WELDON SCHOOL OF BIOMEDICAL ENGINEERING

Development of an Image Processing Algorithm and Smartphone Application to Analyze Paper ECG Scans

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PURDUE ENGINEERING

Background

Paper ECG's are still commonly used in hospitals nationwide[1][2]

90% of all medical transmitted medical communication is through **fax**

Traditional methods of ECG analysis **vary in degrees of accuracy** at all clinician training levels.

75% **Cardiologists' median accuracy** for ECG analysis

Paper and digital reprints of ECGs, or electrocardiograms, are faxed, sent as digital images, or pdf documents to cardiac specialists for detailed diagnosis [1] [2]. These methods of transmission are **time-consuming** and have **low image resolution**, leading to **larger diagnostic errors** when compared to the original ECG scan. In cases where the ECG scan received by the clinician is not consistent with the original paper ECG, clinician diagnostic accuracy is often reduced, resulting in poorer patient outcomes.

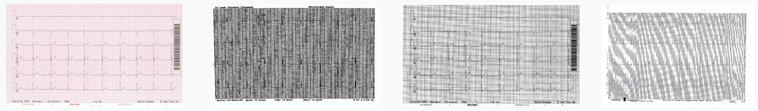

Figure 1: Sample ECG scans with inconsistent grids, darkened grids, and image artifacts

Objective

CARDIAC CAPTURE

There is a need for a solution that:

- **Cleans** and **Filters** a noisy ECG grid
- **Accurately measures** and **quantifies physiological measurements**
- **Easily usable** and **transferable** through an **interactive app**

Figure 2: Overview of proposed design solution

Through our software, Cardiac Capture, we aim to improve the poor image quality of ECG scans and improve their measuring times. We aim to create a user-friendly interface granting clinicians the ability to quickly, accurately, and independently detect ECG physical characteristics from any scanned waveform.

Methods

The final solution design consists of two main components:

1. **Image Processing and Analysis Algorithm**
2. **iOS Smartphone Application**

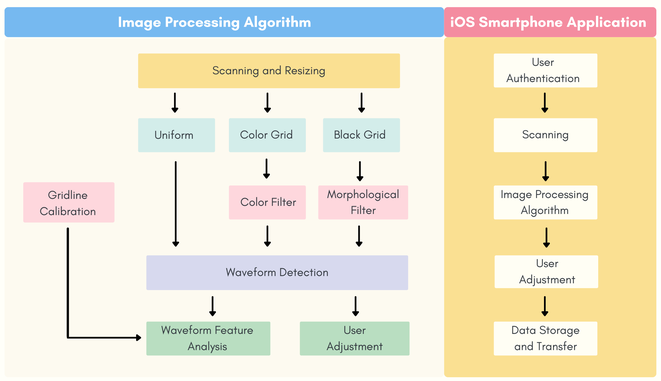

Figure 3: Block Diagram depicting the image processing algorithm and iOS smartphone application workflow

Figure 4: Major and minor subcomponents of proposed Cardiac Capture design solution

- **Scanning and Digitization**
  - Automatic image thresholding - Binarize
  - Automatic image resizing - Remove excess Whitespace
- **Image Cleaning**
  - Removal of image artifacts
  - Waveform Detection for Grid Removal
- **Waveform Adjustment**
  - Calibration
- **Integration**
  - Integration of Image Processing Algorithm and Waveform Analysis
- **iOS Smartphone Application**
  - iOS App development, Secure data storage and transfer
  - User Interface

Results

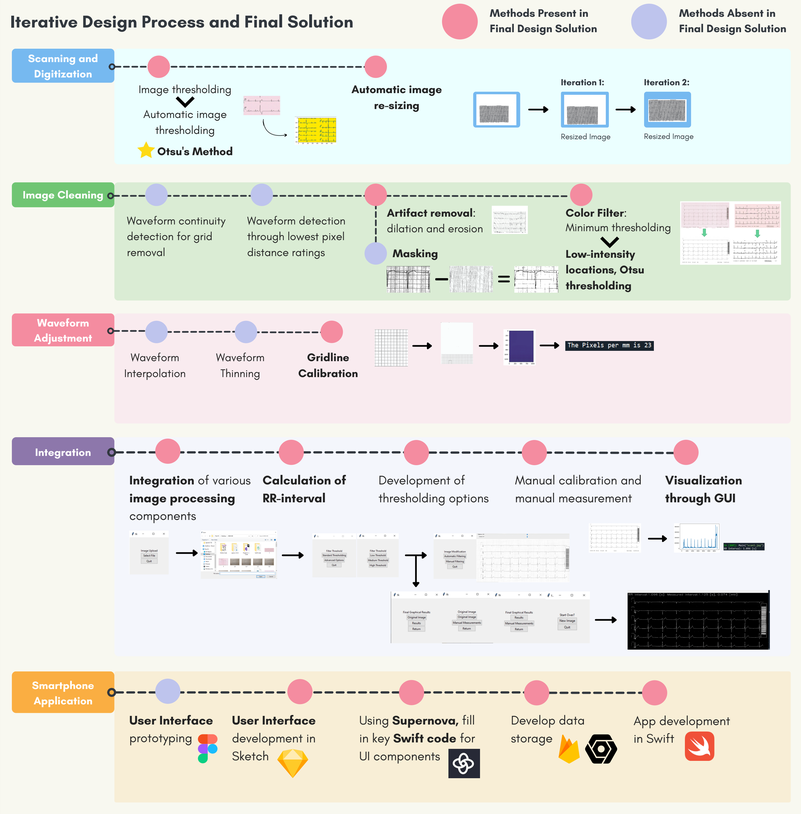

Figure 5: Iterative development of final design subcomponents

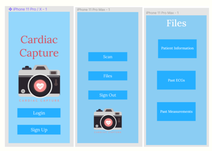

Figure 6: Prototype of iOS smartphone application

Several sample screens have been designed to simulate possible avenues that users may take through navigating the app. Shown in Figure 6, are the home screen, possible actions, and file storage. The user may also scan in an ECG or choose from their photo library.

Figure 7: Statistical verification of algorithmic subcomponents

Method	Verification Techniques	Statistical Method	Results
Image Cleaning	Boundary Recall, Contour Segmentation	Two-tailed t-test, 95% significance	No significant difference between filtering methods and Cardiac Capture (CC) algorithm.
Calibration	Manual Pixel Determination	Two-tailed t-test, 95% significance	Algorithmically calculated pixel values are not significantly different from manually calculated values.
RR-Interval Calculation	Manual RR-Interval Determination, Computer Assisted Measured Data	Applies variation within RR interval to determine whether value falls within standard range	For scans that are able to be adequately cleaned by the CC algorithm, the calculated RR-Interval falls within the acceptable range.

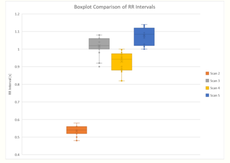

Figure 8: Boxplot of manually measured RR Intervals within each scan

RR Interval Acceptance Criteria				
Image	Scan 2	Scan 3	Scan 4	Scan 5
Manually Measured Data [s]	0.532	1.019	0.929	1.078
Calculated RR Interval [s]	0.522	1.427	0.945	1.096
% Difference	1.88%	40.04%	1.72%	1.67%
Acceptance Range	[0.521, 0.542]	[1.000, 1.037]	[0.906, 0.953]	[1.055, 1.100]

Table 1: RR Interval Integration Verification Results

Table 1 showcases the acceptance ranges of the RR intervals and the actual computer-calculated RR-interval. The data showcases a system capable of producing an accurate RR-interval on all scans except Scan 3, where the background grid was unable to be properly cleaned. The other RR-intervals are successfully predicted. Figure 8 is also used in order to properly validate the use of manual measurement in the determination of the correct RR interval. Figure 8 shows tight grouping of the RR-interval within each graph and also provides an appropriate range in which the calculated RR-interval should be within.

Conclusions

The Cardiac Capture image processing algorithm **successfully cleans** and **measures both color and black/white ECGs** using a combination of morphological filtering, automatic thresholding, and calibration. The smartphone application includes data storage capabilities through Firebase's cloud storage real-time database and a fully operable user interface, accessible through an iOS simulator. Previous methods to clean ECG images have often used a combination of masking methods and morphological filters [3] [4]. The final Cardiac Capture image processing algorithm does not use any masking methods, instead relying heavily on grid calibration and dilation and erosion morphological filters. This adds speed to the Cardiac Capture algorithm, but can limit its abilities when faced with ECG scans with highly irregular grids and low contrast between gridlines and ECG waveforms.

Recommendations

Deep learning image analysis methods · **Integrate image analysis with iOS App** · **App store beta-testing** · **Configure data transfer capabilities**

The application of deep learning neural networks to apply image recognition of the ECG signal should eliminate most background noise and is supported by literature that currently applies deep learning to find slight discrepancies within ECG signals for analysis. The next steps for the Cardiac Capture smartphone application include further security configuration using the Firebase authentication system, the introduction of CC to beta-testing through the Apple App store, and configuration of secure user data transfer. All of these steps will be possible after the CC image processing algorithm is incorporated into the smartphone application through Swift.

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References

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