ECGLens: Interactive ECG Classification and Exploration

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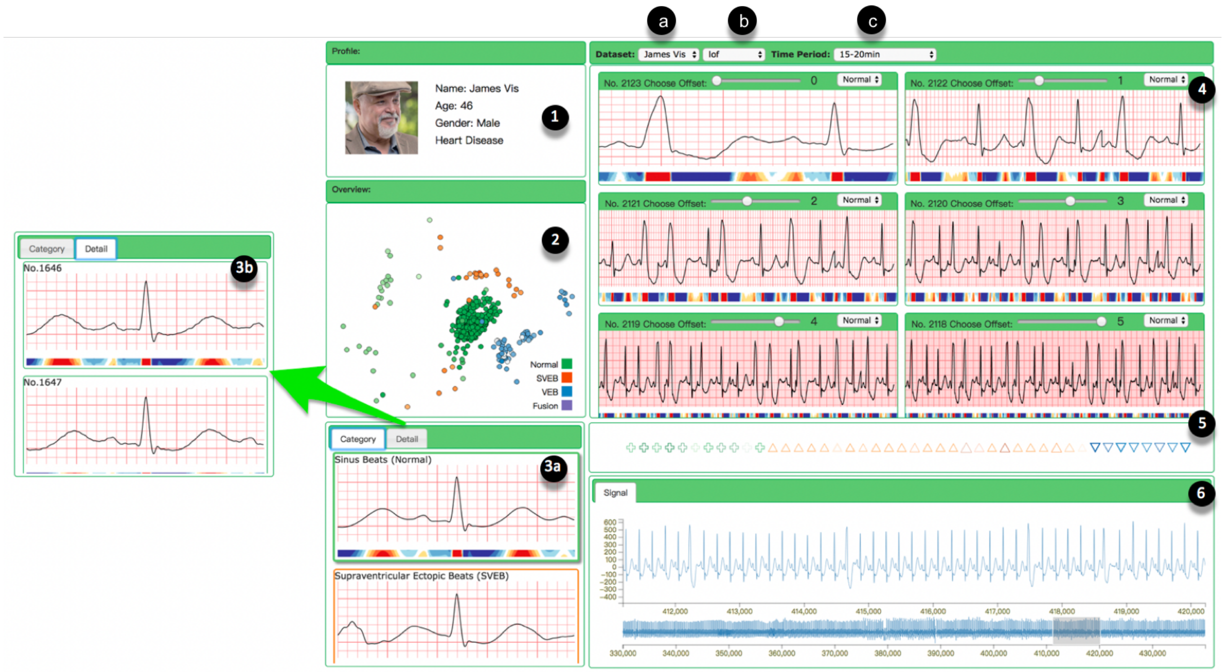

Figure 1: The ECGLens system contains 7 interactively coordinated views: (1) a Profile window provides personal information of the patient; (2) an Overview window distributes heartbeats in the two-dimensional (2D) space; (3a) a Category window displays the overall morphology of the 4 types of heartbeats; (3b) a Detail window demonstrates detailed heartbeat information, (4) a Main window presents the information of all the heartbeats selected by brushing or clicking operation which is in the form of heartbeat information card, where the user can modify the type of the heartbeat; (5) an Event window shows the event sequence of all heartbeats where a symbol represents a heartbeat; and (6) a Signal window constituted by all ECG waveforms.

Abstract

With the development of portable electrocardiogram (ECG) monitors, a huge amount of high-quality ECG data have been collected every day in real time, leaving doctors a much heavier workload to read the ECG diagrams for making a diagnosis. By observing the classification result of a series of consecutive heartbeats and their order, doctors can better know the rhyme of the signal and then detect an arrhythmia. However, the present classification algorithms still have an accuracy gap to industrial production. A system with manual correction is desired for the current ECG classification analysis. Therefore, we propose ECGLens, as the first attempt to interactively interpret and improve the heartbeat classification results and support arrhythmia identification with visualization techniques.

Keywords: Design Studies, Time Series Data, Human-Computer Interaction, Intelligence Analysis

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1 Introduction

The electrocardiogram (ECG) is a simple, painless and cost-effective test for heart disease diagnosis, which shows the sequence of cardiac events [1]. With the development of modern ECG devices, especially the Holter monitor, a portable device to continuously monitor various electrical activities of the cardiovascular system in more than 24 hours; and the ECG can be recorded in real time with good signal quality [2] [3].

According to the deep-learning result of heartbeat classification, all the heartbeat data can be classified into 4 categories: Normal beat (Normal), ventricular ectopic beat (VEB), supraventricular ectopic beat (SVEB), and fusion of a normal and a VEB (Fusion). In this paper, we introduce ECGLens, a visual analysis system and framework to detect anomalous heartbeat classification, interactively modify the classification, and properly present the ECG with statistic information.

2 Visual Analytics

2.1 Outlier Detection with MDS

Based on Multidimensional Scaling (MDS), a heartbeat can be placed in the 2-dimensional space in the Overview window as points. With the 2D feature in Overview, the system naturally shows clusters and outliers. In Fig.1, several clusters are roughly showed: Normal in green, VEB in blue, and SVEB in orange. Besides, we use Mean

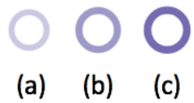

Figure 2: Each heartbeat type is represented as a colored symbol. The purple circles in the figure demonstrate a part of Fusion beats sequence. The lightness is decided by the standard deviation, and the amplitude of the heartbeat determines the stroke width. Thus, the electrical activity of (a) is less active than that of (b). And compared with the heartbeat (c), the heartbeat (a) has a smaller amplitude.

Shift to divide the heartbeat data of each category into several classes. And the lightness of a heartbeat point represents the cosine value of the heartbeat data vector and the average vector of the largest class of its category in Mean Shift result.

Each point in the Overview window can be mapped into a heartbeat card in the Main window by clicking or brushing. In the Main window, each card shows a cardiac cycle of a heartbeat. Considering that heartbeats need to be viewed as a group, we provide a select bar on the right side with the current offset number shown for users to choose offset range to check the surrounding ECG data. And the current offset number is shown on the right of the select bar.

2.2 Reviewing Current Classification

Right beneath the Overview is the Category window which presents the selection field for users to choose among the four heartbeat categories. Every card (the field contains the name, the heartbeats and the horizon graph) in the Category window carries the name of the heartbeat type and the average heartbeat figure in the chosen time period selected by users with conventional ECG visualization and horizon graph. Each category has a special color corresponding to the color in Overview window, shown as the card border color.

For any category card clicked in Category window, the Main window will show all heartbeats belonging to this category within the time series that the user chooses with a default descending order of LOF value. The LOF value is calculated by Local Outlier Factor and can describe the anomaly levels. The larger the LOF value of a heartbeat, the more possible this heartbeat is an anomaly and may be misclassified.

We also allow users to choose the ranking method on the top of the Main window, using the select menu at the right of the patient information. In the select menu, two methods can be chosen, either as ascending time series ranking or descending LOF ranking.

2.3 Correcting Heartbeat Classification

On the right side of the offset select bar, the system provides a drop down select menu for users to correct the category for the false classification.

This function provides users chances to correct and amend the systematic error occurred during classification period. Combining with the LOF ranking system in the Main window and the outlier brushing mechanism in Overview window, ECGLens lets users detect the outliers of the automatic classified categories efficiently and directly. And the new result will improve the classification correction rate of the machine learning algorithm for future application.

2.4 Location, Neighbor and Category Combination

In the Event window, each category of heartbeats is represented by a specific symbol with a designed color as same as that in the Category window: green cross for Normal, orange regular triangle for SVEB, blue inverted triangle for VEB, and purple circle for Fusion. The Event window is a supplemental information for the Signal window which presents an overall view of all ECG data during the selected time period in time order. The Event window provides a simplified visualization for the users to avoid tight and crowded signals from original data. As Fig. 2 shows, the lightness of the signal demonstrates the standard deviation value of the heartbeat. The lighter the color of the symbol, the less standard deviation value it has; and the less active the electrical activity is. The stroke width of the shape shows the amplitude of the heartbeat, the wider the stroke, the larger the amplitude of the heartbeat, which can reveal a cardiac morphology abnormality like ventricular hypertrophy. Users can also zoom in/out to see a closed/an around view of the events.

Right beneath the Event is the Signal window, where all the signal data are presented using the most common ECG visualization method. And users are allowed to zoom in/out or change the ECG to any position in the Signal window. The view in Signal window will also have an impact on Event window with the same zoom rate.

3 Usage Scenario

We identify 2 typical scenarios: (1) doctors can use the tool to find the outliers of heartbeat classification and then modify the classification for better result, (2) doctors can explore the system to get ECG related information, and identify a cardiac arrhythmia.

In the first scenario, users were asked to check all the heartbeats of the Normal type and find outliers. When using traditional ECG visualization in ascending time order, it took participants at least 8 seconds to find the first outlier. However, most of them identified the first outlier at a glance by using our system.

In the second scenario, we asked our users to explain the course of a disease based on the information provided by our system. As shown in the Fig.1 (5), the heartbeats are normal at first. And then the patients gets Supraventricular ectopic beats. And it gradually changes to Ventricular ectopic beats. Furthermore, according to the event sequence and the morphology of abnormal heartbeats, the patient gets sinus tachycardia.

In our interview, our users still want to know more information about the patient's medical history. Thus we will further improve this work in order to help a doctor make a diagnosis more accurately.

4 Conclusion

The paper described a novel visual solution to identify and modify the heartbeat classification interactively, as well as an efficient way to spot an arrhythmia and assist the user to make a diagnosis. We designed and implemented our system called ECGLens which was deployed with real patient ECG data and tested by medical staff. Our evaluation proved that our method is feasible and the proposed system is easy to use. While the algorithms of automatic heartbeat classification have been developed in recent years, the novelty of our design is that we used visual approaches to detect anomalies, and introduced event sequence to represent all the heartbeats. As part of our future work, we plan to extend the ECGLens by including more patient history information and the complete 12-lead data in our system. We believe that this design can be applied widely in cardiac data analysis because it can relieve people from the massive amount of ECG data and helps the user to make a more accurate and efficient diagnosis.

Acknowledgments

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