Grenze International Journal of Engineering and Technology, June Issue

Simulation of FHR Signals with Abnormal Variability

Ushasri Akkanapalli [1], Dr. Malini Mudigonda [2], Sai Sreeja Samavedam [3] and Meghana Koppadi [4]
[1-4]Department of Biomedical Engineering, University College of Engineering, Osmania University, Hyderabad, India
Email: usha.chary@gmail.com, malini.m@uceou.edu, saisreejas.be23@uceou.edu, meghanak.be23@uceou.edu

***Abstract*—Cardiotocography or CTG is usually performed by obstetricians to examine fetal well-being during or before labor. Generally, visual inspection of the trace is performed to analyze the fetal heart rate signal, but due to its highly subjective nature, it lacks specificity and reproducibility. Computerized analysis of the trace provides a more objective standpoint for the identification and interpretation of various physiological and pathological conditions in the fetus. However, abnormalities in the trace are generally hard to come by. In the present paper, we have developed an algorithm for the simulation of FHR signals with abnormal variabilities using three distinct patterns. This algorithm was implemented on the CTG records of 57 subjects collected from hospitals. The morphological features of both original and simulated signals were plotted and the results were tabulated.**

***Index Terms*— Cardiotocography, Morphological features, Simulation, Floating line, Gaussian tract and Fetal heart rate.**

I. INTRODUCTION

Cardiotocography or CTG is the simultaneous recording of Fetal Heart Rate (FHR) and Uterine Contractions (UC) used in clinical practice for fetal health monitoring. It is the most diffused technique for both in antepartum and intrapartum periods to assess fetal well-being and to avoid fetal death due to birth asphyxia [1]. Obstetricians generally rely on visual inspection of the CTG trace to analyze and diagnose anomalies in the signal. This method of interpretation is subject to intra- and inter-observer variability as shown by several FHR reliability studies [2, 3]. Therefore, to overcome these shortcomings, a computerized analysis of the CTG trace was developed to assist clinicians in the identification of various physiological and pathological events during labor.

The commonly evaluated features from the FHR signal in clinical settings are baseline, baseline variability, accelerations and decelerations, collectively referred to as morphological features.

- Baseline is defined as the mean FHR within a 5-10-minute window ignoring any accelerations and decelerations.
- Baseline Variability, more commonly called Fetal Heart Rate Variability (FHRV), are the oscillations in the signal around the baseline in amplitudes of 5-25 beats per minute (bpm).
- Accelerations correspond to elevations in the signal of at least 15 bpm greater than the baseline and last for not less than 15 seconds.
- Decelerations are the nadirs (lowest points) in the signal of at least 15 bpm less than the baseline and lasting for more than 15 seconds.

These definitions of the morphological features are in accordance with the guidelines dictated by the Royal

Grenze ID: 01.GIJET.8.2.502

College of Obstetricians and Gynecologists (RCOG). The interpretation of FHR features according to these guidelines is shown in Table I. Accelerations are the sign of a healthy fetus while the presence of decelerations is considered as "ominous". Decelerations are further classified as early, late and variable. Early decelerations are the gradual decline in the heart rate, the nadir coinciding with the peaks of Uterine Contractions. These generally occur during the second stage of labor and do not indicate any fetal distress. Late decelerations correspond to the periodical heart rate decelerations occurring typically 20 seconds after a contraction. They are usually associated with uteroplacental insufficiency. Lastly, a variable deceleration is a rapid fall and recovery of the FHR to the baseline [4,5]. These reflect fetal hypoxia due to the compression of the umbilical cord.

TABLE I. RCOG GUIDELINES FOR THE INTERPRETATION OF FHR SIGNAL [1]

	Baseline Rate	Variability	Decelerations	Accelerations
Normal	110–160	>5	None or early	Present
Non-reassuring	100-109 161–180	<5 for 30–90 minutes	• When variable decelerations drops from baseline by 60 bpm or less and takes 60 seconds or less to recover; if present for >90 minutes with >50% of contractions • When variable decelerations drops from baseline by >60 bpm or takes >60 seconds to recover; if present for up to 30 minutes, occurring with >50% of contractions • When late decelerations are present for up to 30 minutes, with >50% of contractions	When there are no accelerations with an otherwise normal CTG, it is a case of uncertain significance.
Abnormal	<100 >180 Sinusoidal pattern for more than 10 minutes	<5 for >90 minutes	• Non reassuring >30 minutes after conservative measures, >50% contractions • Late >30 minutes with >50% contraction • Bradycardia/prolonged deceleration >3 minutes	

Based on the variation in the occurrence of these parameters, the FHR signal can be classified as normal, non-reassuring and abnormal.

II. METHODOLOGY

A. Need for Simulation

Despite the development of modern computerized software for the analysis of cardiotocographs, confidential inquiries over the last few decades suggest that faulty care during labor contributes to poor results and misdiagnosis [6]. Inability to interpret the CTG trace and poor understanding of the physiology and pathology behind the causes of FHR variability are some of the reasons for poor results [1]. Moreover, abnormal variabilities in the trace are very rare to occur and interpreted. Taking these factors into account, artificial simulation of FHR variabilities would assist in the better understanding and interpretation of the CTG trace during labor. It also finds its use in testing various computerized software developed to identify birth-asphyxiating conditions in the fetus.

Cardiotocographic data was collected from Vijay Marie Hospital and Durgabai Deshmukh Hospital and Research Centre in Hyderabad after taking relevant ethical clearance permissions. The subjects were pregnant women with a mean gestational age of 38 weeks i.e., who are approaching or experiencing labor. The sample size for the current study was fifty-seven subjects. After the extraction and thorough analysis of morphological features of our data, no cases of abnormal fetal heart rate variability (FHRV) were noted. Hence in the present study, FHR traces were simulated with the morphological features of pathological variability.

B. Floating Line Estimation

The morphological features were replicated in the simulated FHR signals in accordance to the definitions given by RCOG such that these features mimic a real FHR trace. The floating line estimate method was used for the simulations [7,8]. The baseline variability was simulated by generating a constant slowly varying sinusoidal

signal. The acceleration and deceleration events were simulated by generating Gaussian pulse tracts whose amplitude, pulse-width, and position can be modified to meet the requirements of the user. The floating line is the signal that represents the sum of these simulated baseline variabilities, acceleration, and deceleration events. The floating line was then added to the original FHR signal to give the resultant simulated signal with the above-mentioned features. The algorithm for these simulations was developed using the MATLAB R2021a software.

C. Gaussian Tract

Accelerations and decelerations were simulated using the Gaussian function defined as per equation (1) [8].

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} . e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (1)$$

Here, σ and μ denote the mean and standard deviation respectively. The amplitude, position and duration of the acceleration or deceleration can be manipulated as per the user's requirement by varying the values of σ and μ in equation (1). We simulated these periodic and/or sporadic perturbations in three different patterns as shown in Table II. Figure 1 shows the step-by-step algorithm of the program developed for the simulations. The original waveform, baseline, floating line and the simulated waveform of subject S12 are shown in Figure 2.

TABLE II. SIMULATION PATTERNS

PATTERN NUMBER	POSITION			
	FIRST	SECOND	THIRD	FOURTH
1	A	D	-	-
2	A	A	D	D
3	A	D	A	D

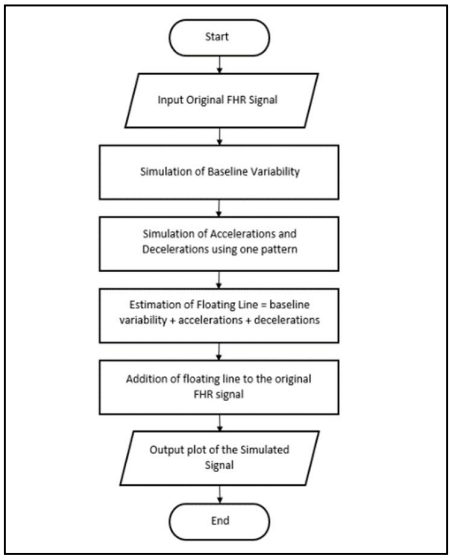

Figure 1. Generation of Simulated Waveform by Floating Line Estimation

II. RESULTS AND DISCUSSION

The morphological features were simulated in the 57 FHR traces collected as per each of the patterns described in Table II using the MATLAB R2021a software. In this paper, we report the simulation of FHR traces of 5 selected subjects S12, S15, S16, S24, and S27. The baseline, number of accelerations (Na), number of decelerations (Nd), the onset of acceleration (Ta), and the onset of deceleration (Td) of the original signal as well as the three simulated signals were tabulated as depicted in Table III and Table IV. The parameters used to generate the Gaussian pulses for the simulation of accelerations and decelerations, which include the standard deviations (Sd1, Sd2, Sd3, Sd4), means (M1, M2, M3, M4), and the amplitudes of accelerations (A1, A2) and decelerations (D1, D2) are tabulated in Table V. The waveforms of the original FHR signal and the three

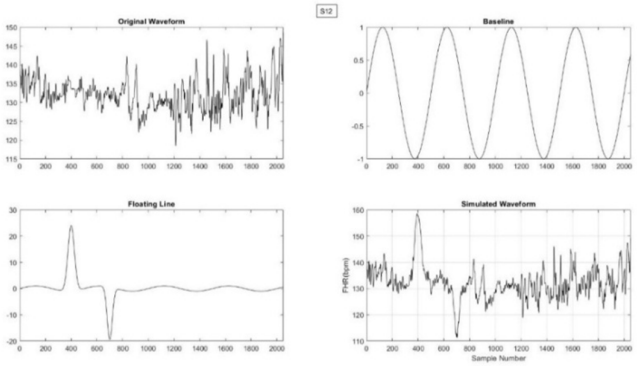

Figure 2. Original and Simulated Waveforms of subject S12

simulated signals were plotted and shown in Figures 3 through 7. To this aim, we were successfully able to induce abnormal variabilities in the original data collected from hospitals.

TABLE III. MORPHOLOGICAL FEATURES OF ORIGINAL AND SIMULATED SIGNAL (P1)

Subject Number	ORIGINAL SIGNAL					SIMULATED SIGNAL (P1)				
	Baseline	Na	Nd	Ta	Td	Baseline	Na	Nd	Ta	Td
S12	132	0	0			132	1	1	82.75	157.75
S15	150	1	1	381.00	157.25	151	2	2	85.75, 381	157.25, 229.75
S16	133	0	0			133	1	1	87.75	158.25
S24	136	0	0			137	1	1	87.75	262
S27	145	0	0			145	1	1	82.25	168.5

TABLE IV. MORPHOLOGICAL FEATURES OF SIMULATED SIGNAL (P2) AND SIMULATED SIGNAL (P3)

Subject Number	SIMULATED SIGNAL(P2)					SIMULATED SIGNAL(P3)				
	Baseline	Na	Nd	Ta	Td	Baseline	Na	Nd	Ta	Td
S12	132	2	2	13.75, 162.75	228.25, 285	132	2	2	13.75, 240	157.75, 285
S15	150	3	3	113.75, 185.25, 381	157.25, 278.5, 413	151	3	3	16.25, 287.25,381	157.25, 229.75 ,413
S16	133	2	2	13, 163.25	228.75, 285.5	133	2	2	13, 240.25	158.25, 285.5
S24	136	2	2	112.25, 184.75	261.75, 357.75	136	2	2	14.75, 254.75	181.75, 357.75
S27	145	2	2	13.75, 164	202.25, 246.25	145	2	2	13.5, 164	142.5, 217.25

TABLE V. PARAMETERS FOR GAUSSIAN PULSES

Subject Number	Pattern (Pn)	Sd1	Sd2	Sd3	Sd4	M1	M2	M3	M4	A1	A2	D1	D2
S12	P1	25	-	20	-	400	-	700	-	25	-	20	-
	P2	22	23	25	25	200	700	1000	1200	15	20	13	13
	P3	23	26	25	23	200	1000	700	1200	20	20	17	16
S15	P1	25	-	20	-	400	-	1000	-	25	-	20	-
	P2	22	23	25	25	500	800	1200	1700	20	20	17	17
	P3	23	26	25	23	100	1200	1000	1700	20	20	17	16
S16	P1	25	-	20	-	400	-	700	-	25	-	20	-
	P2	22	23	25	25	200	700	1000	1200	15	20	13	13
	P3	23	26	25	23	200	1000	700	1200	20	20	17	16
S24	P1	25	-	20	-	400	-	1100	-	25	-	25	-
	P2	22	23	25	25	500	800	1100	1500	20	20	25	25
	P3	23	26	25	23	100	1100	800	1500	17	20	17	25
S27	P1	25	-	20	-	400	-	700	-	25	-	20	-
	P2	22	23	25	25	100	700	850	1000	15	20	13	13
	P3	23	26	25	23	100	700	600	900	20	20	17	16

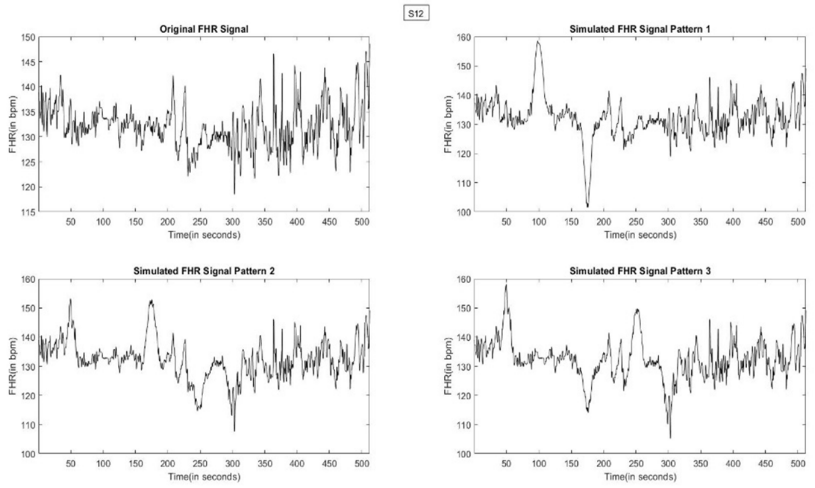

Figure 3. Original and Simulated Waveforms of subject S12

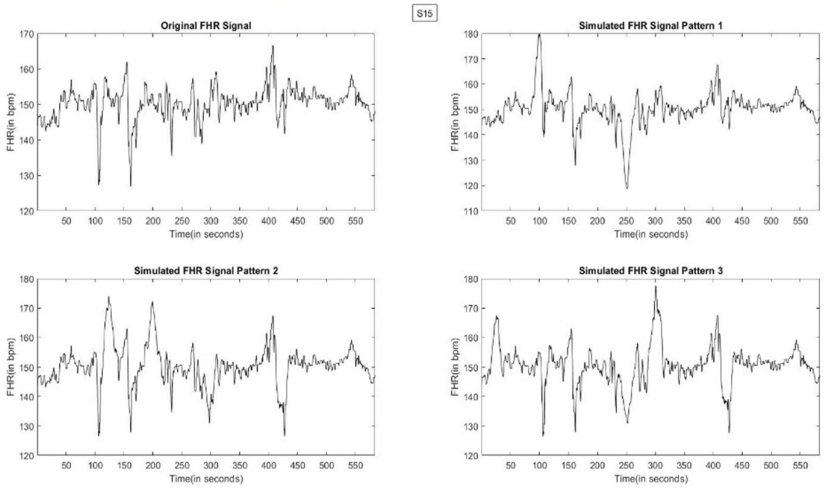

Figure 4. Original and Simulated Waveforms of subject S15

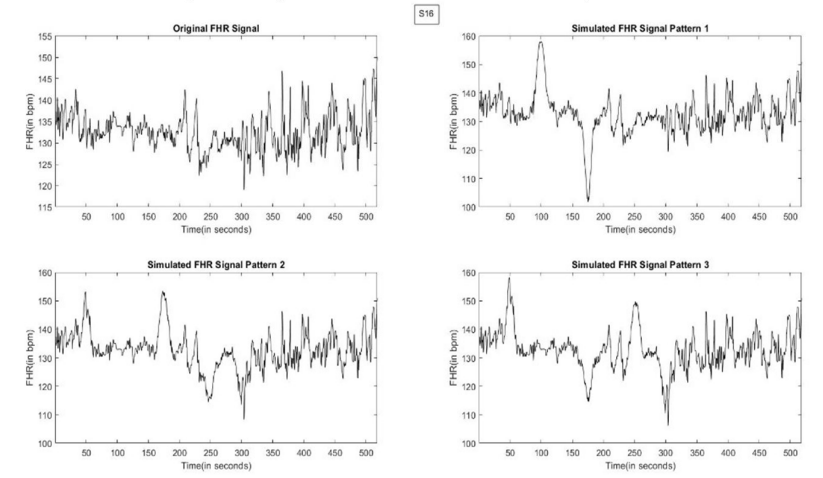

Figure 5. Original and Simulated Waveforms of subject S16

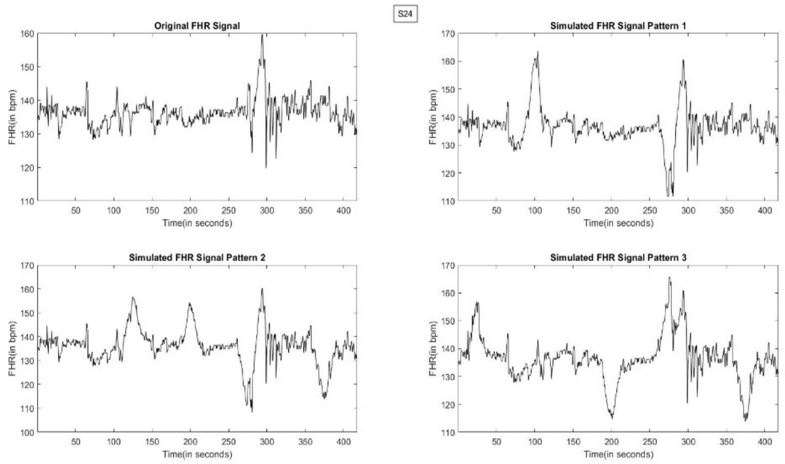

Figure 6. Original and Simulated Waveforms of subject S24

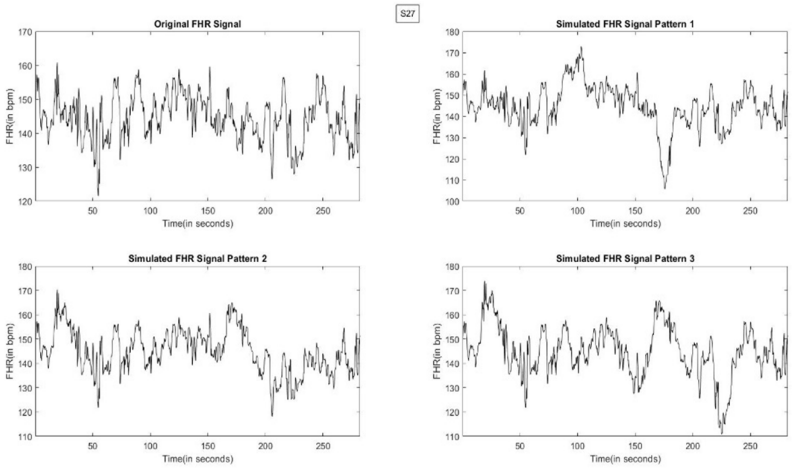

Figure 7. Original and Simulated Waveforms of subject S27

III. CONCLUSION

Modern computerized software developed for the analysis of FHR signals aims in automating the process of FHRV interpretation. This in turn helps in reducing the misinterpretation of CTG during labor and contributes to efficient clinical decision making. In order to test such software, FHR signals with all categories of variability are required. But non-availability of FHR signals with pathological variability becomes the major limitation. Hence in the present paper, we presented an algorithm to generate synthetic FHR signals with morphological features such as baseline variability, accelerations, and decelerations in three patterns of abnormal FHRV. Simulation of these anomalies would assist in the testing of various software developed for FHR feature analysis and extraction. It would also aid in a better understanding of fetal health during labor.

Similarly, various linear FHR features like short-term variability and long-term irregularity can also be simulated to further improve the resemblance of the synthetic signal to a real CTG trace. Furthermore, such simulation algorithms could be utilized as a teaching tool in medical educational institutions to help the students appreciate various features observed in the abnormal signal.

ACKNOWLEDGMENT

The authors wish to thank DST-PURSE II project for funding this work and also the hospital authorities and staff for the permission and support given during the CTG data collection.

REFERENCES

[1] Arias' Practical Guide to High-Risk Pregnancy and Delivery: A South Asian Perspective, 4/e Bhide, Arulkumaran, Damania, Daftary © 2015 Reed Elsevier India Private Limited.J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] Trimbos, J B., and M J. Keirse. "Observer Variability in Assessment of Antepartum Cardiotocograms." British Journal of Obstetrics and Gynaecology, vol. 85, no. 12, 1978, pp. 900-6.K. Elissa, "Title of paper if known," unpublished.

[3] Mantel, R et al. "Automated analysis of antepartum fetal heart rate in relation to fetal rest-activity states: a longitudinal study of uncomplicated pregnancies using the Sonicaid System 8000." European journal of obstetrics, gynecology, and reproductive biology vol. 71,1 (1997): 41-51. doi:10.1016/s0301-2115(96)02615-2Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[4]] Al-Yousif, Shahad & Mohd, MA & B, Bilal & Sheikh, Mahmoud & Algunaidi, M. (2017). Rule-Based Algorithm for Intrapartum Cardiotocograph Pattern Features Extraction and Classification. Health Science Journal. 10.

[5] A. Sbrollini et al., "Automatic Identification and Classification of Fetal Heart-Rate Decelerations from Cardiotocographic Recordings," 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2018, pp. 474-477, doi: 10.1109/EMBC.2018.8512432.

[6] Confidential Enquiry into Stillbirths and Deaths in Infancy. 4th Annual Report. (1997) - Concentrating on intrapartum related deaths 1994- 1995. Maternal and Child Health Research Consortium. Chiltern Court, 188 Baker Street London.

[7] Importa, Giovanni & Romano, Maria & Ponsiglione, Alfonso Maria & Bifulco, Paolo & Faiella, Giuliana & Cesarelli, Mario. (2014). "Computerized Cardiotocography: A Software to Generate Synthetic Signals." Journal of Health & Medical Informatics. 05. 10.4172/2157-7420.1000162.

[8] M. Romano, L. Iuppariello, G. D'Addio, F. Clemente, F. Amato and M. Cesarelli, "Computerised simulation of fetal heart rate signals," 2017 E-Health and Bioengineering Conference (EHB), 2017, pp. 185-188, doi: 10.1109/EHB.2017.7995392.