Analysis of Electromyography Burst Signals using Topological Feature Extraction for Diagnosis of Preterm Birth

V. Selvaraju, P. Namadurai and R. Swaminathan

NIID Laboratory, Biomedical Engineering, Indian Institute of Technology Madras
vinothinieie14@gmail.com, npunitha92@gmail.com, sramki@iitm.ac.in

Preterm birth (gestation ≤ 37 weeks) is the leading cause of neonatal mortality and morbidity worldwide. Early diagnosis of Preterm is crucial for increasing the survival rate of infants [1]. Surface uterine Electromyography (uEMG) records the electrical activity of uterus during contraction. It quantitatively assesses the intensity, duration and frequency of uterine contractions. These contractions are characterized by a slow cyclic pattern of bursts followed by a period of quiescence [2]. Analysis of these bursts using uEMG signals has high sensitivity in detecting Preterm labor sign [3]. Significant information from these complex signals can be obtained using topological data analysis as it extracts the underlying shape characteristics of the signal [4]. Hence, in this study, an attempt has been made to differentiate Term (gestation > 37 weeks) and Preterm conditions using uEMG signals and topological features.

For this study, 13 Term and 13 Preterm delivery signals from Term-Preterm Electrohysterogram dataset with Tocogram are considered [3]. These signals are recorded using bipolar electrodes at a sampling rate of 20 Hz, with a 16-bit resolution. The signals recorded in the third channel are utilized for the analysis as it has been reported to be free from artifact and effective for distinguishing Term and Preterm conditions [1]. The raw signals are filtered in the range of 0.08 to 5 Hz using a four-pole band-pass digital Butterworth filter. 53 bursts from Term and 47 bursts from Preterm signals are segmented using the annotations provided in the dataset by two clinical experts (refer [3] for more details).

Hilbert transform is applied to the uEMG burst signals to obtain the analytic signals [5]. Real and imaginary coefficients of the analytic signal are plotted against each other to get the complex plane representation. The boundary points of the complex Hilbert coefficients are identified using the standard α-shape method from MATLAB library and the envelope is computed [6]. In this study, an α value of 0.5 is chosen as it encloses all the boundary points. Topological features namely, area, perimeter, circularity and convexity are extracted from the envelope which are mathematically expressed in Equations 1 - 4 respectively. Area is the geometrical property of a region inside a closed curve [7]. Perimeter (P_o) is the boundary length of a closed curve [7]. Circularity represents how the shape of a closed region is similar to a circle. It is the ratio of the area of the shape to the squared perimeter [7]. Convexity is defined as a ratio between the perimeter of convex hull (P_c) to its perimeter (P_o) [8].

$$Area = \frac{1}{2}\sum_{n=1}^{N-1}|X_n Y_{n+1} - X_{n+1} Y_n| \quad (1)$$

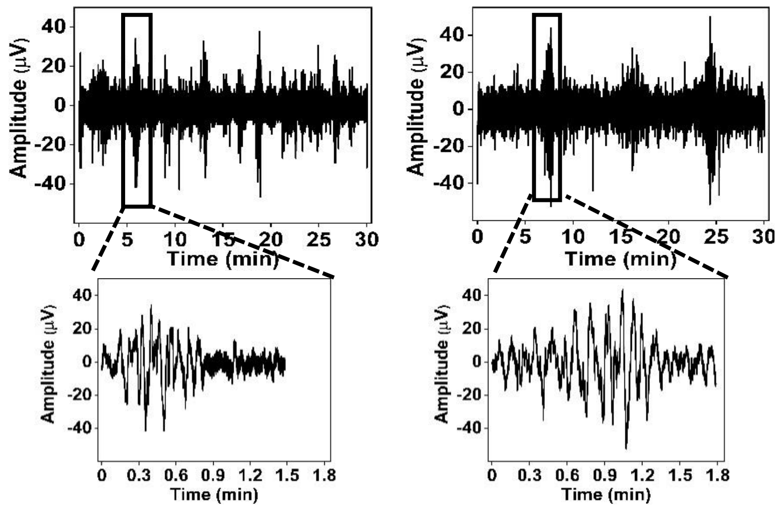
$$Perimeter = \sum_{n=1}^{N-1}\sqrt{(X_{n+1} - X_n)^2 + (Y_{n+1} - Y_n)^2} \quad (2)$$

$$Circularity = 4\pi \frac{Area}{Perimeter^2} \quad (3)$$

$$Convexity = \frac{P_c}{P_o} \quad (4)$$

where, (X_n, Y_n) is a boundary point and N is the total points in the envelope. Anderson-Darling (AD) test is performed to examine the normality of distribution. The Wilcoxon rank-sum test is performed for non-normal distribution, while for normal data, the Student's t-test is utilized to identify the significance between the Term and Preterm groups. Statistical measures namely, mean and standard deviation (SD) are calculated from the topological features. The Coefficient of Variation (CV) is employed to quantify the inter-subject variability of the extracted features.

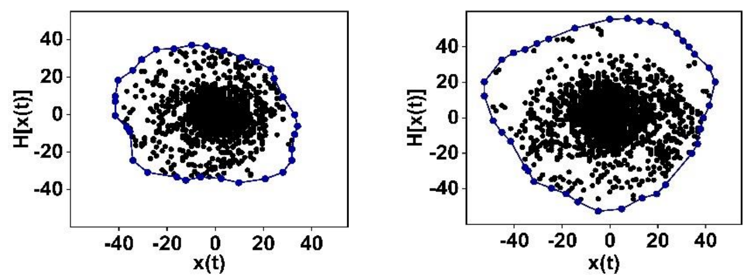
The representative Term and Preterm uEMG signals are presented in Figure 1. The amplitudes of the signals are observed to be subject dependent and visually no specific pattern could be detected. Representative bursts from each of these signals (based on the annotations provided in the dataset) are also highlighted. It is inferred that bursts of higher amplitude and longer duration are found in Preterm when compared to Term condition.



(a) (b)

Figure 1. Representative uEMG signals with highlighted bursts in (a) Term and (b) Preterm conditions

Figure 2 depicts the complex plane representation of analytic signals obtained from burst signals shown in Figure 1. It is observed that Hilbert coefficients are clustered in the complex plane which could be due to the rapid fluctuations in the signals during contractions. The envelopes formed from the data points are highlighted in blue color. It is found that the uEMG bursts exhibit different shapes that vary with subjects.



(a) (b)

Figure 2. Complex plane representation of the burst signals in Figure 1 along with the boundary highlighted in blue color (a) Term and (b) Preterm

The statistical measures calculated from the topological features are given in Table 1. The AD test confirms that all the features are non-normally distributed. Wilcoxon test reveals that features, namely area, perimeter and convexity have significant differences between Term and Preterm groups with $p < 0.05$. The area and perimeter could be related to the variations in the amplitude of uEMG signals. Higher mean values are observed in the Preterm condition which might be due to the rise in the contractions' intensity [2]. The dispersion of the area and perimeter is found to be high, which is evident from the CV values, indicating high inter-subject variations. Circularity feature values in both Term and Preterm are not equal to one indicating that the signal shapes are noncircular. This could be due to the aperiodic nature of uEMG signals.

Table 1. Statistical Measures of Topological Features

Topological Features	Term			Preterm		
	Mean	SD	CV	Mean	SD	CV
Area*	0.12	0.18	1.45	0.33	0.23	0.69
Perimeter*	0.24	0.21	0.88	0.46	0.23	0.49
Circularity	0.88	0.10	0.12	0.84	0.20	0.24
Convexity*	0.88	0.10	0.11	0.95	0.10	0.11

The mean values of convexity show that the shapes obtained from the burst signals are convex in nature reflecting the regularity of uEMG signals. It is perceived that the convexity is increased in the Preterm group indicating more regular signals. This may be due to the increased coordination of uterine cells during contraction [9]. It is observed from CV values that the dispersion of this feature is lower. This suggests that this feature could handle inter-subject variations of uEMG signals and could be used as a biomarker for differentiating the Term and Preterm conditions. It appears that the topological features are able to capture the characteristics of the burst signals during Term and Preterm conditions. Therefore, the proposed approach could be utilized for the early diagnosis of Preterm birth.

ACKNOWLEDGMENTS

This study does not receive any funding from external agencies.

REFERENCES

[1] N. Punitha, P. Vardhini, and S. Ramakrishnan, "Multifractal analysis of uterine electromyography signals for the assessment of progression of pregnancy in term conditions," *IEEE J. Biomed. health inform.*, vol. 23, no. 5, pp.1972-1979, 2018.

[2] C. Rabotti and M. Mischi, "Propagation of electrical activity in uterine muscle during pregnancy: a review," *Acta Physiol.,* vol. 213, no. 2, pp.406-416, 2015.

[3] F. Jager, S. Libenšek, and K. Geršak, "Characterization and automatic classification of preterm and term uterine records," *PloS One*, vol. 13, no. 8, p. e0202125, 2018.

[4] Z. Zhang, Y. Song, H. Cui, J. Wu, F. Schwartz, and H. Qi, "Topological analysis and gaussian decision tree: Effective representation and classification of biosignals of small sample size," *IEEE Trans. Biomed. Eng.,* vol. 64, no. 9, pp. 2288-2299, 2016.

[5] S.M. Kennedy, J.D. Roth, and J.W. Scrofani, "A novel method for topological embedding of time-series data," *Proceedings of European Signal Processing Conference*, 2018, pp. 2350–2354.

[6] H. Edelsbrunner, D. Kirkpatrick, and R. Seidel, "On the shape of a set of points in the plane," *IEEE Trans. Inf. Theory.,* vol. 29, no. 4, pp. 551–559, 1983.

[7] W. Burger and M. J. Burge, *Digital Image Processing: An Algorithmic Introduction Using Java.* London, Springer Science & Business Media, 2008.

[8] Y. Mingqiang, K. Kidiyo, and R. Joseph, "A survey of shape feature extraction techniques," *Pattern recognit.*, vol.15, no. 7, pp. 43–90, 2008.

[9] M. Mischi, C. Chen, T. Ignatenko, H. de Lau, B. Ding, S.G. Oei, and C. Rabotti, "Dedicated entropy measures for early assessment of pregnancy progression from single-channel electrohysterography," *IEEE Trans. Biomed. Eng.,* vol. 65, no. 4, pp.875-884, 2017.

Analysis of Electromyography Burst signals using Topological Feature Extraction for Diagnosis of Preterm Birth

Vinothini Selvaraju*, Punitha Namadurai and Ramakrishnan Swaminathan

Non-Invasive Imaging and Diagnostics Laboratory, Biomedical Engineering, Indian Institute of Technology Madras, India

Email: vinothinieie14@gmail.com, npunitha92@gmail.com, sramki@iitm.ac.in

Introduction

- Preterm birth (Weeks of gestation < 37 weeks) is the leading cause of neonatal mortality and morbidity worldwide
- Early diagnosis of Preterm is crucial for increasing the survival rate of infants
- Uterine Electromyography (uEMG) is a non-invasive method of recording the electrical activity of uterine contraction
- Uterine contractions are characterized by a slow cyclic pattern of bursts followed by a period of quiescence [1]
- Analysis of uEMG bursts signals has high sensitivity in detecting Preterm labor
- Topological data analysis extracts the underlying shape characteristics of the signal and provides the significant information about the complex uEMG signal [2]
- In this study, an attempt has been made to differentiate Term (Weeks of gestation ≥ 37 weeks) and Preterm conditions using uEMG signals and topological features

Methods

Database

- Term-Preterm ElectroHysteroGram dataset with Tocogram of PhysioNet [1]
- 53 and 47 bursts from Term and preterm records respectively
- Sampling rate: 20 Hz
- Frequency range: 0.08 – 5 Hz
- Signals from Channel 3 are used

Envelope Detection

- Hilbert transform is applied to obtain the analytic signals
- Analytic signals are represented in the complex plane
- The boundary points are identified using the α-shape method and envelope is computed

Feature extraction and analysis

- $\text{Area} = \frac{1}{2}\sum_{n=1}^{N-1}|X_n Y_{n+1} - X_{n+1} Y_n|$
- $\text{Perimeter} = \sum_{n=1}^{N-1}\sqrt{(X_{n+1} - X_n)^2 + (Y_{n+1} - Y_n)^2}$
- $\text{Circularity} = 4\pi\frac{\text{Area}}{\text{Perimeter}^2}$
- $\text{Convexity} = \frac{P_c}{P_o}$ [3]
- Anderson Darling test is performed to test the normality
- The Wilcoxon test and Student's t-test is performed for non-normal and normal distribution
- Coefficient of Variation (CV) is computed to study the inter-subject variability

Results & Discussion

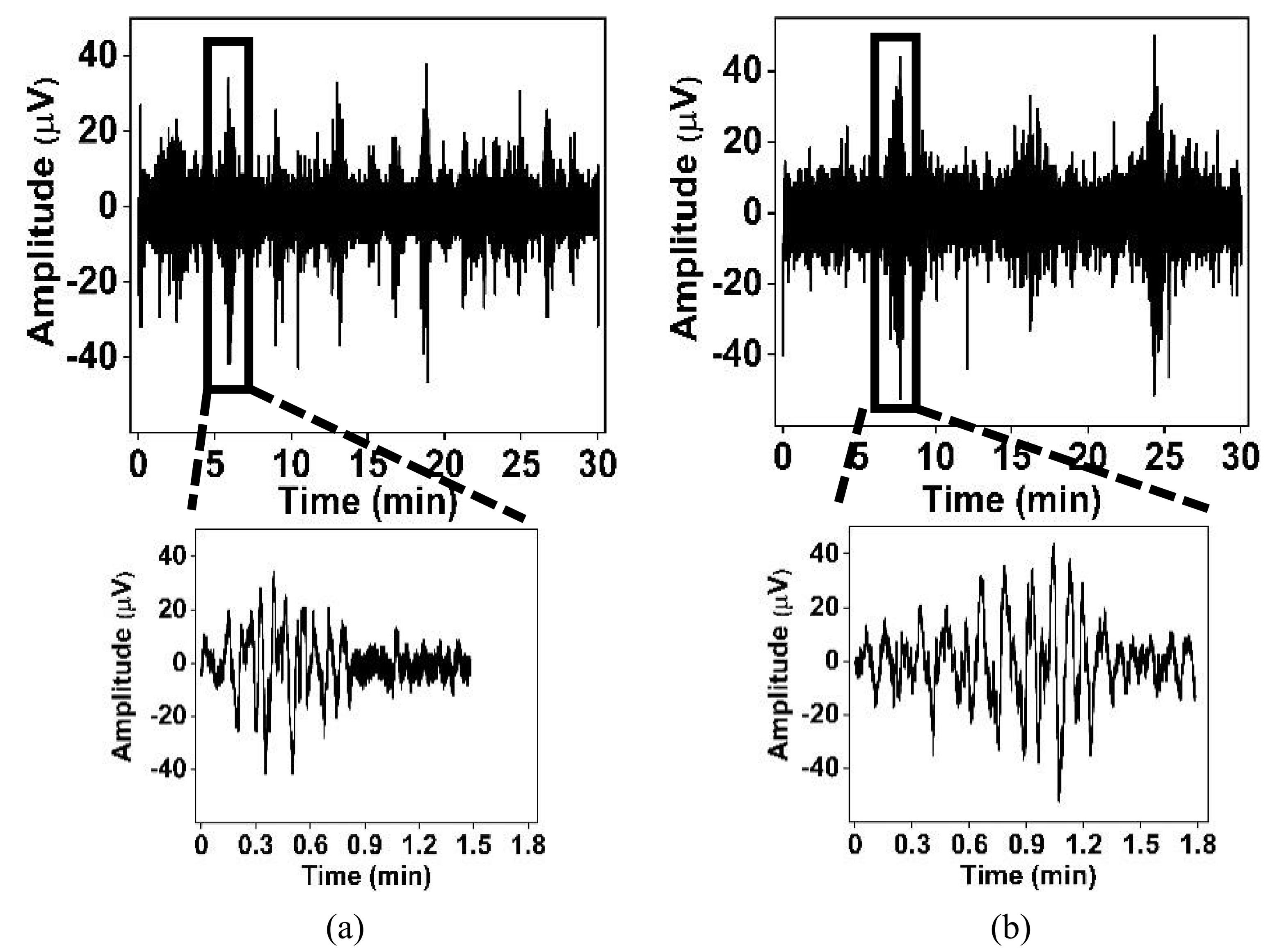


Figure 1. Representative uEMG signals with highlighted bursts in (a) Term and (b) Preterm condition

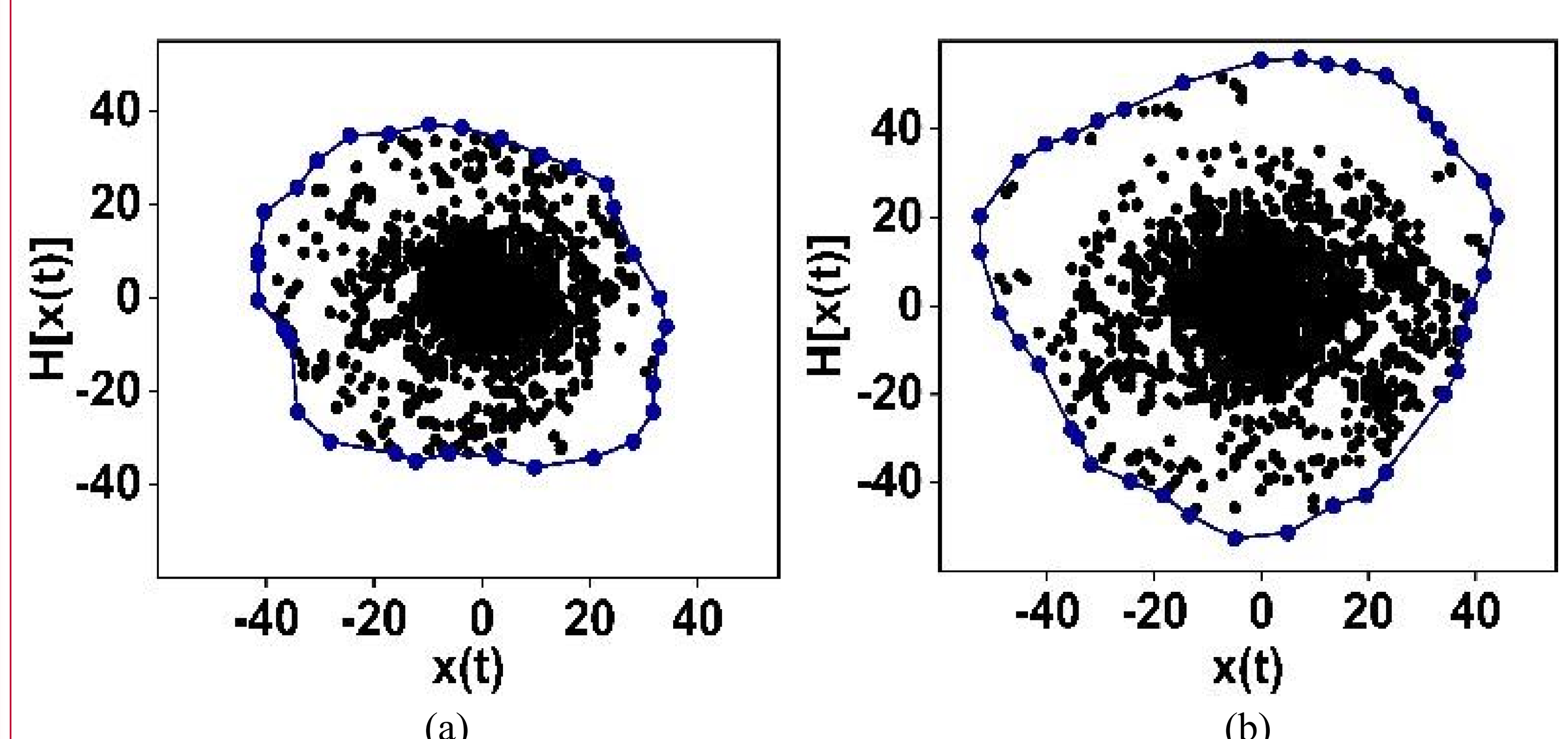


Figure 2. Complex plane representation of the burst signals in Figure 1 along with the boundary highlighted in blue colour (a) Term and (b) Preterm condition

Table 1. Statistical Measures of Topological Features

Topological Features	Term			Preterm		
	Mean	SD	CV	Mean	SD	CV
Area*	0.12	0.18	1.45	0.33	0.23	0.69
Perimeter*	0.24	0.21	0.88	0.46	0.23	0.49
Circularity	0.88	0.10	0.12	0.84	0.20	0.24
Convexity*	0.88	0.10	0.11	0.95	0.10	0.11

*** Statistically significant**

Results & Discussion

- The amplitudes of the uEMG signals are observed to be subject dependent and no specific pattern could be detected
- Higher amplitude and longer duration of burst signals are observed in Preterm as compared to Term condition
- uEMG bursts exhibit different shapes that vary with subjects
- Higher area and perimeter are observed in Preterm condition which might be due to the rise in the contractions' intensity and variations in the amplitude of uEMG signals
- Circularity are not equal to one indicating that the signal shapes are noncircular, which could be due to the aperiodic nature of uEMG signals
- Rise in convexity in the Preterm group reflects the increase in the regularity of uEMG signals due to the improved coordination of uterine cells during contraction
- Convexity can handle the inter-subject variations of uEMG signals

Conclusions

- The topological features can capture the characteristics of the burst signals during term and preterm conditions
- Convexity feature could be used as a biomarker for differentiating the Term and Preterm conditions
- The proposed approach could be utilized for the early diagnosis of Preterm birth.

Disclosure

- This study does not receive any funding from external agencies

References

1. F. Jager, S. Libenšek, and K. Geršak, "Characterization and automatic classification of preterm and term uterine records," PloS One, vol. 13, no. 8, pp. e0202125, 2018
2. Z. Zhang, Y. Song, H. Cui, J. Wu, F. Schwartz, and H. Qi, "Topological analysis and gaussian decision tree: Effective representation and classification of biosignals of small sample size," IEEE Trans. Biomed. Eng., vol. 64, no. 9, pp. 2288-2299, 2016
3. Y. Mingqiang K. Kidiyo, and R. Joseph, "A survey of shape feature extraction techniques," Pattern recognit., vol.15, no. 7, pp. 43–90, 2008.