

Submission ID #: 70359

Scriptwriter Name: Deepthi Das

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Title: Automated 12-Lead Electrocardiograms (ECG) Digitization and WaveForm DataBase (WFDB) Standardization: Insights from Vietnamese Clinical Data

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Author Questionnaire

1. We have marked your project as author-provided footage, meaning you film the video yourself and provide JoVE with the footage to edit. JoVE will not send the videographer. Please confirm that this is correct.

✓ Correct

2. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

3. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes**

If **Yes**, we will need you to record using screen recording software.

We recommend using the screen capture program [OBS](#). JoVE's tutorial for using OBS Studio is provided at this link: <https://review.jove.com/v/5848/screen-capture-instructions-for-authors?status=a7854k>

As these files are necessary for finalizing your script, please upload all screen captured video files to your project page as soon as possible.

4. Proposed filming date: To help JoVE process and publish your video in a timely manner, please indicate the proposed date that your group will film here: **04/25/2026**

When you are ready to submit your video files, please contact our Content Manager, [Utkarsh Khare](#).

Current Protocol Length

Number of Steps: 16

Number of Shots: 47

Introduction

INTRODUCTION:

~~REQUIRED: Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Nho Thai Nguyen:** We present an automated method to convert ECG images into standardized WFDB signals for clinical and research use.

- 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~Describe the research gap or limitation in existing methods and how this protocol addresses them.~~

- 1.2. **Nho Thai Nguyen:** Existing methods struggle with noise and layout variability, and our approach improves robustness and standardization.

- 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

CONCLUSION:

~~What does this protocol allow researchers to study or measure?~~

- 1.3. **Nho Thai Nguyen:** This method enables extraction of calibrated ECG signals for analysis, validation, and machine learning use.

- 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~Describe the most important consideration or challenge when performing this protocol.~~

- 1.4. **Nho Thai Nguyen:** Accurate grid calibration is critical in this protocol, as small errors can significantly affect signal amplitude and timing.

- 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

1.5. **Nho Thai Nguyen:** Future work will improve generalization across datasets and develop automatic failure detection methods.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Ethics Title Card

This research has been approved by the Institutional Review Board (IRB) of Tam Duc Hospital prior to retrospective data collection.

Protocol

2. ECG PDF Conversion and Image Preparation

Demonstrator: Nho Thai Nguyen

2.1. To begin, add all the electrocardiograms or ECGs (**E-C-Geez**) collected from Tam Duc Hospital and provided as grayscale PDF images at a resolution of 300 dots per inch, in a folder labeled 'Data' [1]. Using Python, open the ECG PDF files from the data folder and select the PDF for analysis [2]. Render each page of the PDF at 300 dpi (**D-P-I**) and convert each rendered page to grayscale [3]. Save the processed ECG page as a JPEG (**J-P-E-G**) image using minimal compression to preserve image quality [4]. Store the generated image in the designated output images folder while preserving a filename that matches the original PDF [5]

2.1.1. WIDE: Show the talent seated at a computer, opening a folder labeled *Data*, then zoom in on the screen as they scroll through electrocardiogram files.

2.1.2. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 00:00-00:07

2.1.3. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 00:13-00:20

2.1.4. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 00:28-00:32

2.1.5. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 00:37-00:47

NOTE: Add title card: ECG Image Preprocessing and Quality Inspection

2.2. Apply CLAHE (**Cl**ahe) to the grayscale ECG image to enhance local contrast. Improve the visibility of faint gridlines and waveform features while preserving image details for subsequent analysis [1]. Apply a light Gaussian blur to reduce high-frequency noise while preserving waveform edges [2].

2.2.1. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 00:55-01:03

2.2.2. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 01:03-01:11

2.3. Save the preprocessed image to the designated preprocessed output folder. Confirm that the image has been successfully stored and is available for subsequent feature extraction and analysis [1]. Inspect a subset of preprocessed outputs and confirm that gridlines and traces remain readable [2]. Compare the correctly processed image with an over-smoothed version, and avoid excessive smoothing, as it distorts waveform morphology and reduces analysis accuracy [3].

2.3.1. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 01:18-01:27

2.3.2. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 01:34-01:42

2.3.3. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 01:50-01:53

NOTE: Add Title card: ECG Grid Detection and Scale Calibration

- 2.4. Apply the Hough transform to detect the vertical and horizontal gridlines in the ECG image for subsequent waveform analysis [1]. Calculate the ECG grid spacing and use it to determine the pixel-to-millimeter conversion factor for accurate waveform measurements [2]. Rescale the calibrated image using bicubic interpolation to normalize the image scale while preserving waveform and gridline quality for accurate analysis [3]. Then, save the calibrated image to the designated calibrated output folder and verify that it has been stored successfully for subsequent waveform analysis [4]. Save the calibration parameters as a structured log file to document the calibration process and store it in the calibrated output folder for traceability and future reference [5].

2.4.1. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 02:00-02:05.

2.4.2. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 02:13-02:15

2.4.3. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 02:21-02:24

2.4.4. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 02:30-02:39

2.4.5. SCREEN: 70359_2.1.1-2.4.5_v2.mp4: 02:46-02:45

3. YOLOv12-Based ECG Lead Region Detection and Extraction

- 3.1. Process the calibrated ECG image using YOLOv12 (*Yo-lo-v-12*) with an inference size of 1024 pixels to detect relevant ECG regions for subsequent analysis [1]. Apply non-maximum suppression to remove overlapping detections and retain the highest-confidence bounding box for each ECG lead [2].

3.1.1. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 00:04-00:10

3.1.2. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 00:17-00:21

- 3.2. Export the detected ECG lead bounding boxes as a structured JSON (*J-Son*) file to ensure reproducible storage of the detection results [1]. Show the ECG image with predicted lead-region bounding boxes and labels to verify the detected lead locations.[2].

3.2.1. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 00:27-00:33, 00:37-00:42

3.2.2. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 00:50-00:56

NOTE: Add a title card "ECG Lead Region Cropping and Validation"

- 3.3. Crop each ECG lead region from the calibrated image using the highest-confidence bounding box coordinates for subsequent waveform analysis [1]. Pad each cropped ECG lead image to standardized dimensions to ensure consistent image sizes for subsequent analysis [2]. Save the standardized ECG lead crops to the designated output folder using appropriate filenames for each detected lead [3]. Show the complete set of 12 cropped ECG leads in the standard lead order for verification [4].

3.3.1. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 01:02-01:07

3.3.2. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 01:17-01:22

3.3.3. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 01:28-01:38

3.3.4. SCREEN: 70359_3.1.1-3.3.4_v2.mp4: 01:45-01:50

4. ECG Waveform Segmentation and Binary Mask Generation

- 4.1. Normalize each cropped ECG lead image to an 8-bit intensity range to standardize image values for subsequent waveform processing [1]. Apply thresholding to separate the ECG waveform trace from the background and gridlines, creating a binary mask [2].

4.1.1. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 00:04-00:10

4.1.2. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 00:18-00:25

- 4.2. Apply morphological cleanup to remove residual ECG grid artifacts while preserving the waveform trace [1]. Bridge small gaps in the ECG waveform trace using connectivity-based interpolation to improve waveform continuity [2]. Save the final refined binary mask to the designated output folder for subsequent ECG waveform extraction and analysis [3]. Then, verify the quality of the refined binary mask using representative samples to ensure reliable extraction of ECG waveforms [4].

4.2.1. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 00:30-00:37

4.2.2. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 00:42-00:49

4.2.3. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 00:54-01:05

4.2.4. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 01:12-01:16

NOTE: Add a title card “ECG Waveform Trace Extraction”

- 4.3. Skeletonize the binary mask to generate a centerline representation of the ECG waveform for signal extraction [1]. Remove spurious branches and isolated components from the skeletonized ECG waveform to produce a clean, continuous centerline [2].

4.3.1. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 01:22-01:30

4.3.2. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 01:35-01:47.

- 4.4. Smooth the extracted ECG centerline to generate a continuous left-to-right waveform trace for signal analysis [1]. Interpolate short missing segments along the ECG waveform trace to restore signal continuity [2]. Save the extracted ECG centerline trace to the designated output folder for subsequent signal analysis [3]. Then, save the overlay validation plots to visually verify the accuracy of the extracted ECG waveform trace [4].

4.4.1. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 01:53-01:59

4.4.2. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 02:06-02:12

4.4.3. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 02:19-02:30

4.4.4. SCREEN: 70359_4.1.1-4.4.4_v2.mp4: 02:36-02:42

5. ECG Waveform Calibration and 12-Lead Signal Export

- 5.1. Convert the y-coordinates of the ECG waveform from pixels to voltage values using the established calibration scale [1]. Similarly, convert the x-coordinates into time values

using the same calibration scale [2].

5.1.1. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 00:03-00:08

5.1.2. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 00:13-00:17

- 5.2. Resample the extracted ECG lead signal to 100 hertz to standardize the sampling rate [1]. Save the aligned 12-lead ECG signals as a CSV (C-S-V) file, with each lead organized into its corresponding column [2].

5.2.1. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 00:23-00:28

5.2.2. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 00:33-00:39, 00:50-00:57

NOTE: Add a title card: 12-Lead ECG Conversion to WaveForm DataBase (WFDB) Format and Validation

- 5.3. Convert the 12-lead ECG CSV file into waveform format for standardized signal storage and analysis [1]. Write the WaveForm DataBase header file with the record name, sampling rate, and lead information to define the ECG waveform data.[2]. After that, write the ECG signal file using a consistent 16-bit numeric format for standardized waveform storage [3].

5.3.1. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 01:03-01:09

5.3.2. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 01:14-01:21

5.3.3. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 01:30-01:33

- 5.4. Reload the waveform database record and plot all 12 ECG leads to verify successful signal conversion and storage [1]. Save the validated WaveForm Data header and signal files to the designated output folder for standardized ECG data storage.[2]. Finally, save the validation plots to the designated output folder to document and verify the final ECG waveform results [3].

5.4.1. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 01:40-01:49

5.4.2. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 01:54-02:12

5.4.3. SCREEN: 70359_5.1.1-5.4.3_v2.mp4: 02:21-02:37

Results

6. Results

- 6.1. Enhanced continuity of the extracted ECG trace [1] was illustrated by the trace overlay on the lead image under variable trace thickness [2] and small discontinuities [3].

6.1.1. LAB MEDIA: Figure 9.

6.1.2. LAB MEDIA: Figure 9. *Video editor: Highlight the continuous red line that follows the waveform smoothly across each panel from left to right.*

6.1.3. LAB MEDIA: Figure 9. *Video editor: Zoom into the bottom row, left-side panel (or any other panel where this can be clearly shown) where parts of the original gray waveform look faint or slightly broken, and highlight the red line continuing smoothly across those gaps.*

1. Electrocardiogram

Pronunciation link: <https://www.merriam-webster.com/dictionary/electrocardiogram>

IPA: /ɪˌlek.troʊˈkɑːr.di.əˌgræm/

Phonetic Spelling: ih·lek·troh·KAR·dee·uh·gram

2. Grayscale

Pronunciation link: <https://www.merriam-webster.com/dictionary/grayscale>

IPA: /ˈɡreɪˌskeɪl/

Phonetic Spelling: GRAY·skayl

3. Resolution

Pronunciation link: <https://www.merriam-webster.com/dictionary/resolution>

IPA: /ˌrez.əˈluːʃən/

Phonetic Spelling: rez·uh·LOO·shuhn

4. Compression

Pronunciation link: <https://www.merriam-webster.com/dictionary/compression>

IPA: /kəmˈpreʃ.ən/

Phonetic Spelling: kuhm·PRESH·uhn

5. Preprocessing

Pronunciation link: No confirmed link found

IPA: /ˌpriːˈprɑːses.ɪŋ/

Phonetic Spelling: pree·PRAH·ses·ing

6. CLAHE

Pronunciation link: No confirmed link found

- IPA: /'kleɪ/
Phonetic Spelling: KLAY
7. Gaussian
Pronunciation link: <https://www.merriam-webster.com/dictionary/Gaussian>
IPA: /'gaʊ.si.ən/
Phonetic Spelling: GOW·see·uhn
 8. Morphology
Pronunciation link: <https://www.merriam-webster.com/dictionary/morphology>
IPA: /mɔːr'fɑː.lə.dʒi/
Phonetic Spelling: mor·FOL·uh·jee
 9. Hough transform
Pronunciation link: No confirmed link found
IPA: /hʌf 'træns.fɔːrm/
Phonetic Spelling: HUFF TRANS·form
 10. Calibration
Pronunciation link: <https://www.merriam-webster.com/dictionary/calibration>
IPA: /kæl.ə'breɪ.ʃən/
Phonetic Spelling: kal·uh·BRAY·shuhn
 11. Bicubic interpolation
Pronunciation link: No confirmed link found
IPA: /bəɪ'kjuː.bɪk ɪn'tɜː.pə'leɪ.ʃən/
Phonetic Spelling: bye·KYOO·bɪk ɪn·ter·puh·LAY·shuhn
 12. YOLOv12
Pronunciation link: No confirmed link found
IPA: /'joʊ.loʊ viː twelv/
Phonetic Spelling: YOH·loh vee·twelve
 13. Inference
Pronunciation link: <https://www.merriam-webster.com/dictionary/inference>
IPA: /'ɪn.fə.əns/
Phonetic Spelling: IN·fer·uhns
 14. Non-maximum suppression
Pronunciation link: No confirmed link found
IPA: /,nɑːn 'mæk.sə.məm sə'preʃ.ən/
Phonetic Spelling: non MAK·suh·muhm suh·PRESH·uhn
 15. Bounding box
Pronunciation link: No confirmed link found
IPA: /'baʊn.dɪŋ bɑːks/
Phonetic Spelling: BOWN·ding boks
 16. JSON
Pronunciation link: No confirmed link found
IPA: /'dʒeɪ.sən/
Phonetic Spelling: JAY·suhn
 17. Segmentation
Pronunciation link: <https://www.merriam-webster.com/dictionary/segmentation>

- IPA: /ˌseɪ.mənˈteɪ.ʃən/
Phonetic Spelling: seg·muhn·TAY·shuhn
18. Thresholding
Pronunciation link: No confirmed link found
IPA: /ˈθref.hoʊl.dɪŋ/
Phonetic Spelling: THRESH·hohl·ding
19. Binary mask
Pronunciation link: No confirmed link found
IPA: /ˈbaɪ.nər.i məsk/
Phonetic Spelling: BYE·nuh·ree mask
20. Artifacts
Pronunciation link: <https://www.merriam-webster.com/dictionary/artifact>
IPA: /ˈɑːr.təˌfæktz/
Phonetic Spelling: AR·tuh·fakts
21. Connectivity
Pronunciation link: <https://www.merriam-webster.com/dictionary/connectivity>
IPA: /ˌkɑː.nəkˈtɪv.ə.ti/
Phonetic Spelling: kon·ek·TIV·uh·tee
22. Skeletonize
Pronunciation link: No confirmed link found
IPA: /ˈskel.ə.tən.aɪz/
Phonetic Spelling: SKEL·uh·tuhn·ize
23. Skeletonized
Pronunciation link: No confirmed link found
IPA: /ˈskel.ə.tən.aɪzd/
Phonetic Spelling: SKEL·uh·tuhn·ized
24. Spurious
Pronunciation link: <https://www.merriam-webster.com/dictionary/spurious>
IPA: /ˈspjʊr.i.əs/
Phonetic Spelling: SPYOOR·ee·uhs
25. Centerline
Pronunciation link: No confirmed link found
IPA: /ˈsen.tərˌlaɪn/
Phonetic Spelling: SEN·ter·line
26. Resample
Pronunciation link: No confirmed link found
IPA: /ˌriːˈsæm.pəl/
Phonetic Spelling: ree·SAM·puhl
27. Waveform
Pronunciation link: <https://www.merriam-webster.com/dictionary/waveform>
IPA: /ˈweɪvˌfɔːrm/
Phonetic Spelling: WAYV·form
28. WFDB
Pronunciation link: No confirmed link found

IPA: /ˌdʌb.əl.juː ef diː ˈbiː/

Phonetic Spelling: double·you·eff·dee·BEE

29. Numeric

Pronunciation link: <https://www.merriam-webster.com/dictionary/numeric>

IPA: /nuːˈmer.ɪk/

Phonetic Spelling: noo·MAIR·ik

30. Validation

Pronunciation link: <https://www.merriam-webster.com/dictionary/validation>

IPA: /ˌvæl.əˈdeɪ.ʃən/

Phonetic Spelling: val·uh·DAY·shuhn