EZ Rhythm: ECG Diagnosis Framework Using Novel Patient-Specific Morphology Comparison to Screen Disadvantaged Populations

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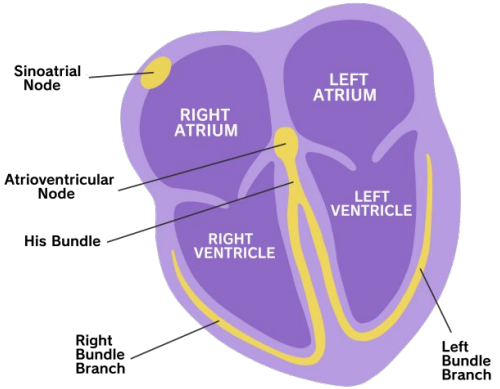
BACKGROUND

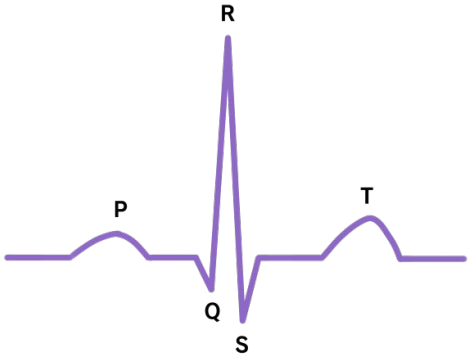
What is an Arrhythmia?

- Arrhythmias are rhythm disorders in the heartbeat, caused by the malfunctioning of the heart's electrical system. They vary in regularity, severity, and frequency.
- In a normal rhythm the heart’s electrical signal comes from the sinoatrial node, known as a sinus rhythm



Why an ECG?

- When the electrical system malfunctions, and the electrical beat originates from another module of the heart, which can be detected by an Electrocardiogram, a device that records the electrical activity of the heart.



Why is detecting arrhythmia Important?

- Prognosis for arrhythmia can be very grave: prolonged, undetected arrhythmia can lead to death or stroke.

INTRODUCTION

Rationale

- Cardiac care is extremely limited in disadvantaged regions
  - 5 of 34 countries in the SSA lacks **a single cardiologis**t for any sort of cardiac care (Bonny et. al).
  - More than hundreds of millions of people are being left without access to cardiac services.
- Arrhythmia in Africa is projected to be more than China, US or India, and Deaths are projected to triple.
- The current standards for Cardiac Care are **expensive** and extremely reliant of **local infrastructure,** and thus are extremely limited in their application to this issue.
  - Existing Technology like the King of Hearts monitor and the twelve lead ECG rely on **expensive devices** and **manual cardiologist review**

Engineering Goal: Bring vital Arrhythmia detection to disadvantaged populations with a system of continuous ECG capture, cloud based Computerized screening, and Telemedicine.

Criteria

- Inexpensive and mobile ECG capture
- Accurate and Efficient screening of ECGs
- Cloud Capabilities
- Easy to use system for deploying in low education countries.

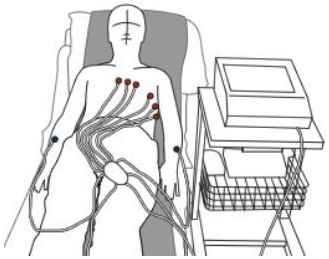
EXISTING TECHNOLOGY

12 Lead Electrocardiogram

- High fidelity ECG data collection
- Five to Ten minute monitoring period.
- done in hospitals

Cons:

- Large Machine unportable machine, generally only applied in hospital
- Difficult to use, Cardiac Tech needed for use
- Expert **manual review** of data necessary
- Diagnosis from machine itself generally **ignored** by practitioners.

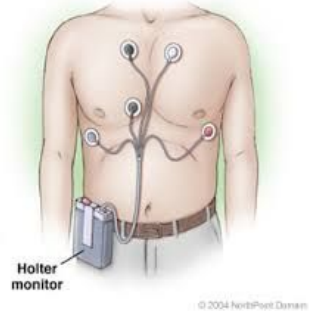


Holter Monitor/ King of Hearts monitor

- Portable ECG Monitoring
- King of Hearts:
  - Symptomatic Event Monitor (Patient Activated)
- Holter Monitor (Extended ECG monitoring 24 hours - 14 days)

Cons:

- Both are recording based systems, requiring an expert to **manually review** all of the ECG data collected
- Both systems store data on the device, requiring **device return** for data collection (as compared to wireless data uploading)
- Transcriber/ Transcription software often required



Zio Patch XT model and AT model

- Mobile cardiac telemetry monitor
- Single Lead
- At clinic or at home application

Cons:

- **Expensive:** 500 to 1000 dollars (based on model) for a monitoring session.
- Model AT: requires **constant internet connection** for Data Upload

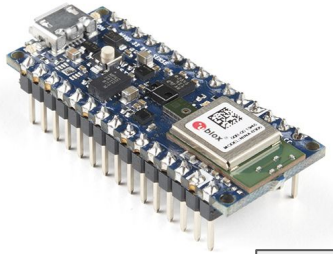
METHODOLOGY

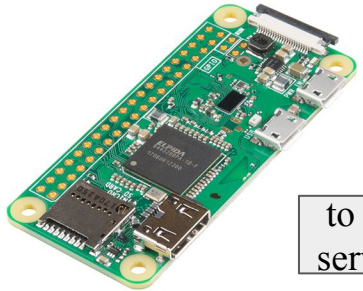
Mobile Electrocardiogram Device:

- DFRobot ECG Board: low cost three lead ECG board
    - Sends ECG data as analog Data to the Arduino
- Arduino BLE 33: Microcontroller; Converts analog data to digital and sends to Raspberry Pi
- Raspberry Pi Zero W: Stores ECG file onboard, uploads to web server when called.

DFRobot ECG Board and Leads

Arduino BLE 33





to framework on web server

Raspberry Pi Zero W

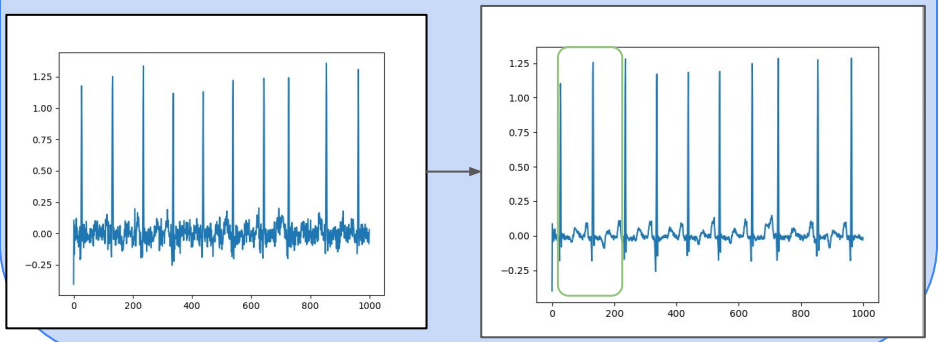
METHODOLOGY - Framework: Signal Processing

ECG Recording → ECG Denoising → Denoised ECG → R Peak Detection ECG segmentation → ECG Beats

From Device

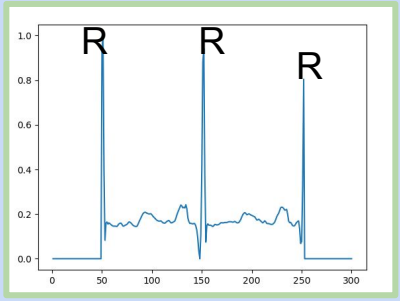
ECG line is denoised using a range of denoising techniques to remove prominent noise artifacts.

- Wavelet Denoising
- Baseline Wandering Removal: High pass filter
- Power Line Interference Remove: Notch Filter
- EMG noise suppression: n-point moving average filter.



Full ECG line is segmented into beats for the machine learning to classify.

- A maximum overlap wavelet transform is applied to the ECG to accentuate the QRS interval, then a peak detection algorithm is applied to find R peaks.
- Beats are then extracted by R-R-R (three successive R peaks) intervals, padded and normalized.



METHODOLOGY: Novel Patient-Specific Morphology Comparison

ECG Beats

Preliminary Sinus Rhythm Detector

Sinus Labels

Sinus Median Extractor

Median Sinus Rhythm

Convolutional Neural Network:

- Trained using three major ECG databases, the CNN detects if the given ECG beat is a sinus rhythm or not.

Pools all labelled Sinus Rhythms from Patient, and find “Median Sinus Rhythm”

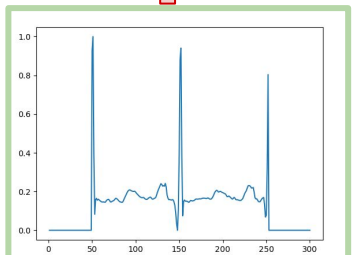
Sinus Detector CNN

Label

Sinus Rhythm

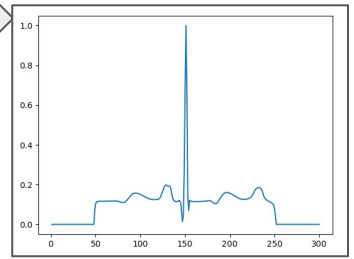
or

Non Sinus Rhythm (arrhythmia)



Pool of Patient’s Sinus Rhythms

Patient Specific Median Sinus Rhythm



METHODOLOGY: Novel Patient-Specific Morphology Comparison cont.

ECG Beats

Median Sinus Rhythm

Sinus Comparison

ECG Beats, MSE

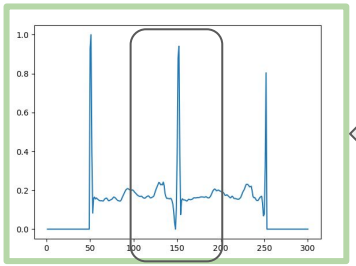
Final Classification

Labels

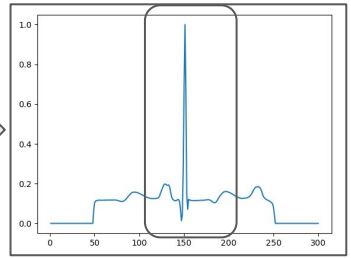
Display

Mean Squared Error:
For each ECG beat, calculate difference (MSE) of the P-T interval of the beat and the and the P-T interval of the median Sinus rhythm.

Convolutional Neural Network:
- Trained using ECG beats and an MSE value as an input. Classifies an ECG line into six labels (listed below)



MSE



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CNN with Feature Input

Labels

Sinus
Bundle Block
Atria
Nodal
Ventricles
Unknown

Novel Patient-Specific Morphology Comparison Details

Current standard (Literature) for Arrhythmia detection:

- Beatwise classification, viewing each ECG beat as an independent case.

However:

- Inter-patient sinus rhythm have variation.
- Intra-patient sinus rhythms are mostly consistent.
- Intra-patient deviation from the regular pattern likely represents a true arrhythmia.
  - Inter-patient variation may be **misinterpreted** as **arrhythmia**.

Patient-Specific Morphology Comparison:

- Views ECG beat's intra-patient context.
- Each patient's normal rhythm is pooled and averaged to create a **patient-specific regular sinus rhythm**.
- Before model training, Mean Squared Error is calculated between each ECG beat and the regular sinus rhythm.
- The final classification model trains on both the ECG morphology and the MSE to make predictions.

This gives the model "context" for each ECG beat.

EZ Rhythm Classification Model Labels:

- Sinus / Paced
- Bundle Block
- Atria
- Nodel
- Ventricles
- Unknown

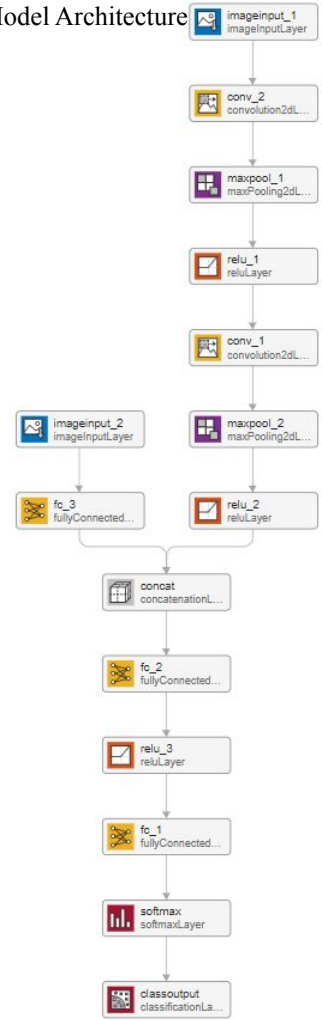
This model labels ECG beats into **6** arrhythmia subcategories, each of which have similar pathophysiology, treatments and prognosis.

Current literature uses the AAMI classes:

MIT-BIH heartbeats
Normal beats
Left bundle branch block beats Right bundle branch block beats Nodal (junctional) escape beats Atrial escape beats

AAMI class for "N" -- Potential Arrhythmia risks (boxed) grouped with normal beats.

Model Architecture



RESULTS - Novel Patient Specific Morphology Comparison (NPSMC)

Using the same model architecture, data, and training configuration, a comparison of two CNN's — one with NPSMC and one without — was made to test the efficacy of NPSMC.

Confusion Matrix - No NPMSC

		Target Class: Arrythmia	Target Class: Sinus
Output Class	Arrythmia	7537	691
	Sinus	2785	56119
Sensitivity	0.7302	Accuracy	93.80%
Specificity	0.9878		

Confusion Matrix - Using NPSMC

		Target Class: Arrythmia	Target Class: Sinus
Output Class	Arrythmia	8384	394
	Sinus	797	56119
Sensitivity	0.9132	Accuracy	97.7%
Specificity	0.9930		

Note: Output Class is the predicted Class, Target Class is the True Class; This confusion matrix is created by consolidating all Arrhythmia classes to create a general detected Arrhythmia. Full Confusion Matrices are shown belows.

Despite the same **low prevalence** of Arrhythmia, the NPSMC model has a **significantly higher Sensitivity**, **Specificity**, and **Accuracy**.

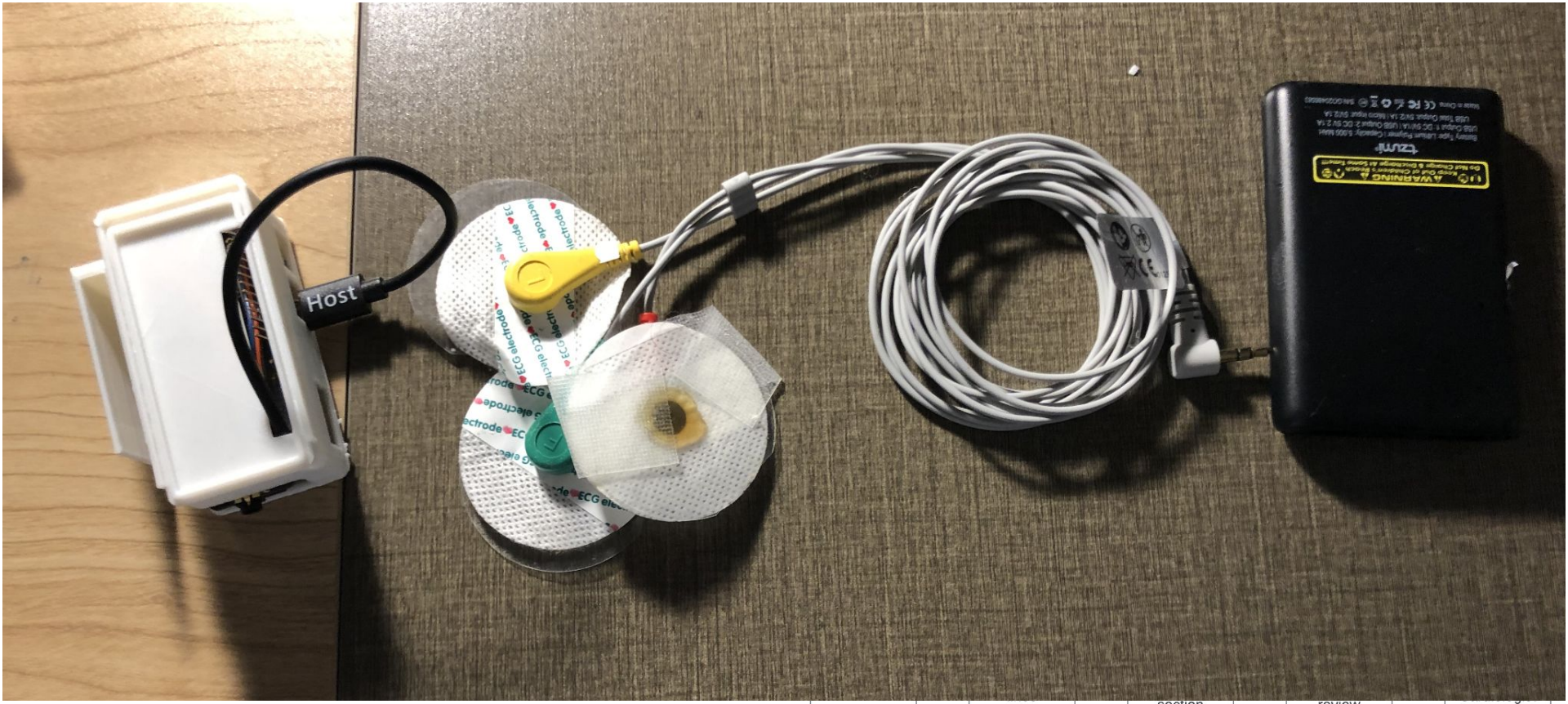
No NPMSC Confusion Matrix - 6 classes of Arrhythmia

Output Class \ Target Class	A	B	N	Q	V	S
A	240	2	10	0	15	22
B	1	1370	5	0	3	62
N	86	2	845	4	303	281
Q	0	0	0	0	0	0
V	63	4	204	5	4375	326
S	237	796	811	13	928	56119

Confusion Matrix Using NPSMC - 6 arrhythmia subclasses

Output Class \ Target Class	A	B	N	Q	V	S
A	322	0	1	0	8	17
B	2	2060	2	0	2	4
N	19	3	1431	2	152	318
Q	0	0	0	0	0	0
V	17	12	40	4	4307	55
S	139	79	308	7	264	54500

RESULTS - ECG device



section

review

review

DISCUSSION

- EZ Rhythm ECG Device:
  - Low production costs ($8.86 USB without battery, $13.61 with battery)
    - Provides affordable and accessible means for ECG data recording.
    - Production is **fraction** of the cost of industry equivalents (300 - 500$)
  - Internet Capabilities, **Data uploaded in One Click**
    - Ease of Use to be deployed in disadvantaged populations; Less experts needed to use the device
  - Continuous Monitor Capable of recording for extended periods, allowing for a **higher diagnostic yield** when diagnosing paroxysmal arrhythmias.
- Web Server:
  - Cloud Processing and Telemedicine lifts burden on local infrastructure.
  - Cardiologists do not have to **manually review** 24+ hours of ECG data, and have the liberty to view an appended summary.

The Final Diagnostics Model:

- sensitivity and specificity (91% and 99%) reached **cardiologist level** sensitivity and specificity.
  - High specificity addresses general ECG issue of False Positives. Higher sensitivity (91 % vs 73 % can better detect undiagnosed patients.
- Application of Novel Patient Specific Morphology Comparison (NPSMC) **significantly increased** per class **accuracy** of the model, demonstrating the effectiveness of patient specific comparison machine learning.
- This technique can transform the detection of not just ECG based disease but also other time series biosignals like EGGs to significant improve sensitivity and specificity given **disproportionate** data

EZ Rhythm System:

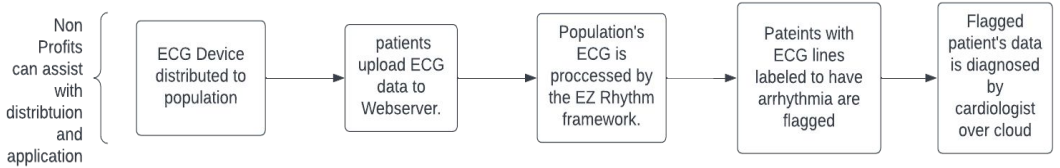
- First low-cost pipeline for Arrhythmia screening, diagnosis and Cardiologist review.
- EZ Rhythm is ***vital*** to counteracting the rise of Arrhythmia in developing countries.

Conclusion

- <u>The EZ Rhythm Framework has the capability for mass screening in an disadvantaged population.</u>
  - Affordable and Accessible ECG deployment
  - Accurate Detection of Arrhythmia
  - Simple System relies minimally on local infrastructure
- No one should have to die from such a preventable disease — EZ Rhythm is here to prevent that.

<u>Next Steps:</u>

1. **Clinical Validation** of ECG device
2. **Expansion** of ECG system to include more complex diagnosis.
3. **Compartmentalization** of Diagnosis models:
   a. Optimizing of diagnosis models to sensitivity and specificity rather than accuracy.



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TMED 063

Cardiac Care is extremely limited in developing regions.
EZ Rhythm Aims to …

Bring vital Arrhythmia detection to disadvantaged populations with a system of continuous ECG capture, cloud based Computerized screening, and Telemedicine.

EZ Rhythm has three key components …

- portable continuous ECG capture device with wireless data transfer.
- Novel timed series technique: Patient Specific Morphology Comparison, allows the final model to reach cardiologist level sensitivity and specificity.
- Web server: creates a filtered summary to avoid lengthy cardiologist manual review.

EZ Rhythm is …

- The first low-cost framework for electrocardiogram capturing, processing, and monitoring.
- The first diagnostic model to utilize intrapatient context for more robust models during population screening.
- EZ Rhythm allows for cardiologists to assist in international Arrhythmia aid efforts through telemedicine.

The EZ Rhythm Framework has the capability for mass screening in an disadvantaged population.

- Affordable and Accessible ECG deployment
- Accurate Detection of Arrhythmia
- Simple System relies minimally on local infrastructure
- EZ Rhythm is vital to counteracting the rise of Arrhythmia in developing countries.