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Research Article

Classification of Premature Ventricular Contractions from ECG Signals using Multi-Domain Feature Extraction and Dimensional Reduction based on a Variational Autoencoder

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Main Subjects: Classification of premature ventricular contractions

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Abstract

The most serious disease and the main cause of death worldwide are recognized to be cardiovascular ailments. The most common kinds of cardiac arrhythmia are premature ventricular contractions (PVCs). the most common (and least invasive and low-cost) techniques for examining cardiac problems are the recording and analysis of electrocardiogram (ECG) data. Through a combination of manually extracted features from ECG signals and feature reduction based on deep learning, a novel supervised strategy for the automatic identification of PVC has been established in this work. The suggested technique extracted several properties from ECG signals using a variety of approaches, including statistical, chaotic analysis in the time domain and time-frequency domain, as well as morphological evaluation. Then, in order to minimize the amount of extracted features and acquire the most discriminating features, a variational autoencoder (VAE) network is constructed as a deep learning based feature reduction approach. In order to identify ECG data, support vector machines, k-nearest neighbors, and neural network classifiers with five-fold cross-validation are used. The suggested strategy is assessed using the MIT-BIH database. The obtained results showed that the proposed method using an SVM classifier reached 99.85% accuracy, 99.95% sensitivity, and 99.42% specificity, which performed better compared to existing similar studies.

Keywords: Premature ventricular contraction (PVC), Electrocardiogram (ECG), Feature Extraction, Auto-Encoder, Feature Reduction, Machine Learning.

Highlights

- Detection of premature ventricular contractions using a new algorithm using deep learning techniques that has better accuracy than previous work.
- Using a feature reduction method to increase the speed of the algorithm based on deep learning techniques and using the VAE technique.
- Using various features, including time, frequency, and time-frequency features, to increase accuracy and reduce algorithm error, ultimately achieving better accuracy.

Citation: [in Persian].

1. Introduction

In the past decade, cardiovascular disease has become a leading global cause of mortality, and timely and accurate recognition of arrhythmias, particularly premature ventricular contractions (PVC), is crucial for both preventing and treating heart diseases, with electrocardiogram (ECG) signals serving as a standard, non-invasive method for evaluating heart function and diagnosing cardiac issues.

2. Innovation and contributions

In this paper, Among the innovations of this paper, the following can be stated:
1. In this research, anew algorithm with better accuracy than previous works was presented using deep learning techniques to detect premature ventricular contractions.
2.A feature reduction method was presented in order to increase the speed of the algorithm based on deep learning techniques and using the VAE technique, and a good result was obtained.
3. In order to increase the accuracy and reduce the error of the algorithm, various features were used, such as time, frequency and time-frequency features, which ultimately resulted in better accuracy.
4. Finally, by using the method used in this research, it is possible to detect premature ventricular contractions earlier and in a more timely manner and prevent premature death of more patients.

3. Materials and Methods

The study highlights the limitations of end-to-end deep learning in outperforming traditional machine learning approaches, prompting the development of a two-level feature engineering strategy that combines multi-domain feature extraction, Empirical Wavelet Transform (EWT), and dimensionality reduction with Variational Autoencoder (VAE), resulting in a PVC detection algorithm achieving 99.85% accuracy on the MIT-BIH dataset, a novel contribution not previously explored in the literature.

4. Results and Discussion

First, a scenario is conducted to demonstrate the necessity and advantage of feature extraction in different domains. Then, the proposed approach is compared with other feature reduction methods to demonstrate the advantage of the proposed feature reduction approach. In Table (1) and Table (2), the performance of the classifier with different feature dimensions extracted from different domains is examined. Also, the result of detecting premature ventricular contractions using the combined feature vector and without feature reduction is also shown. Table (1) can be inferred that the frequency domain feature vector has the lowest classification performance among the three feature domains. In addition, it is shown that by simply combining all the features (joining all the features together), the performance of detecting premature ventricular contractions is further reduced, which indicates the problem of high dimensionality. To avoid the challenge of high dimensionality and improve the performance of the classifier algorithm, feature selection or dimension reduction techniques are proposed to reduce the number of features and balance the classes. As can be seen, the proposed VAE network is capable of selecting more compact and yet more distinct features, which achieves higher accuracy while using fewer features.

Table 1. Classification evaluation results based on automatic variable coding and proposed extracted features

Domain	**Time + VAE**			**Frequency + VAE**			**Time-Frequency + VAE**			**Raw signal + VAE**			**Proposed VAE**		
Record	**Acc.**	**Se.**	**Sp.**	**Acc.**	**Se.**	**Sp.**	**Acc.**	**Se.**	**Sp.**	**Acc.**	**Se.**	**Sp.**	**Acc.**	**Se.**	**Sp.**
105	87.3	90.3	90.5	82.4	83.9	81.9	91.1	92.1	92.8	86.6	85.4	87.38	99.63	100	99.16
106	89.4	91.1	87.1	85.1	84.9	85.2	93.4	94.6	92.9	84.9	87.1	83.9	100	100	100
107	85.4	84.9	-	83.7	83.8	-	89.9	90.1	-	86.2	85.3	-	98.88	98.88	-
108	89.9	91.9	92.3	85.9	84.6	85.1	93.9	94.1	94.2	86.5	87.1	86.2	100	100	100
109	80.3	79.8	-	76.2	76.3	-	83.9	83.1	-	79.9	80.1	-	95.11	95.11	-
114	88.1	90.34	91.5	83.9	84.7	83.2	94.8	95.2	94.3	88.9	88.2	86.7	99.95	100	99.95
116	89.1	90.2	93.8	84.7	85.9	84.1	94.2	96.7	95.1	88.5	89.3	85.7	99.97	100	99.97
118	92.8	93.1	-	89.9	89.9	-	96.2	97.1	-	89.2	89.6	-	100	100	-
119	89.3	89.8	89.1	87.1	86.2	86.9	96.2	97.3	96.1	88.6	90.1	88.9	100	100	100
Average	**89.4**	**92.2**	**91.3**	**84.6**	**85.8**	**83.8**	**94.1**	**94.6**	**95.1**	**87.3**	**89.1**	**85.2**	**99.85**	**99.95**	**99.42**

Table (2) shows the proposed approach, the raw signal along with the proposed dimensionality reduction approach and the combination of all features and the application of the proposed method for dimensionality reduction. The effect of VAE network on feature reduction and performance enhancement of the classifier system is also examined in this table. Without considering the features extracted from the signal, the VAE network could not provide significant performance. It can be claimed that due to data limitations, the network suffered from the overfitting problem. Moreover, the highest enhancement was achieved when all the features extracted from all the domains were considered as input to the VAE network. The performance of the proposed approach was compared with other state-of-the-art methods using the MIT-BIH database. As shown in Table (3), the proposed method showed superior performance in terms of accuracy, sensitivity, and specificity compared to the state-of-the-art methods.

Table 2.Comparing the performance of the proposed methods with the latest available methods

Ref	Method	Acc.	Se.	Sp.
[1]	Feature extraction from Multi-domain	99.78	99.91	99.37
[2]	Deep learning	99.7	99.87	97.45
[3]	Active learning	96.49	81.50	97.56
[4]	Feature extraction + CNN	98.6	98.9	99.2
[5]	CNN + IGRU	99.3	98.4	98.2
[6]	Semantic segmentation + Deep learning	0.932	0.963	0.882
[7]	Machine learning + Random Forest	90.91	90.91	----
Ours	VAE + NN	99.32	98.56	99.04
Ours	VAE + KNN	99.43	99.62	99.21
Ours	VAE + SVM	99.85	99.95	99.42

5. Conclusion

In this work, a novel approach for PVC detection is proposed through a combination of multidimensional feature extraction and deep learning-based feature reduction. In the first step, multiple features are extracted from ECG signals. Then, neural network-based VAE is used to reduce the dimensionality of the features. Numerical findings demonstrate the effectiveness of the proposed approach for PVC detection on the MIT-BIH database. The final results indicate a promising application for VAE in feature reduction tasks. The proposed scheme outperforms similar and up-to-date studies, recording an overall accuracy of 99.85%, and the effectiveness of the proposed approach for feature reduction is proven.

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