# ECG-Based Biometric System using TinyML: Implementation and Performance Evaluation on ESP32

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# Outline

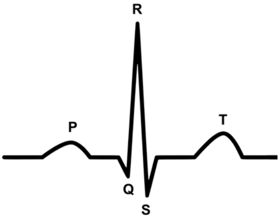
# Introduction

**What is biometrics?**

Biometrics are unique physical or behavioral characteristics that can be used to identify an individual. The term "biometrics" comes from the Greek words "bios," meaning life, and "metron," meaning measure.

- Heart is the most important part of the human body.
- It is also an uninterrupted data source.

# Introduction




Schematic diagram of normal sinus rhythm for a human heart as seen on ECG

- **P-Wave:** Its frequency spans from 10 to 15 Hz, while its duration varies between 0.06 and 0.12 seconds.
- **QRS-Complex:** Its amplitude varies between 0.5 and 1 mV, and its duration spans from 80 to 120 ms.
- **ST-Segment:** Can be anywhere from 0.1 to 0.5 millivolts in amplitude, and it can last anywhere from 120 to 180 ms.

# Motivation

# Motivation

- To explore the use of **electrocardiogram (ECG)** signals as a biometric modality for personal identification.
- To exploit the recent advances in **tiny machine learning (TinyML)** techniques to deploy and evaluate an ECG biometric system on a low-power device such as the **ESP32** microcontroller.
- To demonstrate the feasibility and performance of real-time biometric authentication using **deep learning** and **TensorFlow Lite** on an embedded system.

# State of the Art

# State of the Art

| Authors | Databases | Approach | Results |
|---|---|---|---|
| Azam et al. | Private | Extraction of features using DWT + MLP | 96.40% |
| Yuniarti et al. | MIT-BIH Arrhythmia | Extraction of QRS waveform features + 1D-CNN | 92.00% (F1-Score) |
| Li et al. | Five public datasets | Two CNN models | 94.30% (Average) |
| Zehir et al. | MIT-BIH Arrhythmia | Frequency domain features + SVM | 97.00% |

# Proposed Method

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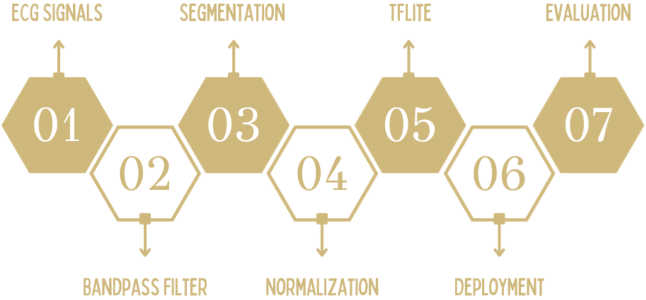



Proposed System Architecture

# Proposed Method

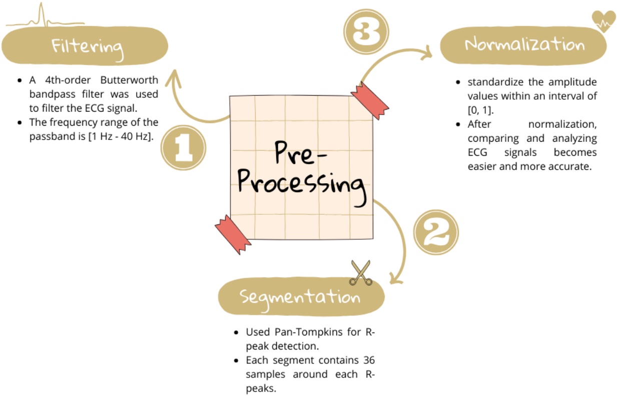
## Database

# MIT-BIH Arrhythmia Database

- It is a publicly available ECG database from the PhysioNet repository.
- The database contains ECG recordings from a total of 47 subjects.
- Each subject has one recording lasting for 30 minutes.
- Each signal is digitized at 360 samples per second.
- We only used data from 10 subjects.

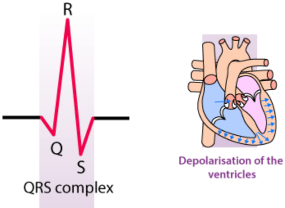
# Proposed Method

## Pre-processing




The Pre-processing steps of the proposed system

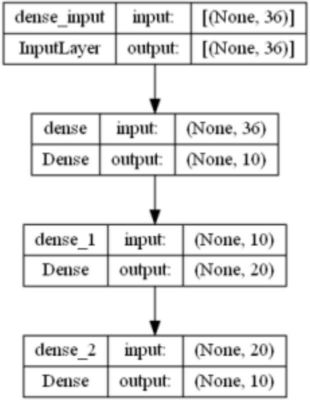
- More than 26000 QRS complexes were obtained from 10 subjects.
- Those samples are more than enough to train the deep learning model.




QRS complex is the main spike seen in the ECG.

# Proposed Method

## Deep Learning Model




Proposed Architecture of Our Deep Learning Model

# Deployment On The Esp32 Board

- The trained deep learning model is converted to TensorFlow Lite (TFLite) format, which is a lighter version of the TensorFlow library designed for devices with low computational power.
- The TFLite model is further transformed into an Arduino library compatible with the ESP32 microcontroller using the Edge Impulse Framework, which supports the development of TinyML models for embedded systems.

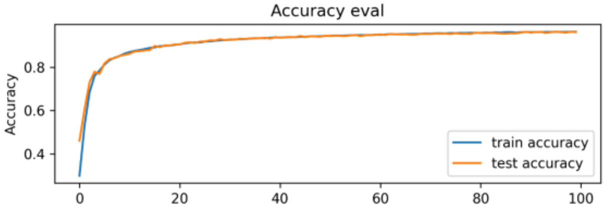
# Experiments and Results

# Experiments

- 10 subjects from the MIT-BIH Arrhythmia Database
- Single Lead Only
- Classification of QRS Complexes

- Accuracy as a Metric:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{1}$$




Training progress of our system, showing training accuracy alongside validation accuracy

- 70% training, 10% validation, and 20% test.
- Epochs: 100
- Mini-batch size: 150
- Learning rate: 0.001
- Optimizer: ADAM

- The model was successfully deployed on the ESP32 board.
- The on-device performance of the model is evaluated in terms of **inference time**, **RAM usage**, and **flash usage**.

| Processing Time | RAM Usage | Flash Usage |
|---|---|---|
| 3 ms | 1.3 k | 12 k |

# Results

Our System versus State-of-the-Art ECG Biometric Systems

| Authors | Database used | Accuracy achieved |
|---|---|---|
| Zhang et al. | MIT-BIH Arrhythmia | 91.31% |
| Zihlmann | MIT-BIH Arrhythmia | 91.15% |
| Zehir et al. | MIT-BIH Arrhythmia | 95.31% |
| Our method | MIT-BIH Arrhythmia | 96.71% |

- Superior accuracy compared to state-of-the-art models.
- Significant implications for decision-making processes in healthcare.
- Enhance the efficiency and accuracy of medical processes.
- Critical in time-sensitive medical scenarios.

# Conclusion

# Conclusion

- We proposed an approach based on ECG biometrics.
- Our approach obtains better results on the MIT-BIH Arrhythmia Database.
- Only use QRS complexes.
- For future works, model quantization.

# Thank You

## Questions?