A Novel Algorithm for Full-Automatic ECG Interpretation and Diagnostics

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Abstract

A full-automatic algorithm for ECG diagnostics is considered as a clinical decision support software (CDSS) and is usually designed to provide physicians and other health professionals with clinical decision support. In this work, a new high accurate and full automatic algorithm for interpretation and diagnostics of standard 12-lead ECG signals is presented.

1. Introduction

Electrocardiogram (ECG) is the recording of the hearts electrical activity. The spread of electrical excitation through the myocardia (the heart muscle) generates characteristic signal on the body surface. A series of electrical waves and peaks form each heart beat and give two sorts of information. The first important information collected from the ECG is the duration of the electrical waves spreading throughout the heart, since it reflects whether the electrical activity is normal, slow or even irregular. The second factor is the amount of electrical activity passing through the myocardia (heart muscle). The later gives diagnostic hints whether, for instance, the parts of the heart are too large or overworked. ECG is considered as one of the most important non-invasive tools in the cardiology. Each year, over 250 million ECGs are analyzed within Europe and the United States including standard resting ECG analysis. During standard resting ECG analysis, full measurement and full diagnosis of 10-second simultaneously recorded conventional ECGs according to Eindhoven, Goldberger and Wilson are performed. The measurement and diagnosis can be carried out manually, semi-automatically and full-automatically by means of ECG diagnosis algorithms and programs. There are some clear advantages using computer-assisted ECG analysis. ECG Diagnosis algorithms provides analysis results very consistently. Also, they carry out objectives measurements, which are useful for long-term observation and serial comparison. Furthermore, they provides diagnosis based on carefully selected diagnosis criteria and not based on 'single-ECG-school' research. The results of the large European diagnosis study from the project CSE (Common Standards for Quantitative Electrocardiography) presented in [2, 3] shows that the best ECG diagnosis programs exhibit results almost as good as experienced cardiologists. There is in fact a large interest in accurate full automatic ECG diagnosis algorithms not only in clinical applications, but also in different other application, like in cardiopulmonary resuscitation applications, home monitoring applications, tele-monitoring application and the clinical studies application during drug safety evaluations [1]. In this paper, full automatic algorithm called 'KhawajaCode® Resting Essential' for interpretation and diagnostics of standard 12-lead ECG signals is illustrated. The first objective of this work is to provide a full-automatic and full-scope ECG diagnosis algorithm with very high degree of accuracy for detections, measurements and diagnostic interpretations. Whereas, the second objective is to make the algorithm available for any kind of cardiac applications, for off-line and real-time applications and for any kind of hardware platforms.

2. Methods

The main process of the 'KhawajaCode® Resting Essential' algorithm is illustrated in Figure 1. This process consists of nine main steps as follows:

2.1. Step 1: Beat Detection

The performance of ECG analyzing system basically depends on reliable detection of the QRS complexes, which is done in this step by means of the algorithm 'KhawajaCode® ECG Beat Detector'.

2.2. Step 2: Signal Quality

The quality of the recorded ECG signals to be anaylsis is investigated in this step by means of the algorithm 'KhawajaCode® ECG Quality'.

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2.3. Step 3: QRS Complex Classification

In this step the type of each QRS complex is identified between 'normals', 'ventricular extra systoles', 'aberrants' and 'noise'. Pacemaker spikes are also classified in this step whenever available. This classifications are done using the algorithm 'KhawajaCode® Beat Classification Essential'.

2.4. Step 4: Essential Rhythm Analysis

Basic rhythm analysis, as Bigeminus, Trigeminus, salve and heart rate, is performed in this step using the algorithm 'KhawajaCode® Rhythm Analysis Essential'.

2.5. Step 5: Heart Beat Classification

All heart beats available in the ECG recording including P waves and T waves are fully classified in this step using 'KhawajaCode® Beat Classification Expert'.

2.6. Step 6: Representative Heart Beat

All representative heart beats available in the ECG recording are derived out from dominant heart beats of all ECG leads using 'KhawajaCode® Representative Beat'.

2.7. Step 7: Essential Heart Beat Delineation

The essential fiducial points, segments and intervals of representative heart beats are measured in this step by means of 'KhawajaCode® Beat Delineation Essential'. The fiducial points localized here are P wave onset, P wave offset, QRS complex onset, QRS complex offset and T wave offset. Whereas, the segments and intervals are PQ / PR segment, ST segment, PR interval, QRS interval/duration and QT interval.

2.8. Step 8: Full-Scope Heart Beat Delineation

Once the essential Heart beat delineation has been taken place, further and detailed delineation procedure is performed in this step by means of 'KhawajaCode® Beat Delineation Expert'. Over thousand biomarkers and markers are extracted from representative heart beats are carried out here. Those biomarkers are very essential for the further analysis.

2.9. Step 9: Full-Scope Rhythm Analysis

In this step number of rhythm analysis statements are provided using 'KhawajaCode® Rhythm Analysis Expert'. These statements include conduction blocks analysis, asystoly, cardiac pause, escape rhythm and rhythm events as well as ventricular fibrillation/flutter flags, atrial fibrillation flags, Delta wave flags and WPW diagnosis.

2.10. Step 10: Full-Scope Contour Analysis

Numerous contour analysis statements are provided in this step by means of 'KhawajaCode® Contour Analysis' algorithm. That is, thorough diagnostic statements including atrial diagnosis, ventricular diagnosis for Myocardial Infarction (MI) and hypertrophy, repolarisation disturbance diagnosis and cardiac conduction system diagnosis are furnished here. Furthermore, technical hints as well as final bottom-line statements are also carried out. The algorithm used in this step is based on using a combination of complex decision tree and chosen methodologies of machine learning.

3. Validation Procedure and Validation Databank

The development of the proposed algorithm was carried out by means of an internal annotated training databank, whereas the initial performance was validated using an internal annotated test databank. The total number of ECG signals included in the databanks was over seven thousand. Furthermore, the accuracy of diagnostic interpretative statements was carried out using the well-known European CSE study and databank (Common Standard for qualitative Electrocardiography) with a total size of 1220 biological ECG signals. CSE Databank is widely accepted as the 'clinical truth'.

4. Results

Figure 2 and Figure 3 show the results of beat detection and heart beat classification as well as the extracted representative heart cycles of each leads of one CSE Databank signal, respectively.

Figure 4 shows the results of the main fiducial points detected by 'KhawajaCode® Delineation' on a randomly chosen signal from CSE databank.

The results obtained from the diagnostics algorithm on the internal databank illustrate a high degree of agreement with the reference annotations. The algorithm was able to detect normal, hypertrophy and MI subjects with the sensitivity greater than 95%, 75% and 92%, respectively. Accordingly, The Positive Predictive Value (PPV) were greater than 83%, 91% and 90%, respectively. Having the diagnostics algorithm validated on CSE databank, the reported results shows that the algorithm can detect normal, hypertrophy and MI subjects with the sensitivity of 87.7%, 67.5% and 79.9%, respectively. The total accuracy

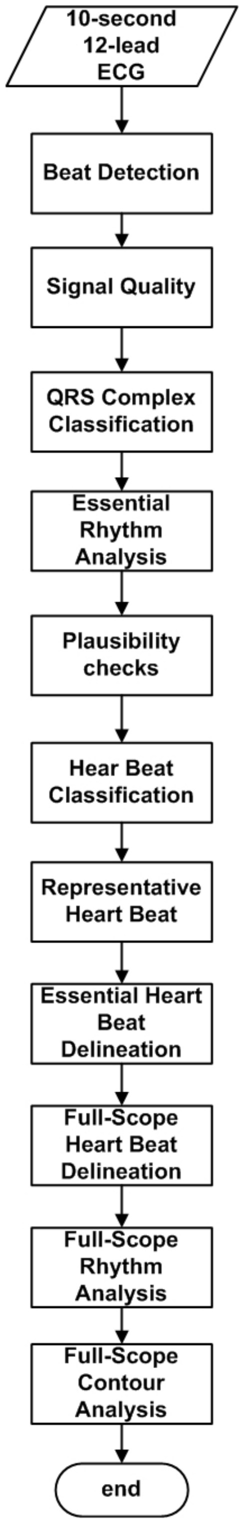

Figure 1. The delineation process of the 'KhawajaCode® Resting Essential' algorithm with the ten main steps for full-scope rhythm analysis, full-scope measurements and full-scpope contour anaylsis (diagnosis).

is 74.6%. Whereas, the specificities are 91.5%, 95.7%and 88.5%, respectively. These results are performed on CSE databank including additional so-called BVH or MIX testing at the coordinating center. By excluding the additional BVH or MIX testing at the coordinating center, the sensitivities of detecting normal, hypertrophy and MI subjects are 87.7%, 73.9% and 84.0%, respectively. Whereas, the specificities are 91.5%, 95.7% and 88.5%, respectively. The total accuracy is in this case 70.8%.

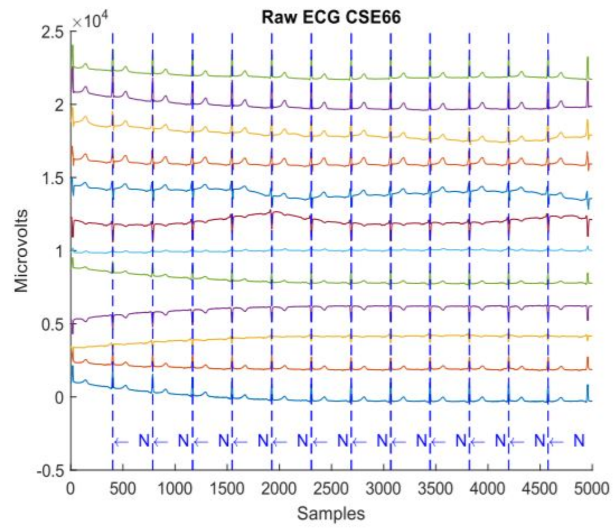

Figure 2. The delineation process of the 'KhawajaCode® Resting Essential' algorithm with the ten main steps for full-scope rhythm analysis, full-scope measurements and full-scpope contour anaylsis (diagnosis).

5. Discussion and conclusion

The presented algorithm shows high promising results and a top performance regarding the sensitivity and PPV using internal databank. Furthermore, the performance accomplished by the algorithm using the CSE databank shows a superior performance compared to the performance of other relevant ECG algorithms illustrated in [3].

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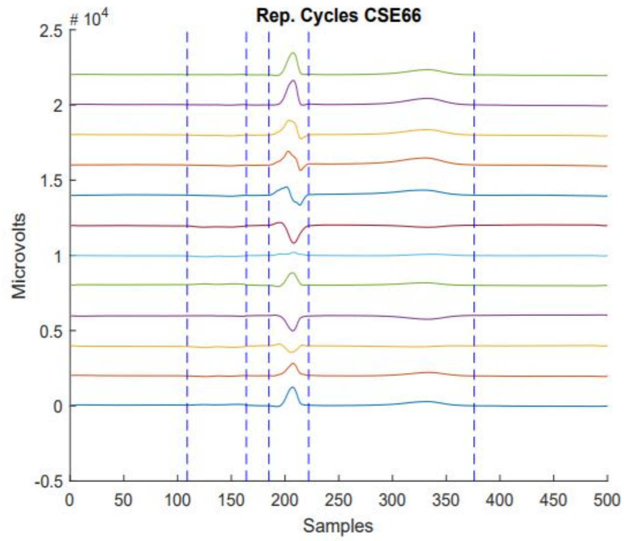

Figure 3. The delineation process of the 'KhawajaCode® Resting Essential' algorithm with the ten main steps for full-scope rhythm analysis, full-scope measurements and full-scpope contour anaylsis (diagnosis).

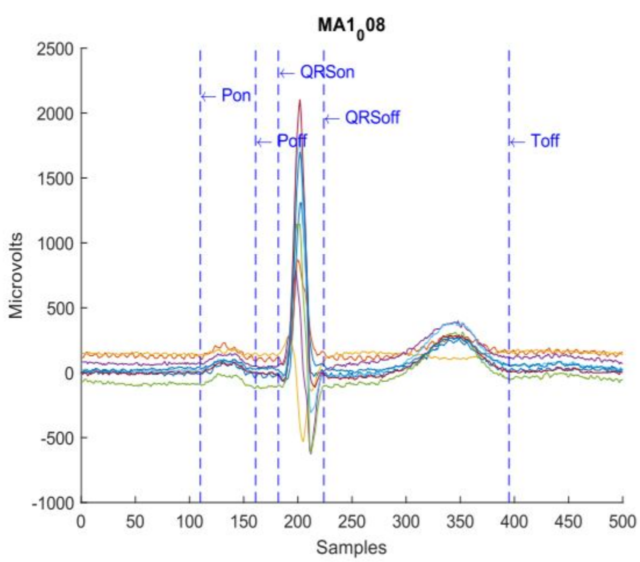

Figure 4. The results of the main fiducial points detected by 'KhawajaCode® Delineation' as a part of 'KhawajaCode® Resting Essential' algorithm on a randomly chosen signal from CSE databank.

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