基於PPG信號多面向改進血糖預測模型

Optimizing Non-Invasive Blood Glucose Prediction through Data Preprocessing and ResNet50

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I. Abstract

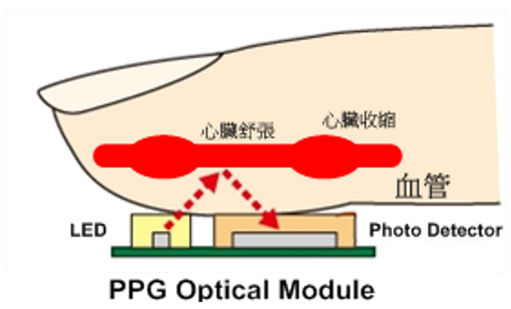
According to the International Diabetes Federation (IDF), the global number of diabetes patients is expected to increase to 642 million by 2040, making diabetes one of the fastest-growing diseases of the 21st century. Currently, traditional blood glucose measurement methods rely primarily on finger-prick blood tests, which are invasive procedures that can cause discomfort and pose a risk of infection for patients. In contrast, non-invasive methods can effectively address these issues; however, the primary challenge lies in their insufficient accuracy.

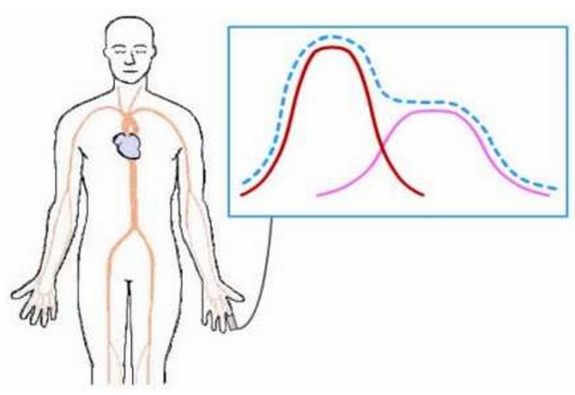
This study aims to enhance the efficiency of non-invasive blood glucose prediction models from multiple aspects. We selected the MIMIC-III dataset, containing 170,000 records of 5-second PPG signals with glucose values ranging from 70 to 250, covering 4,157 subjects to increase the model's generalizability. In terms of model selection, we adopted the ResNET50 architecture and introduced a data stratification preprocessing concept to improve data quality by filtering high-quality signals for training.

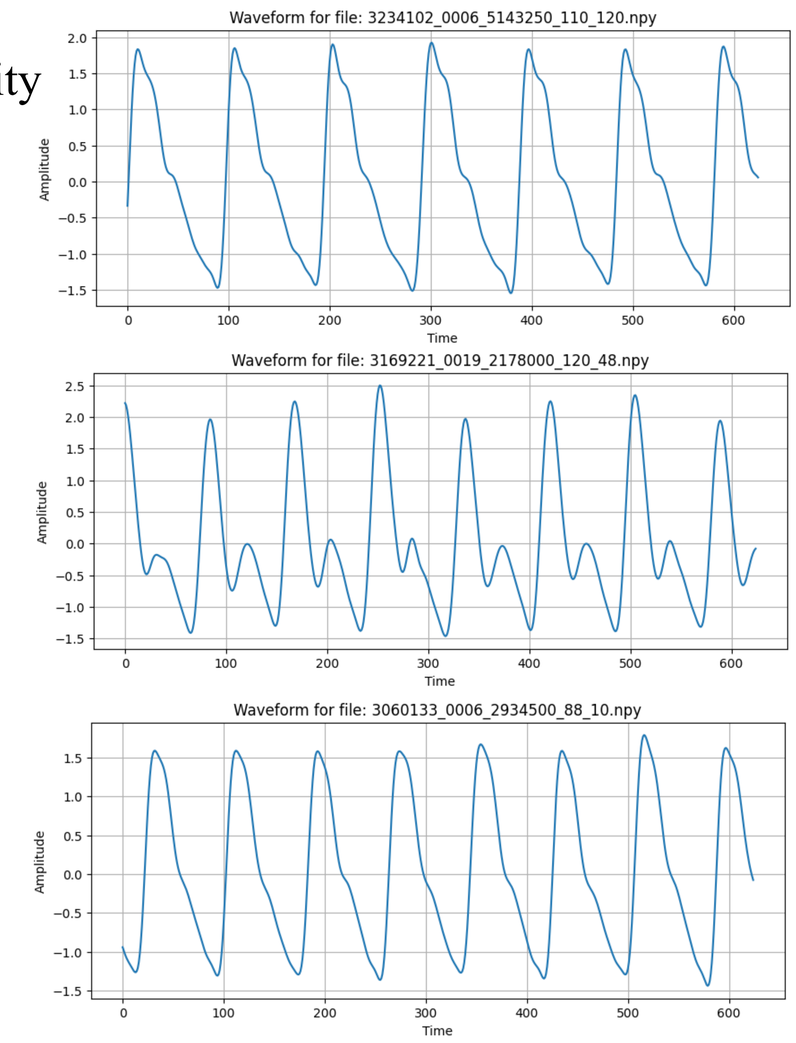
To validate the model's performance, we conducted evaluations based on the ISO:15197 2013 standard to determine reasonable error ranges. In personalized tests (where specific individual data is included in the model training), our model achieved an accuracy of 91.02%, with 97.44% of the results falling into the best A zone of the Clarke Error Grid. The model also showed excellent results in non-personalized studies.

II. Research Objective and Method

1. Severe individual variability







2. Insufficient training data volume.

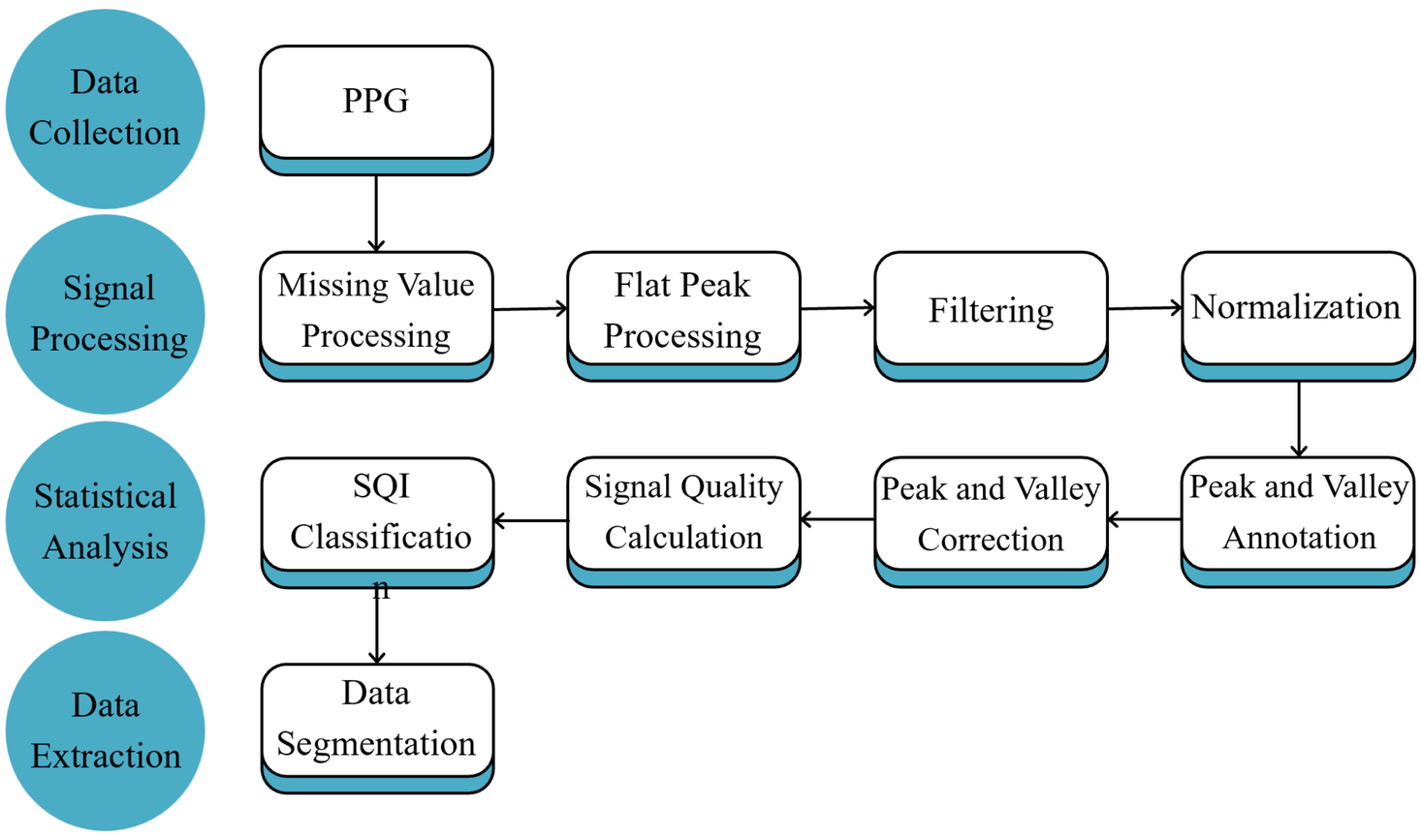
We randomly selected 4,157 subjects from the MIMIC-III dataset to use as training data.

Training Data	Number
Normal blood glucose(70~140)	80,000
Prediabetes(141~199)	80,000
High blood glucose (≥200)	80,000

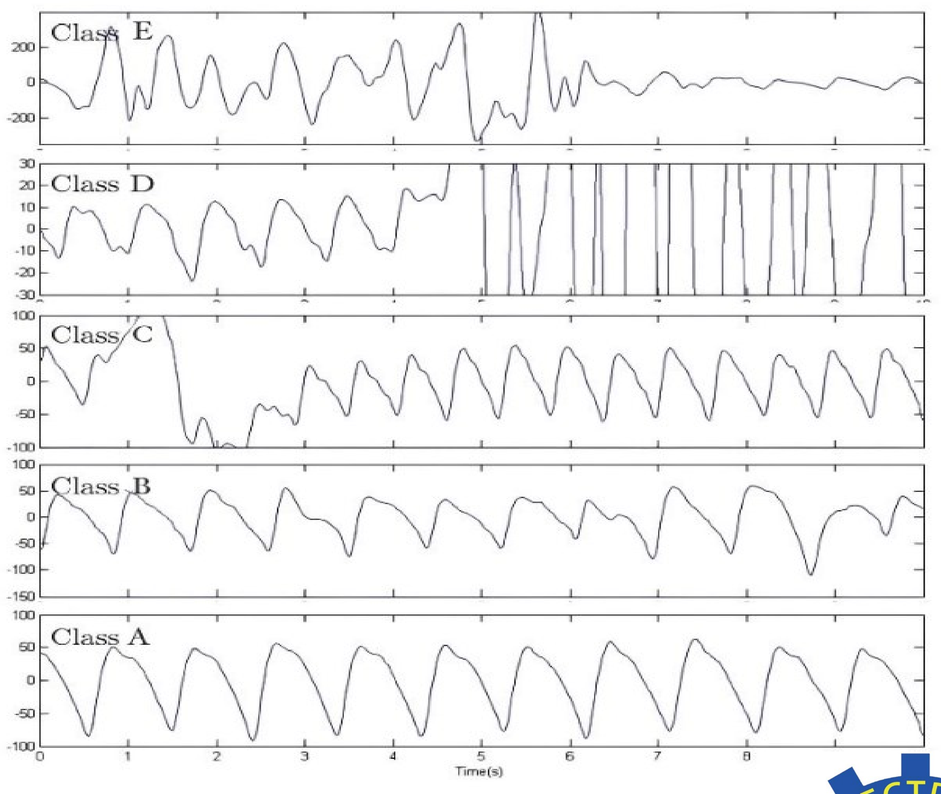
The test set, on the other hand, was comprised of an additional 1,846 subjects who were independent of the Training set.

Testing Data	Number
Normal blood glucose(70~140)	20,000
Prediabetes(141~199)	20,000
High blood glucose (≥200)	20,000

3. Lack of rigorous data preprocessing



SQI classification



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4. CNN model architecture

We adopted the ResNet50 (Residual Network 50) architecture of the Convolutional Neural Network (CNN) as the core model. ResNet50 builds upon VGG by adding skip connections, which do not add any new parameters but can solve the problem of vanishing gradients. The skip connections perform element-wise addition with the convolutional layers rather than directly connecting, which means that each layer only needs to learn the residual between the input and the output. This greatly reduces the difficulty of model training. The residual blocks use a bottleneck structure, where a 3x3 convolutional kernel is decomposed into a sequence of (1x1, 3x3, 1x1) convolutional kernels, which helps reduce the number of parameters used by the model.

III. Results

Experiment 1:To explore the effect of SQI classification

I. A-grade Data (240,000 data)

II. A + B-grade Data (190,000 A-grade data +50,000 B-grade data)

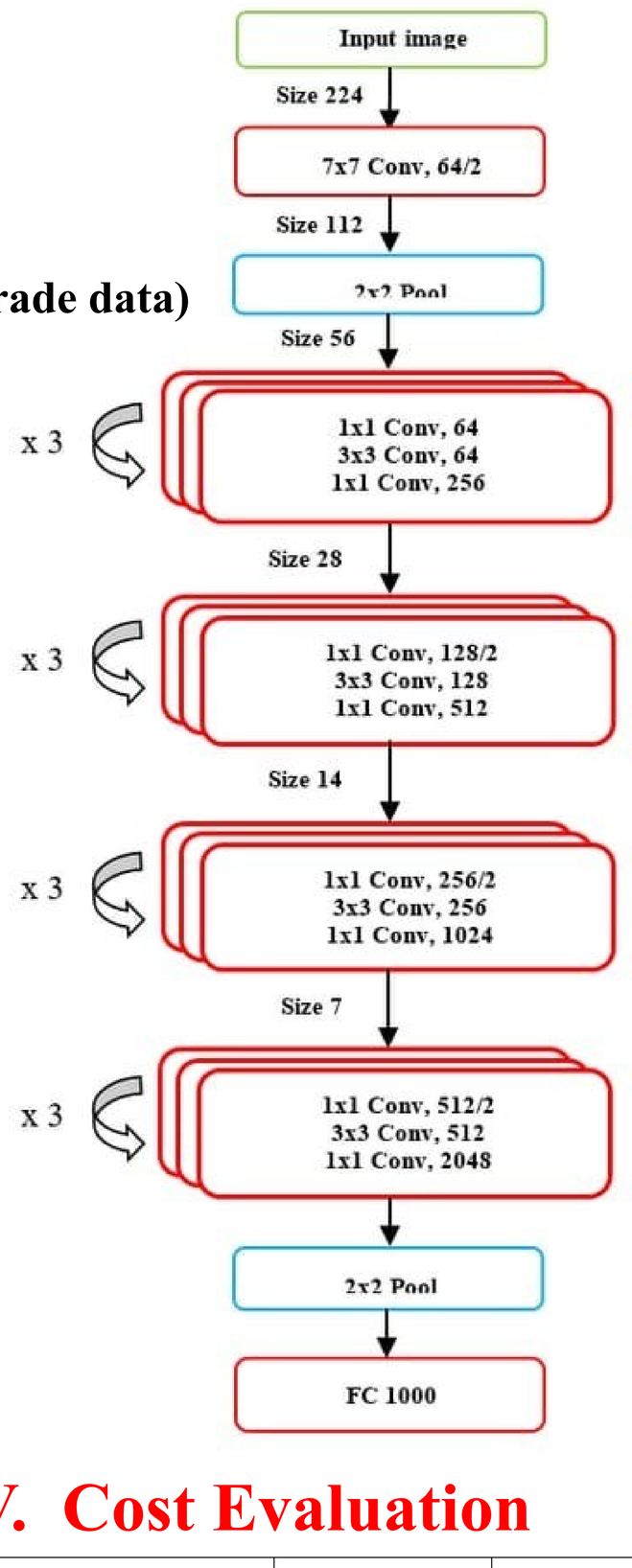
III.A+B+C-grade Data (165,000 A-grade data +50,000 B-grade data+25,000 C-grade data)

IV. Unclassified Data (240,000 data)

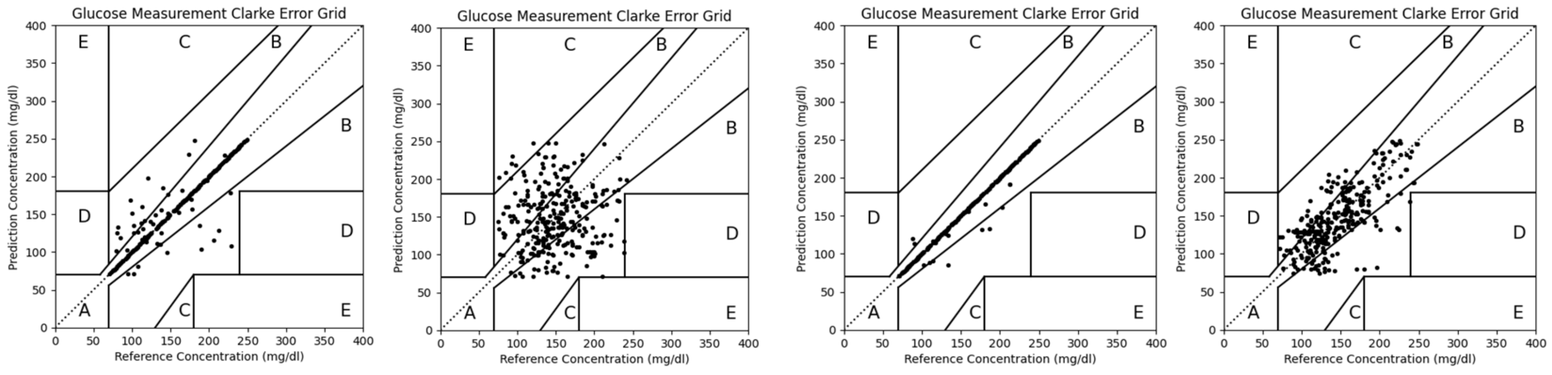
Experiment 2: Adding Other Physiological Features

I. Convert 1D PPG into 2D HHT Images

II. Add the Previous Blood Glucose Measurement Value and Time Interval



	Ungraded	A-grade	A+B-grade	A+B+C-grade
Train	91.7%	95.94%	96.7%	91.89%
Personalized	56.98%	83.92%	77.46%	69.02%
Non-personalized	50.62%	50.8%	48.16%	46.49%



	A-grade	A-grade HHT + Blood Glucose + Time
Train	95.94%	98.08%
personalized	83.92%	91.02%
Non-personalized	50.8%	75.38%

V. Cost Evaluation

	Time	Cost
Estimated Before Production	1 year	120,000
Actual After Completion	300 days	120,000

IV. Conclusion

The experimental results indicate that data quality and feature extraction have a significant impact on model performance. Firstly, SQI classification significantly improved the accuracy of personalized data, with the model trained on pure A-grade data achieving an accuracy of 83.92%, which is much higher than the 56.98% accuracy of the unclassified data. Secondly, HHT feature extraction enhanced the performance of non-personalized data, increasing accuracy from 50.8% to 79.38%, demonstrating that time-frequency features and data fusion can comprehensively improve the model's predictive ability. The Clarke Error Grid analysis further confirmed these effects: the personalized accuracy of pure A-grade data reached 91.01%, and after incorporating HHT features and other physiological features, it increased to 97.44%. meeting the ISO:15197 2013 medical standard. For non-personalized data, the accuracy also improved from 44.33% to 70.2%.

According to the international ISO:15197 2013 standard, we have reached the medical standard.