Title: Heart Digital Twin Using PCG Signals

Subtitle: Real-time heart monitoring and classification

Introduction

Digital Twin:

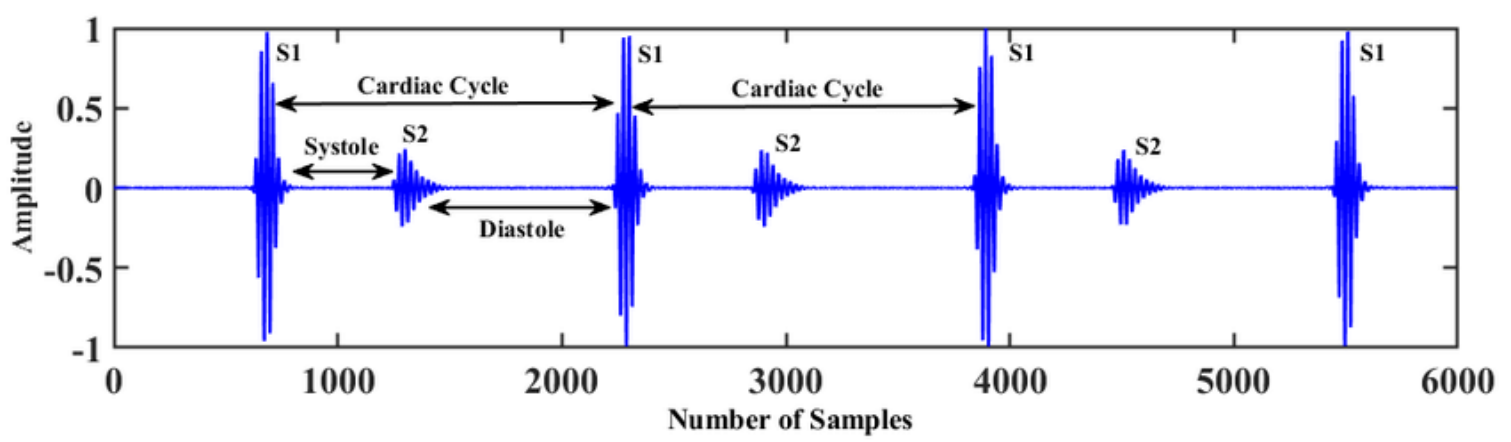
- digital replica of a physical heart
- simulates real-time behavior

Why PCG:

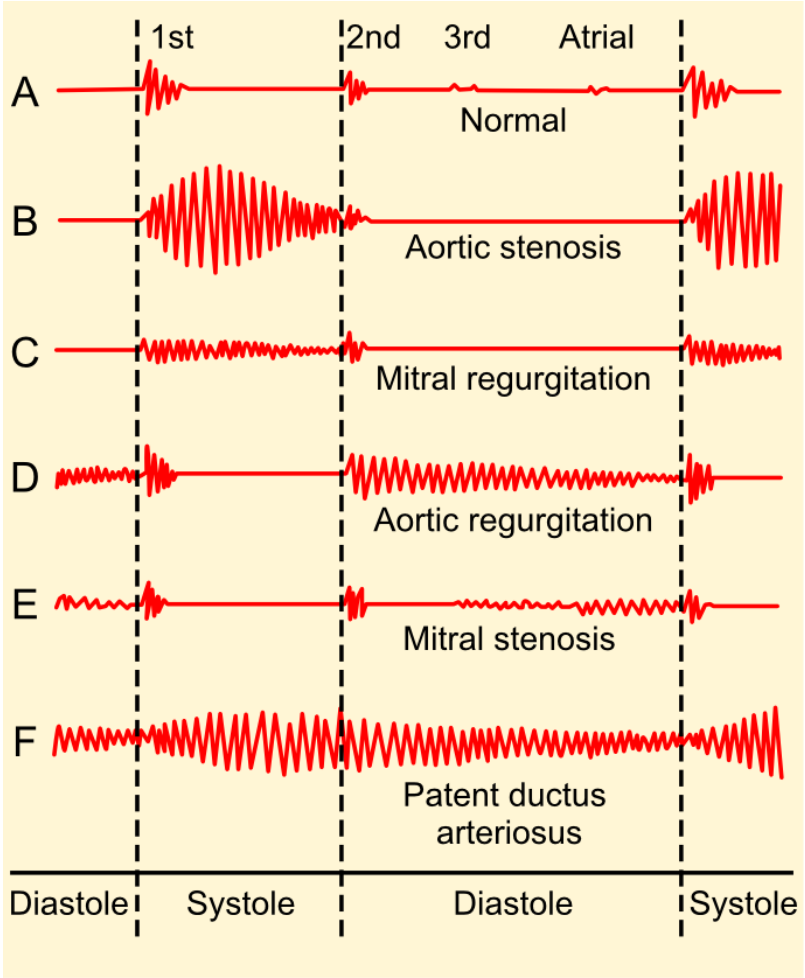
- Non-invasive
- Captures heart sounds
- Early detection of murmurs or valvular diseases
- Not expensive

Heart Sound / PCG Basics

- **Murmurs** are sounds caused by the turbulent blood flow that are often the first sign of structural heart disease in patients.
- **Phonocardiograms (PCG)** is the digital representation of a heart sound and can be recorded by a phonocardiograph.
- A **phonocardiograph** is a stethoscope that transmits the sounds to a digital sampling device instead of transmitting them to the clinician's ears like stethoscope.
- The first "lub" sound denoted as **S1** is occurred when there is closing of the AV (Atrioventricular) valves after the atria have pumped blood to the ventricles.
- The second "dub" sound **S2** happens when there is closing of the aortic and pulmonary valves, just after the ventricles have ejected the blood.



S1 [70-150] ms
S2 [60-120] ms
Mean Systolic time : 300ms
Mean Diastolic time: 500ms



Lab Setup of Heart digital twin

DT platforms + healthcare-oriented tools

1. Cloud Platforms with DT Support

- **Azure Digital Twins**
  - Model physical systems (like the heart) in a graph-based environment.
  - Integrates with IoT Hub, ML, and visualization tools.
  - Good for showing *how a PCG signal can update a virtual heart twin in real time*.
- **AWS IoT TwinMaker**
  - Similar to Azure DT, but AWS-focused.
  - Allows 3D scenes, IoT data ingestion, and ML integration.
- **Siemens Mindsphere / PTC ThingWorx**
  - Industry-grade DT platforms.
  - Strong for IoT + visualization. (Good to mention but not hands-on unless you want industrial flavor).

DT platforms + healthcare-oriented tools

2. 3D Visualization Tools

- **Unity / Unreal Engine**
  - Create interactive 3D models (e.g., a beating heart).
  - Can connect with live data streams.
- **Three.js / pythreejs / Blender *****
  - For web-based or notebook-based visualization.
- **Azure Remote Rendering** (if showing very high-fidelity anatomy models).

DT platforms + healthcare-oriented tools

3. Data & Simulation Tools

MATLAB Simulink / Simscape/ Jupyter(NumPy / SciPy) ***

Biomedical system modeling, real-time signal simulations.

Ansys Twin Builder

Physics-based digital twins.

Could be used to simulate blood flow, valve function, etc.

OpenFOAM (open-source CFD)

For cardiovascular flow simulations.

DT platforms + healthcare-oriented tools

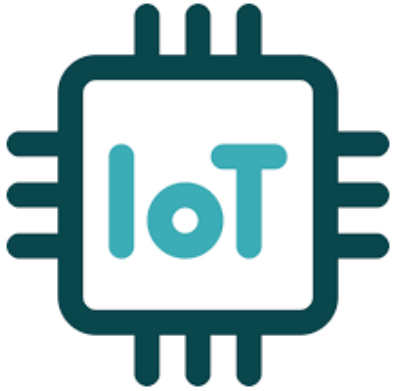
4. AI/ML Integration

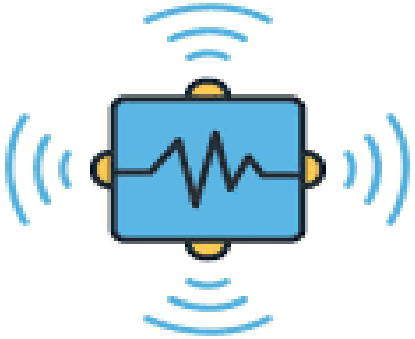
Azure Machine Learning / Google Vertex AI	Training and deploying ML models for PCG classification.
TensorFlow / PyTorch	Custom DT intelligence (e.g., your Random Forest*** + Transformer PCG models).
MLflow	Tracking DT experiments and results.

DT platforms + healthcare-oriented tools

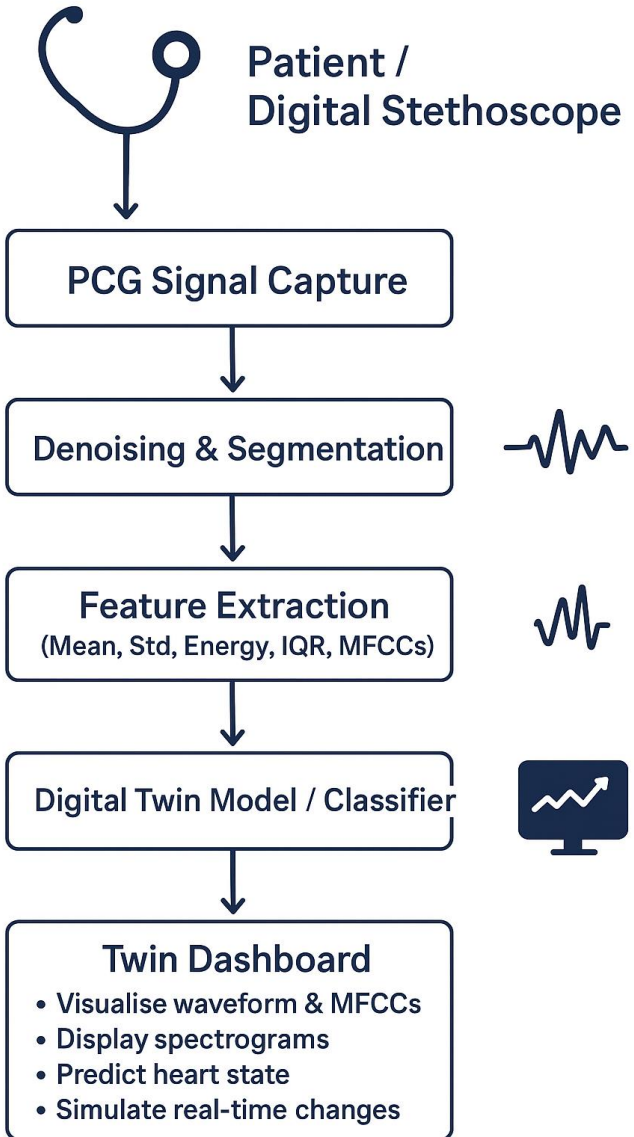
5. IoT + Real-Time Streaming

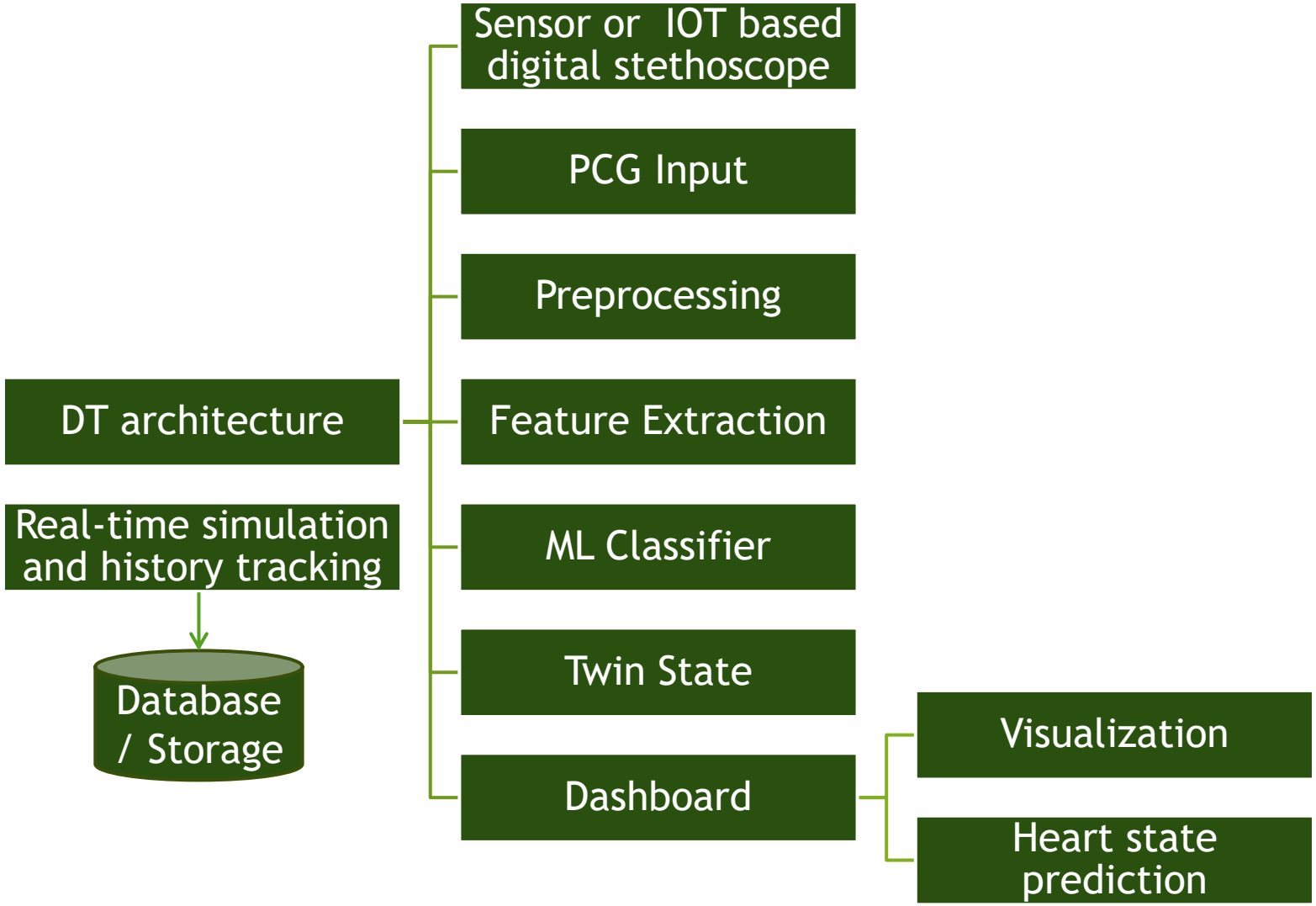
- **Azure IoT Hub / AWS IoT Core**
  - Connects sensors (digital stethoscope, ECG).
- **Node-RED**
  - Easy-to-teach visual tool for IoT + DT integration.
- **Kafka / MQTT brokers**
  - For streaming biomedical signals into a DT.
- IOT based sensor/chip





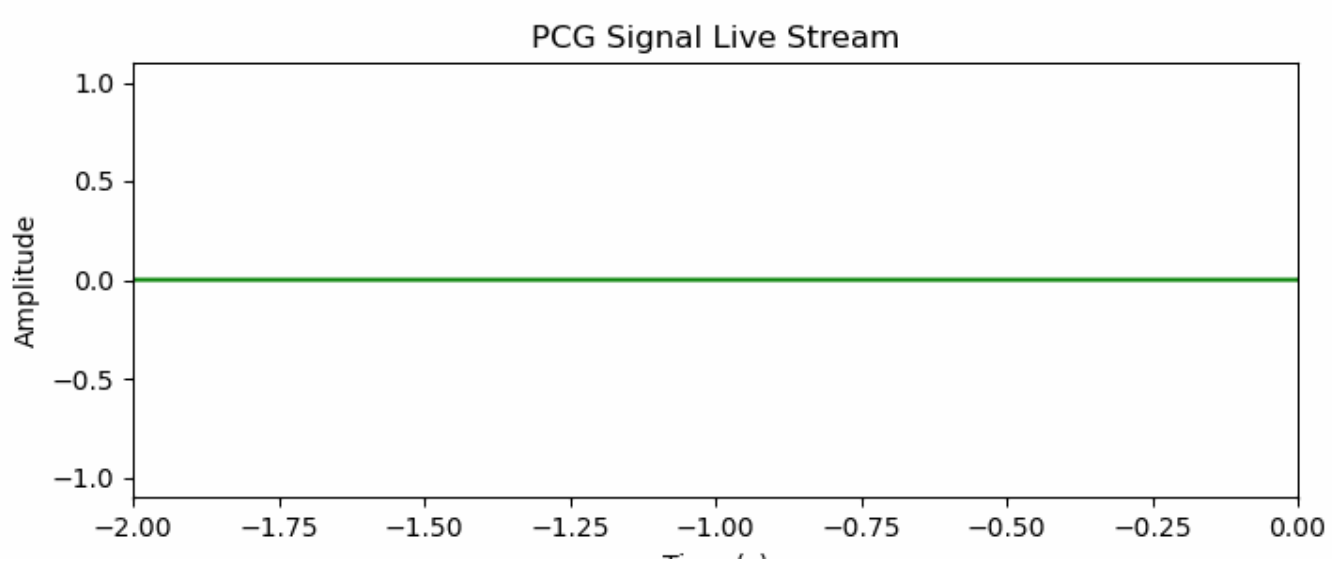
Real Time Digital Twin of heart Architecture





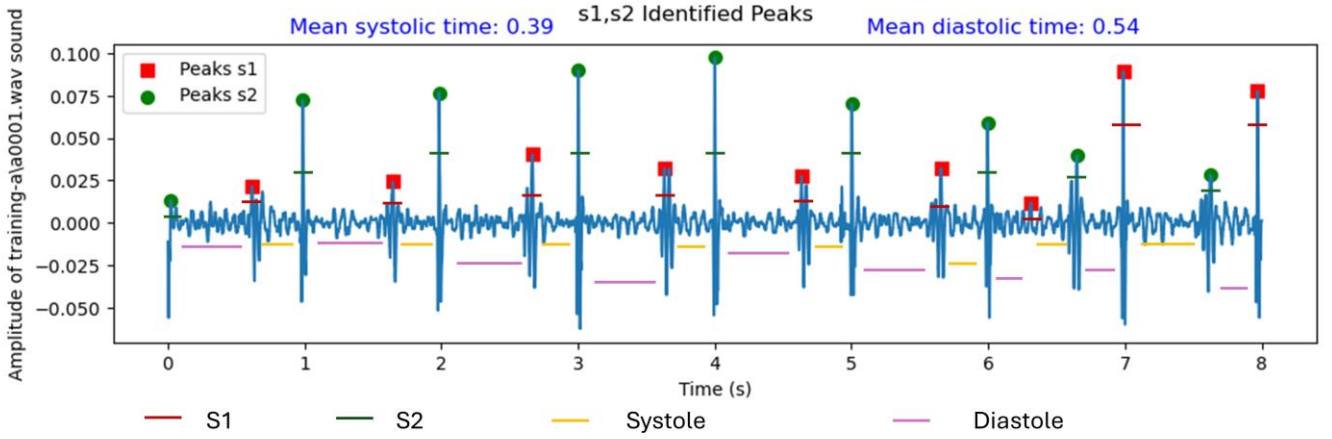
Data acquisition: Digital stethoscope / PCG dataset

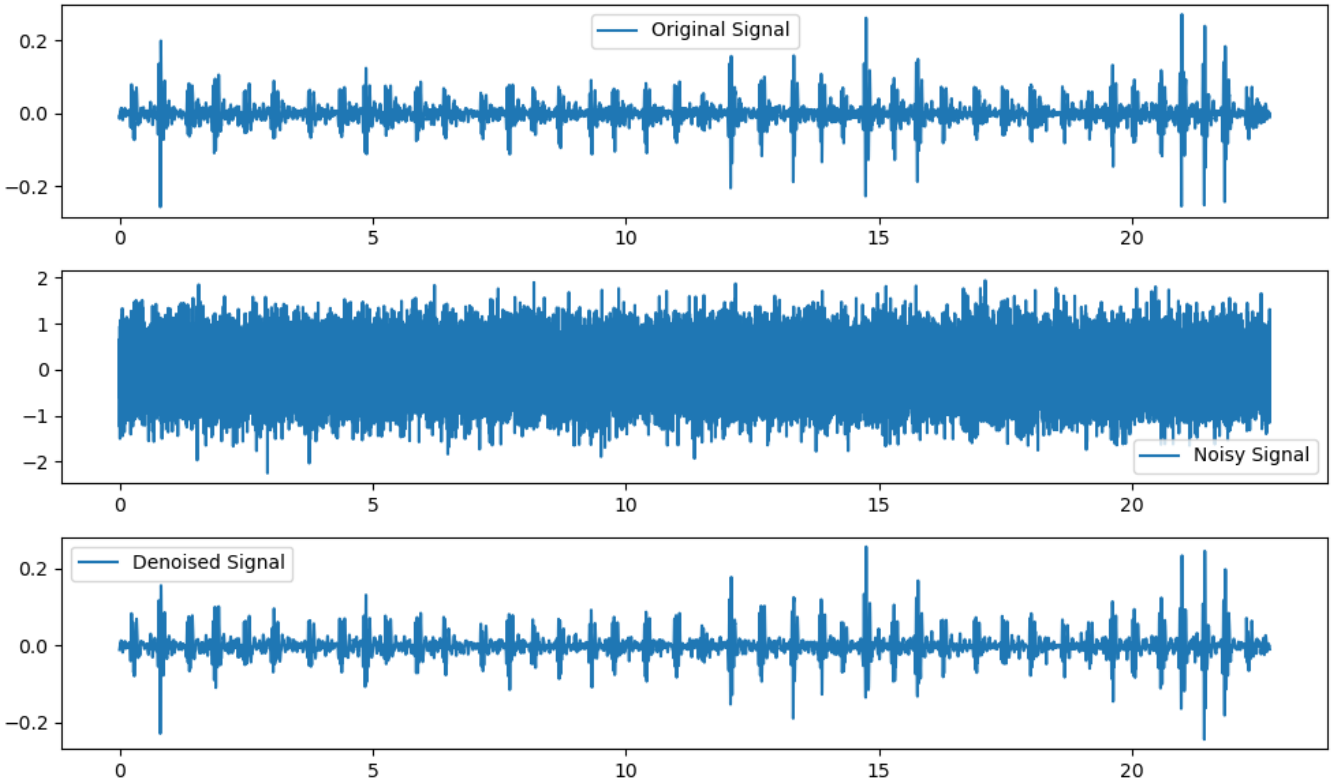
- Sampling rate: 2000 Hz
- Types:
  - Normal
  - Anormal/ murmured (AS, MS, MR, MVP)



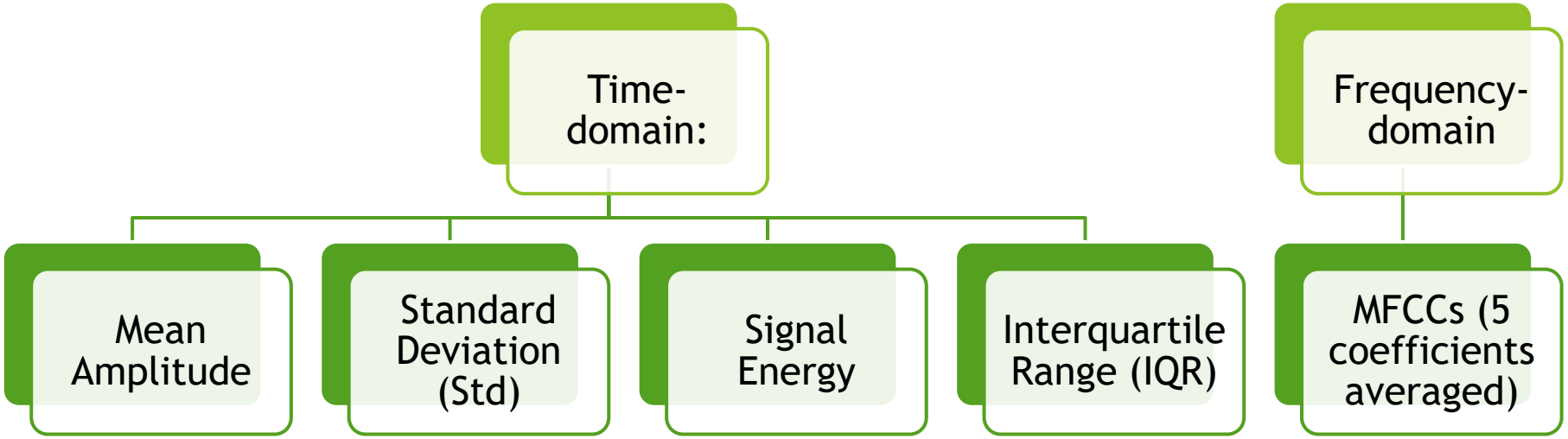
Preprocessing

- Noise removal: Bandpass filter, wavelet denoising
- Segmentation: detect S1/S2, heart cycles
- Visual: waveform before & after denoising



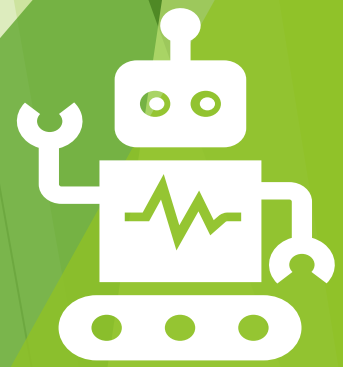


Feature Extraction

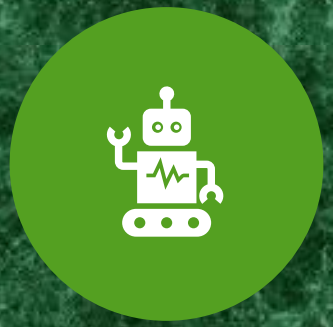


AI Classifier model

- Algorithm: **Random Forest** / TST / ML model
- Input: extracted features
- Output: Normal / Murmur / Murmur type
- Metrics: Accuracy, Precision, Recall, F1-score
- Visual: Confusion matrix or feature → classifier → output flow



Dashboard / Visualization



INTERACTIVE SLIDER FOR NOISE SIMULATION.

TOGGLE BETWEEN NORMAL AND MURMUR SIGNALS.

DISPLAY WAVEFORM, FFT AND PREDICTION.

HEART SOUND AUDIO PLAY

Conclusion

Digital twin enables real-time heart monitoring.

Helps early diagnosis of murmurs.

Combines visualization, feature extraction, and classification.

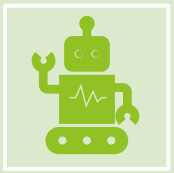
Future Work

Integrate ECG + PCG for multimodal digital twin

Combining **electrical (ECG)** and **acoustic (PCG)** signals gives a richer physiological representation.

It can improve the **accuracy of anomaly detection**, e.g., better differentiation of valve diseases or arrhythmias.

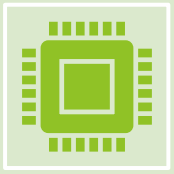
This is a natural progression from a single-signal digital twin.



Mobile / IoT deployment for continuous monitoring

Moving from offline dataset-based analysis to **real-time monitoring** makes the digital twin clinically useful.

Wearables and mobile devices can stream data to the twin for **personalized, continuous heart monitoring**.

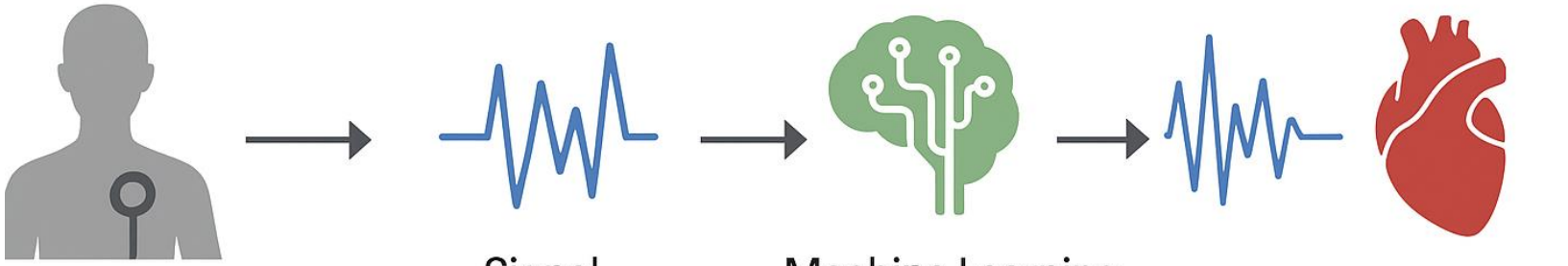


Sensor integration

Incorporating multiple sensors (ECG patches, digital stethoscopes, SpO_2, accelerometers) can create a **comprehensive digital twin**.

This allows the twin to simulate not only heart sounds but also broader physiological responses under different conditions.

Digital Twin of heart



Patient Interface

Attach digital IOT-based stethoscope

Signal Processing

Preprocessing
Denoising

Machine Learning /AI Layer

Feature extraction
ML/DL model predicts class

Digital Twin Layer

Visualization of PCG waveforms
3D beating heart synced with PCG

Results send to clinician / app dashboard

Digital Twin Layer

Feedback Loop

Data stored for continuous monitoring


GHULAM ISHAQ KHAN INSTITUTE OF ENGINEERING SCIENCES AND TECHNOLOGY
PAKISTAN


Thank you!


CATCH VR
Erasmus+
DIGITAL TWIN