevation myocardial infarction: A report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines. Circulation 2013;127:e362–e425.

[5] Steg PG, James SK, Atar D, et al. ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation. Eur Heart J 2012;33:2569–619.

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