US011344246B2

(12) **United States Patent**
Hajimolahoseini et al.

(10) **Patent No.: US 11,344,246 B2**
(45) **Date of Patent: May 31, 2022**

(54) **LONG QT SYNDROME DIAGNOSIS AND CLASSIFICATION**

(71) Applicants: **QUEEN'S UNIVERSITY AT KINGSTON**, Kingston (CA); **KINGSTON HEALTH SCIENCES CENTRE**, Kingston (CA)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,623,910 B2 * 11/2009 Couderc A61B 5/349

[redacted]

(CA); **Damian P. Redfearn**, Kingston (CA); **Javad Hashemi**, Kingston (CA)

(73) Assignees: **Queen's University at Kingston**, Kingston (CA); **Kingston Health Sciences Centre**, Kingston (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 199 days.

(21) Appl. No.: **16/715,017**

(22) Filed: **Dec. 16, 2019**

(65) **Prior Publication Data**

US 2020/0196898 A1 Jun. 25, 2020

Related U.S. Application Data

(60) Provisional application No. 62/782,738, filed on Dec. 20, 2018.

2007/0260151 A1 * 11/2007 Clifford A61B 5/7264
600/509
2008/0015453 A1 * 1/2008 Lux A61B 5/349
600/509
2018/0116593 A1 * 5/2018 An A61N 1/0587
2021/0275080 A1 * 9/2021 Noseworthy A61B 5/339

OTHER PUBLICATIONS

Waddell-Smith, K. et al., "How to measure a QT interval", Medical Journal of Australia, vol. 207 (3), pp. 107-110, (2017).

(Continued)

Primary Examiner — Kennedy Schaetzle
(74) *Attorney, Agent, or Firm* — Stephen J. Scribner

(57) **ABSTRACT**

A method for detecting long QT syndrome in a subject comprises obtaining data corresponding to an electrocardiogram (ECG) signal of the subject, identifying a set of features in the data based on selected inflection points of the ECG signal, using the set of features to categorize segments [redacted]

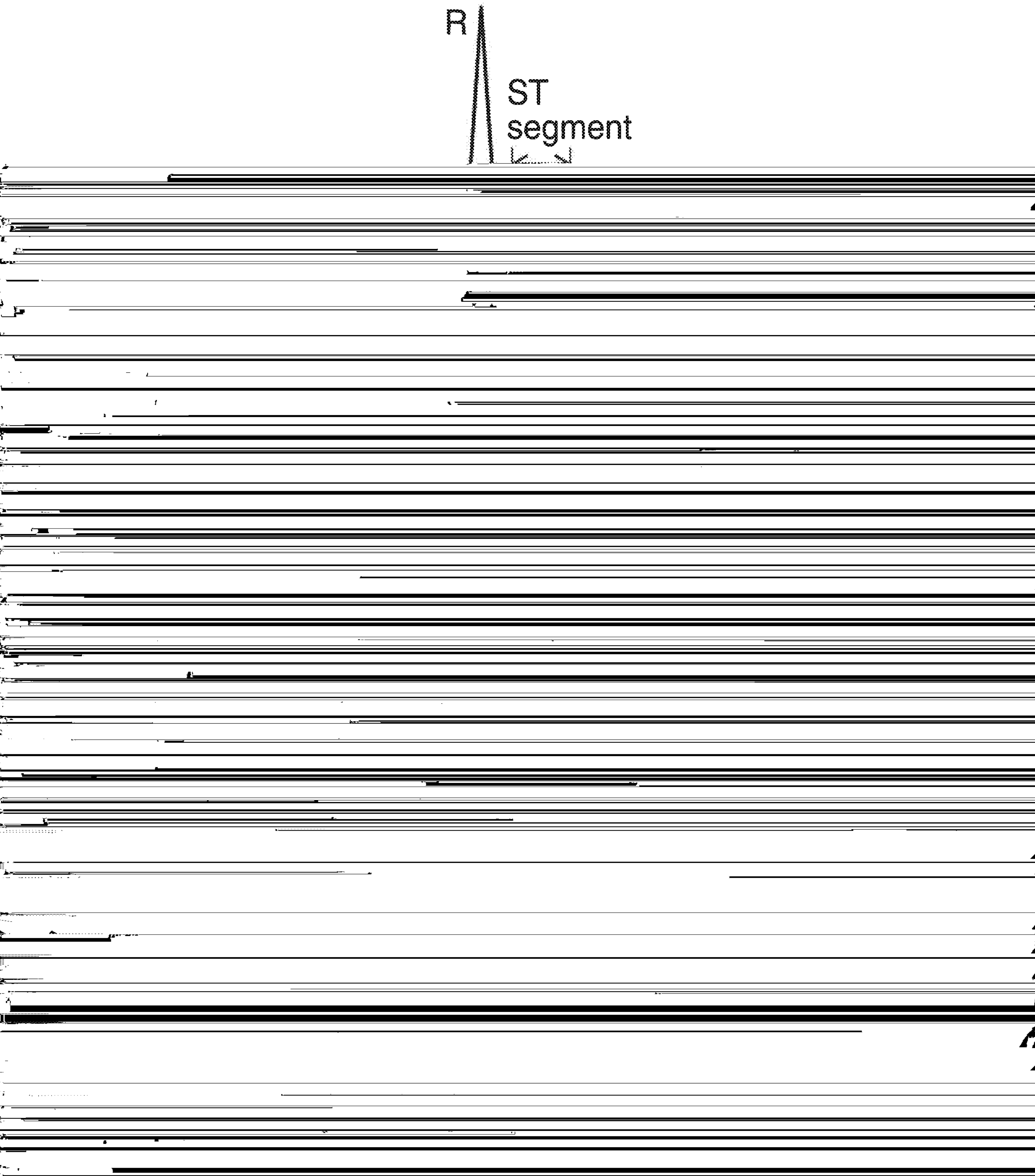
[redacted]

OTHER PUBLICATIONS

Immnanuel, S. et al., "T-wave morphology can distinguish healthy [redacted]

[redacted] classification of ventricular premature and ischemic heartbeats: A comprehensive experimental study" Scientific Reports, vol. 7, No. 1, p. 11239, (2017).

Thorpe, J.R. et al., "Comparative Study of T-amplitude Features for Fitness Monitoring Using the ePatch ® ECG Recorder" Engineer- [redacted]


R
ST segment

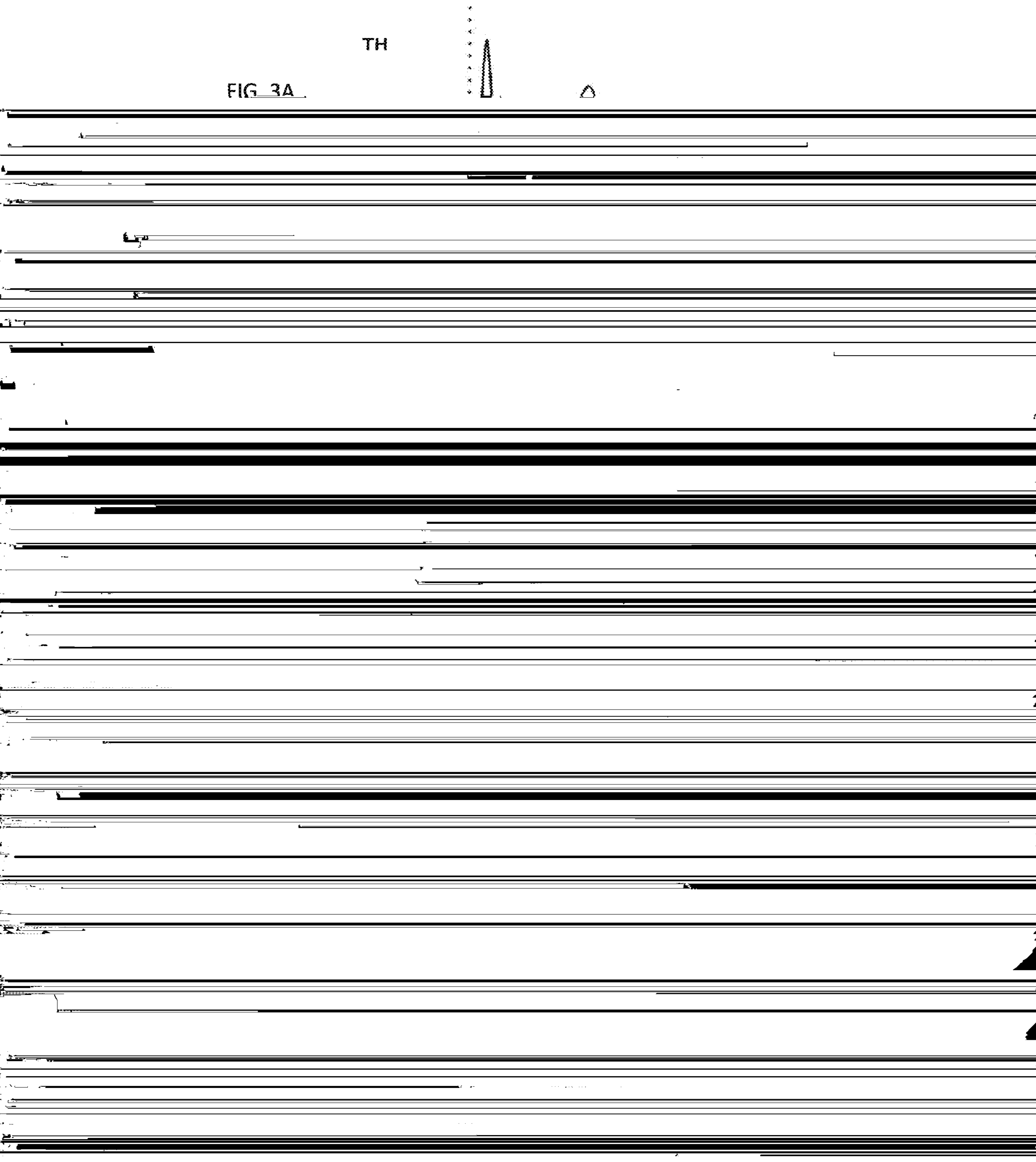
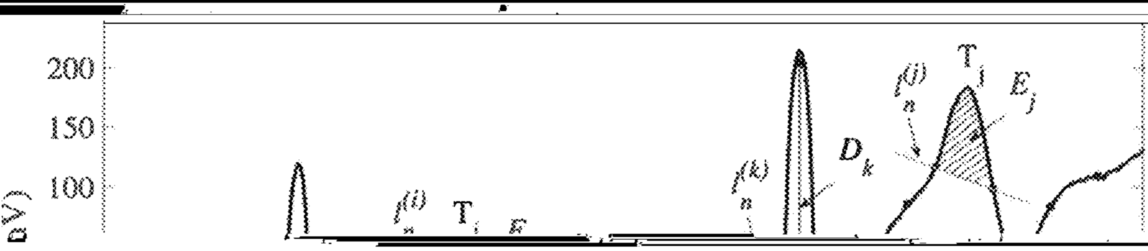
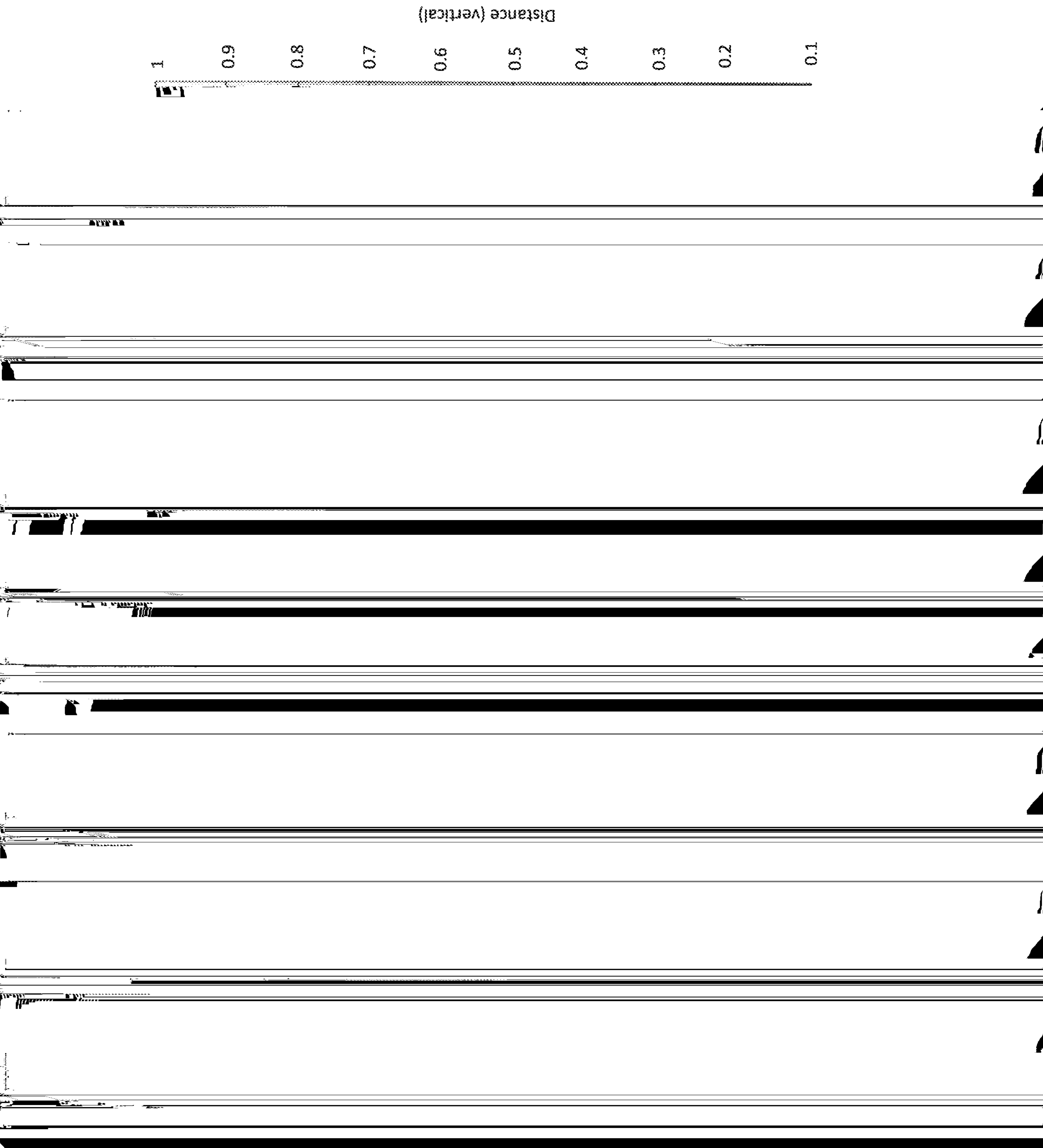
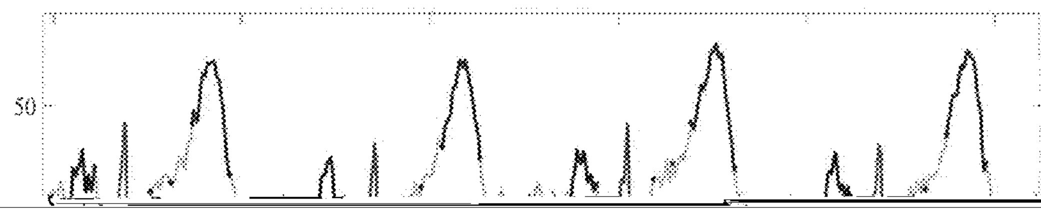


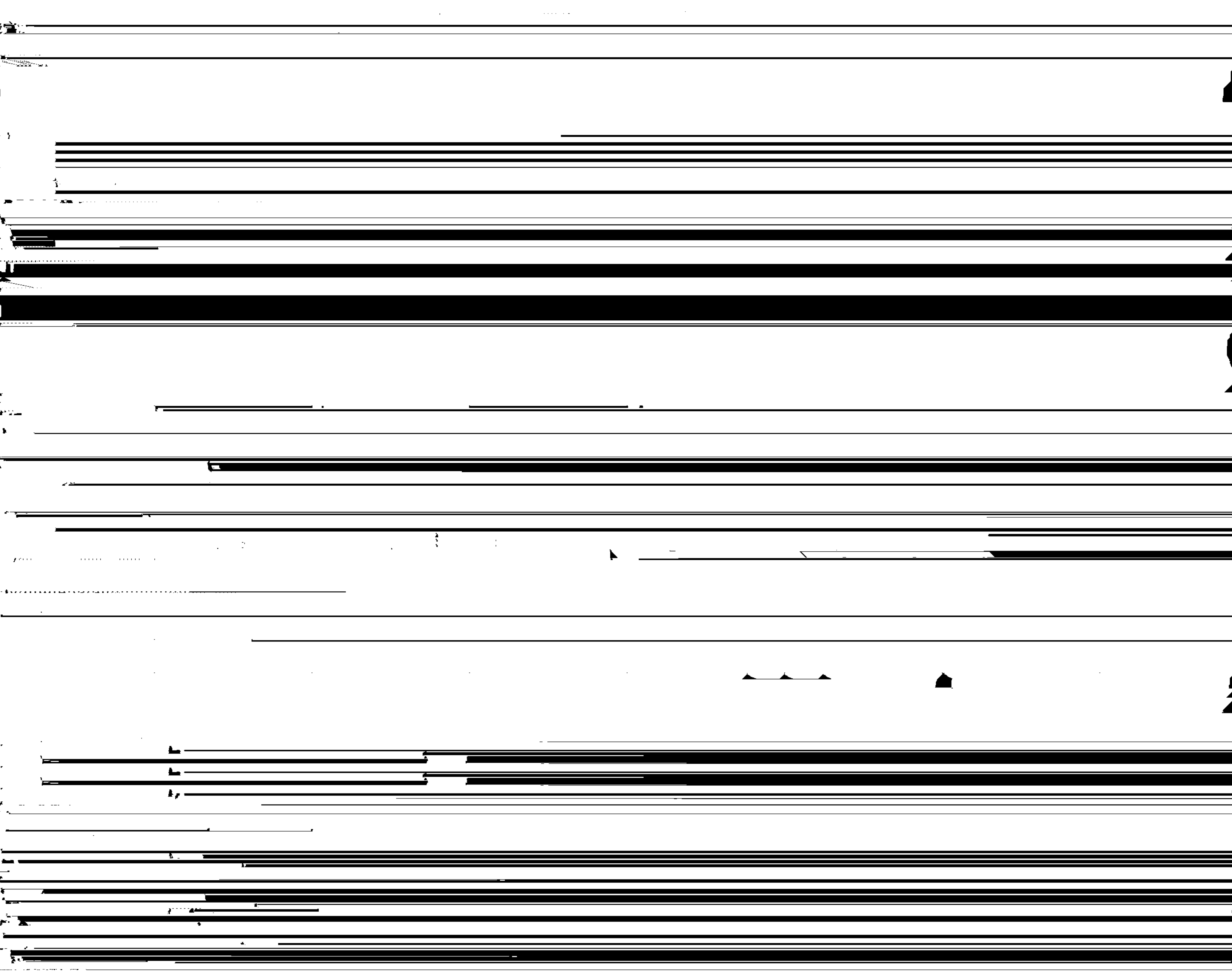
FIG. 3A

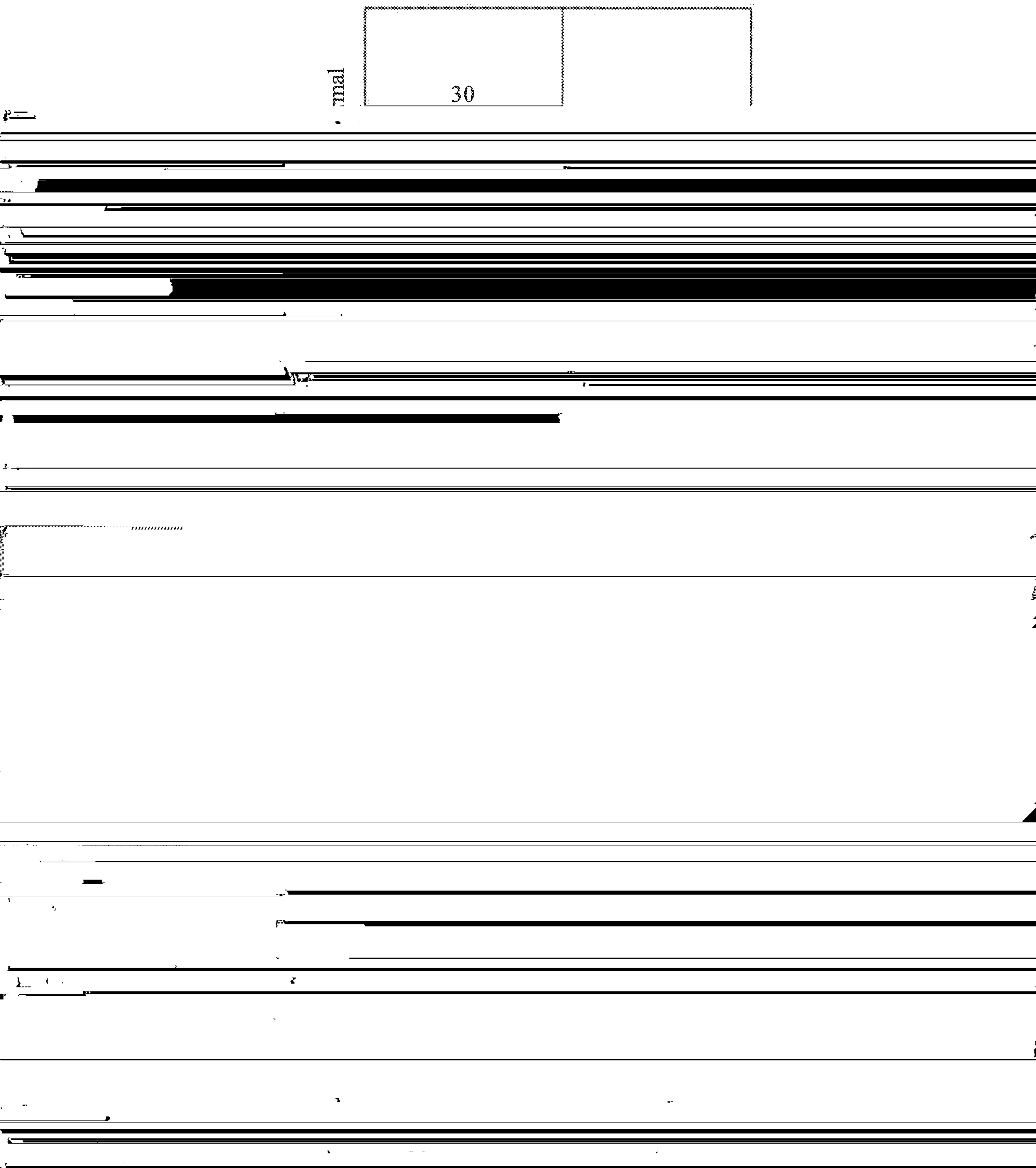

200
150
100
T
D
E


Distance (vertical)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


50


R
Lz_{k+1}




mal
30

LONG QT SYNDROME DIAGNOSIS AND

to noise ratio and low amplitude of the T wave, observation

the cases.

The distribution of QTc for genotype-positive LQTS and genotype-negative normal ECGs in a dataset is depicted in FIG. 2. As seen in this figure, there is a wide range of overlap between QTc in normal and LQTS patients. A similar observation is also reported in [4] for a large dataset of

RELATED APPLICATION

This application claims the benefit of the filing date of Application No. 62/782,738, filed on Dec. 20, 2018, the

The method may comprise classifying the ECG signal as normal or as LQT syndrome based on two or more features selected from QT interval, base of T wave, rate of T wave

distance between two inflection points at boundaries of the T wave, and heart rate.

The method may comprise using logistic regression on the two or more features to determine a linear boundary between normal and LQT classes.

The method may comprise further classifying a LQT syndrome ECG signal as a LQTS1 ECG signal or a LQTS2 ECG signal.

The method may comprise subjecting the LQT syndrome ECG signal to logistic regression based on a set of features related to T wave morphology.

FIG. **7** is a diagram showing inflection points and intervals in an ECG.

FIG. **8** is a diagram showing inflection points extracted

FIG. **9** is a block diagram of a system architecture according to one embodiment.

FIGS. **10**A and **10**B show classification accuracy results for (A) normal/abnormal classifier and (B) LQTS type classifier.

DETAILED DESCRIPTION OF EMBODIMENTS

A variety of approaches have been proposed for automatic QT interval analysis including: threshold-based algorithms [7], [8], hidden Markov models [6], curve fitting [2], wavelet higher resolution and lower computational complexity. Furthermore, the method is robust to noise and baseline wandering.

In addition, prior approaches may locate IPs by finding zero-crossings of the second derivative of ECGs. However,

The second feature used was energy of ECG segments. The energy of an ECG segment may be defined as the sum of squared values of that wave. However, because of baseline wandering, this may not be accurate as low-energy waves positioned at higher baseline values may mistakenly be considered as high energy segments. Furthermore, iso features may be used, and/or other numbers of features may be used to create a multi-dimensional feature space, as noted above.

According to the multi-dimensional feature space, the mth ECG segment between two consecutive IPs is represented

by the following feature vector:

tions on its peak. Although the onset of the T wave is more obvious in this case, locating the end point is still challenging.

To quantify these measures so that they can be employed in an automatic classification technique, a new set of features based on the IPs is set forth herein:

1) QT Interval: The first feature that needs to be measured is the QT interval.

6) Heart Rate: The feature of heart rate may be measured as follow:

$$HR = \frac{60}{RR} \quad (17)$$

where RR represents the time interval between two consecutive peaks of the R wave in seconds.

LQTS Diagnosis and Classification

tant aspect of embodiments. The ability to classify different

commands from a user of the system, etc.), analyzing data, and displaying results and/or images on a display of the system. For example, the processor may receive and/or process data corresponding to an ECG signal of a subject, and/or perform one or more function as described above, and output a result indicating whether long QT syndrome is detected, and optionally whether the long QT syndrome is Type 1 or Type 2.

The computer includes executable programmed instructions for directing the computer to carry out embodiments of

puter prompting the user for input at various steps. Pro-

[2] S. Immanuel, A. Sadrieh, M. Baumert, J.-P. Couderc, W

[redacted]

Zareba, A. P. Hill, and J. I. Vandenberg, "T-wave morphology can distinguish healthy controls from LQTS

[redacted]

2. The method of claim 1, wherein categorizing segments

[redacted]

of the ECG signal includes determining beginning and end points of Q and T waves.

[redacted]

16. Apparatus, comprising a processor and a non-transitory computer-readable medium having instructions stored thereon, wherein the instructions cause the processor to:

[illegible] (ECG) signal of a subject;

identify a set of features in the data based on selecting inflection points of the ECG signal by finding zero-crossings of a second derivative of the ECG signal, wherein the second derivative is determined using a finite impulse response (FIR) filter;

use the set of features to categorize segments of the ECG signal;

use the categorized segments of the ECG signal and the inflection points to classify the ECG signal as normal or as long QT syndrome (LQTS);

output a result indicating whether the subject's ECG signal is classified as normal or as long QT syndrome.

17. The apparatus of claim **16**, wherein the instructions cause the processor to output a result indicating whether the subject's ECG signal is classified as LQTS Type 1 or LQTS Type 2.

* * * * *