Detection of Abnormal Fetuses Using Biorthogonal Wavelet Analysis

Rand Kasim Mohammed
medical engineering, Dyiala University /college of medicine
e-mail:
randkasim_09@yahoo.com

Abstract

Biomedical signals are generated by complex self-regulating systems that process inputs with a broad range of characteristics. Many physiological time series, such as the fetal heart rate, are extremely inhomogeneous and non-stationary, fluctuating in an irregular and complex manner.

In this project, the amplitude of low-frequency fluctuation of fetal heart rate frequency was studied using analysis called wavelet transform. The nature and maturational changes of low-frequency fluctuation of the FHR in normal fetuses were investigated and probability distribution of FHR wavelet coefficients was studied from 28 wk of gestation onward. The value of the parameter a of this distribution did not exceed 1.939 regardless of the gestational age in a normal condition. The value of index a range from 2.1585 up to 3.1652 in fetuses from pregnant women with pregnancy-induced hypertension.

This project also presents a system capable of calculating index for the fetal heart rate low-frequency fluctuation distribution value and uses it to identify the fetus condition using the MATLAB 7.3 package.

FHR data of 12 normal fetuses and 18 fetuses from pregnant women with pregnancy-induced hypertension all between 28 and 38weeks of gestation were studied.

First, the cardiotocography tracing was converted from CTG paper images into digital series using image processing so that the system can analyze it. The FHR was then converted to inter-heart beat time series. Biorthogonal wavelet transform was used to analyze inter-heart

beat time series. The histogram of the absolute value of resulting wavelet coefficients was analyzed then probability distribution of wavelet coefficients frequency was used to calculate the fluctuation parameter a.

Statistical analysis methods where used to compare between the results. The Kruskal-Wallis test was used to test the significance of the difference among the parameters obtained; Pearson's test was used to test goodness of fit of the distribution function. In addition, the t-test was used for other statistics.

Index a values were used in last stage of the system to identify sick fetuses. When analyzing fetal heart rate of 18 fetuses from pregnant women with pregnancy-induced hypertension the system succeed to identify the presence of a problem in 6 fetuses.

1. Introduction

For several decades efforts have been made to computerize the analysis of fetal heart rate [1]. Visual interpretation of the cardiotocography (CTG) is known to be difficult, uncertain and inconsistent. This has led to the development of computerized CTG analysis. However, most of the fetal heart rate tracings are recorded in paper form and these must first be converted into digital values if they are to be retrospectively analyzed by computers [2, 3].

Spectral analysis with an auto regression method was used on fetal heart rate fluctuations for the purpose of investigating the change in gestational age and examining the usefulness as a method of estimating fetal blood gas. When examine Low-frequency area (LFA) in normal fetuses, there was a relation between LFA and fetal blood gas values. This makes analyzing Low frequency for FHR effective tool in fetus condition detection [4]. A dual peak was observed in the range of 0-0.125 cycles/beat from at least 20 weeks of gestation when an autoregressive non-stationary frequency analysis used with fetal heart rate fluctuations, which increased in the resting state with gestational age. The peak area increased remarkably with fetal movement which make analyzing FHR from week 20 on word more beneficial with more accurate results. Fetal heart rate fluctuations do not show a long-term stationarity in the resting or the active state; they show stationarity only for a short period. Therefore, FFT is not suitable because various fetal states would then be included [5, 6, 7].

The wavelet transform has emerged over recent years as a powerful time-frequency analysis and signal-coding tool favored for the interrogation of complex non-stationary signals. Its application to biosignal processing has been at the forefront of these developments where it has been found particular useful in the study of problematic, signals: such as ECG [8]. It was used on ECG R-R fluctuation in adults to study the structure of temporal fluctuation of the HF component. All the amplitude distributions of the temporal fluctuation of the HF component in normal cases are almost identical to one another regardless of the case [6]. We studied temporal fluctuation of LF component of the fetal heart rate frequency using Biorthogonal wavelet transform. When plotting histogram of wavelet coefficients, we noticed that histogram distribution is similar to that of chi square distribution. We used maximum amplitude of chi square distribution function to find index a for normal FHR. Appling same method for fetuses from pregnant women with pregnancy-induced hypertension, value for index a of abnormal FHR was calculated and used in diagnosis of abnormal fetuses.

2 Collecting CTG And Wavelet Analysis Methods

Cases were selected from patients attending out patients clinic (the antenatal care clinic) of Baghdad Teaching Hospital (12 cases), and pregnant women who were admitted in the obstetrics and gynecology department (18 cases) at the same period of the study. The selection of cases was conducted over a period of 4 months from January 2006 to may 2006.

CTG paper tracing included in this study were taking for pregnant women in their 28-38 weeks of gestation (week 28, 30 , 32, 34, 36, 38) . 12 normal fetuses associated with uncomplicated pregnancies and uneventful prenatal periods (All pregnant women age between 22-35 years, for all there were neither medical nor obstetrical abnormalities on history, examination and investigation) and 18 fetuses from pregnant women with pregnancy induced hypertension.

The FHR data were recorded for 40 minutes with the pregnant women in a semi- recumbent position in 45o with the horizontal plane using a fetal heart rate monitor Corometrics 120 external monitor. FHR, uterine contraction, and fetal movements were recorded on CTG paper with recording speed of 3cm/minute.

A scan image of each CTG paper is used(Fig.1). All images scanned using a horizontal resolution of 152 dpi (unit define scanned image resolution) that three pixel represented a one second epoch. Static grid markings and hand written annotations on the trace were removed by manual editing technique. This leaves only the fetal heart rate tracings. After calculating the original fetal heart rate the data <60 beats per minute or >200 beats per minutes was encountered because these are not usually included in the fetal heart rate analysis because the may affect the analysis results, so they were removed. When this method validated by comparing the difference between the fetal heart rate values obtained directly from the fetal monitor with those obtained indirectly from the paper recordings. The maximum mean difference between the actual and derived heart rate values was less than 1.17 beats per minute. For all segments, the actual values were greater than the derived values with an overall mean difference of less than a beat per minute (0.76) [9,10].

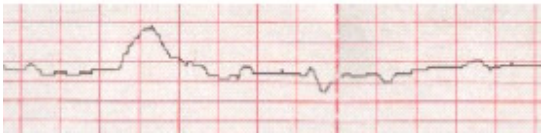

Figure (1) The scanned image CTG of FHR

To perform the wavelet analysis on the FHRs time series (Fig. 2)resulting from digitizing CTG tracing, first FHR time series was converted to inter beat interval time series with sampling =0.334s as shown in Fig.3. A time series of 2048 or more heartbeats was included in the study.

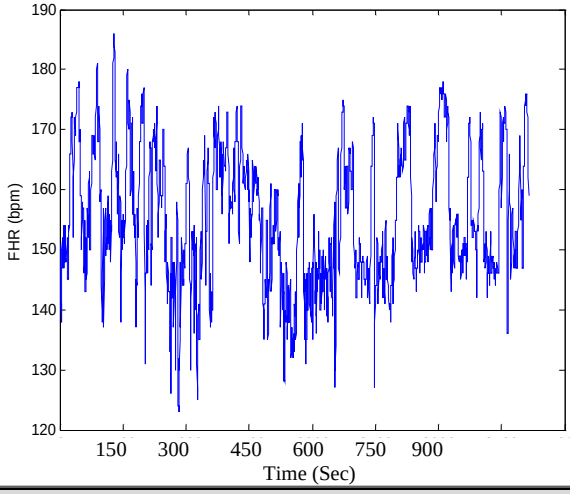

Figure (2) The FHR time series resulting from digitizing of CTG

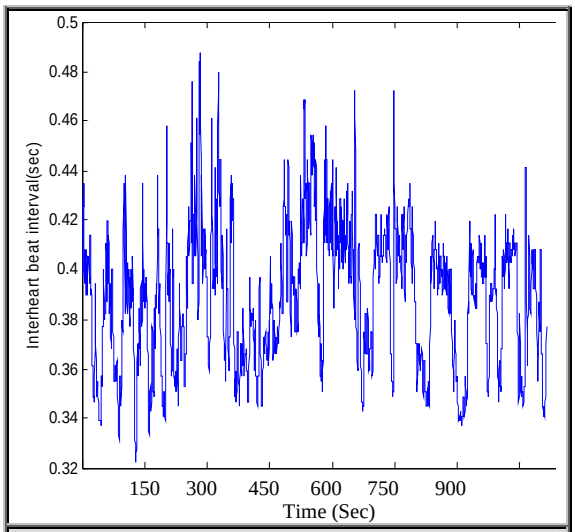

Figure (3) Time series of inter-heartbeat interval

In this study, Biorthogonal Wavelet transform is used. This family of wavelets exhibits the property of linear phase, which is needed for signal and image reconstruction. for decomposition it Use low- and high-pass decomposition filters [11] .

•□˜ , is used in the analysis, and the coefficients of a signal s are

$$\tilde{C}_{j,k} = \int s(x)\tilde{\psi}_{j,k}(x)dx \qquad 1$$

Where s is input signal s(t) and the wavelet function □ j,k obtained by dilating and shifting the function □ , by the scaling parameter j and the shift parameter k. The order of both low- and high-pass decomposition filters = 4 its shown in Fig.4. This wavelet function has one of the best possible simultaneous concentration properties in both the time domain and the frequency domain [12].

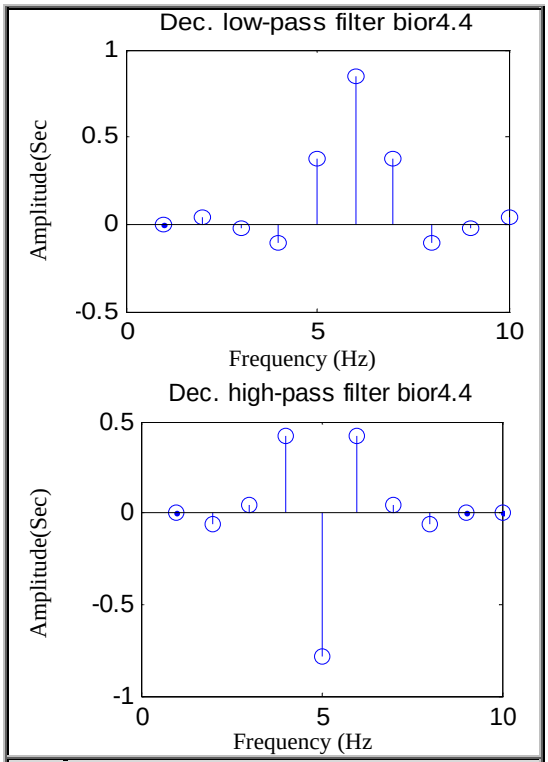

Figure (4) Biorthogonal Wavelet decomposition filters

Here, the scaling parameter j provides a frequency band to be extracted. The larger the scaling parameter k, the higher the frequency it represents. In the discrete wavelet transform j= 2-n, we assumed j to be 1/32. Consequently, the extracted frequency band centers around 1/(32 3* 0.334) = 0.094 Hz, corresponding to a low-frequency domain in which 0.334 s was the sampling interval.

The shift parameter k, which signifies the passage of time, is a nonnegative integral value. The shift parameter k, which signifies the passage of time, is a nonnegative integral value.

A time series expressed as S j, k , where k = 0, 1, 2, 3, 4, ...,resulted as shown in Fig. 5 . Taking the absolute value of resulting coefficients

$$C_{j,k} = |S_{j,k}| \qquad 2$$

Cj, k is a time series representing the amplitude of S j, k signal as shown in Fig .6.

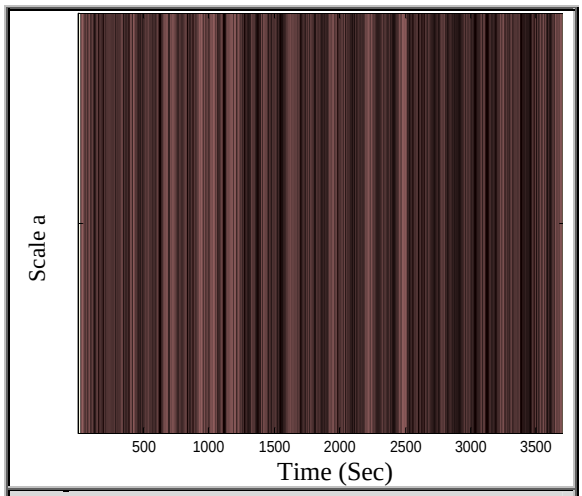

Figure (5) Plot of wavelet coefficients amplitude

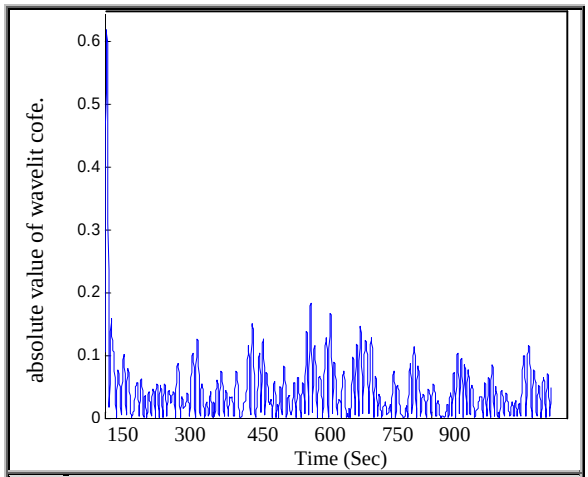

Figure (6) Plot of absolute value of wavelet oefficients amplitude

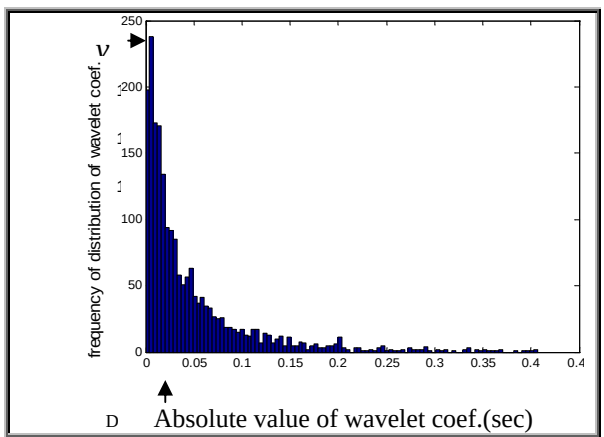

Figure (7) histogram of absolute value of wavelet coefficients amplitude

When plotting (ce), which is the histogram of the absolute value of wavelet coefficients amplitude (C) the shape of this distribution graph is shown in Fig.7. It is similar to shape of chi square (2) distribution.

Chi-square probability density function

$$y = f(x|a) = \frac{x^{(a-2)/2} e^{-x/2}}{2^{a/2}\Gamma(a/2)} \qquad (3)$$

Where (·) is the Gamma function. a degrees of freedom The degrees of freedom parameters in a must be positive integers, and the values in x must lie on the interval [0 1].

The gamma function is defined by the integral:

$$\Gamma(a) = \int_0^{\infty} e^{-t} t^{a-1} dt \qquad (4)$$

The gamma function interpolates the factorial function. For integer n: gamma(n+1) = n! [13] As shown in fig7 The (ce) value at which maximum coefficients distribution is D; normalizing distribution to get maximum coefficients distribution = 1 . This means for Chi-square probability density function ymax = 1 at x =D. substituting values of y and x in eq. (3). this yields

$$a = 2 + (D / \ln D) \qquad (5)$$

D value for each inter-heart beat time series (all 30 cases) was calculated then value of index a was calculated using eq.(5)

Statistical analysis was made to results taking α =0.05 significant level for all of statistical methods that were used

Kruskal-Wallis was used to assess significant differences in D, a index between the gestational weeks. The outline of Kruskal-Wallis test for comparing g groups is as follows:

A. Data: yij(FHR index),i=1,2, .,g(number o of week); j=1,2, ..ni .

B. Assumptions: yij conforms to the model

$$yij = \mu i + eij \qquad (6)$$

Where the eij are independently and identically distributed with zero mean and variance 2.

C. Computations:

1. Rank the ij y from smallest to largest using midranks for tied
observations.
2. Denoting the ranks and means of the ranks, compute the statistics

$$k = \frac{12}{N(N+1)} \sum_{i=1}^{g} n_i (\bar{R}_{i+} - \bar{R}_{++})^2 \quad (7)$$

Ranks are found by ordering the data from smallest to largest across
all groups, and taking the numeric index of this ordering. N is the
number of samples, i R is the mean of ranks of group i.
D. Statistical test:
1. Null hypothesis: H0: 1 = 2 . . . = g.
2. Alternative hypothesis: Ha: Not all equal.
3. Decision rule for an ' -level test: Reject H0 if KT (or K if no ties)
exceeds) 1 .Kruskal-Wallis box plot was also used to show these differences in fig 8. A p value of less than 0.05 was considered statistically significant. Performing a t-test of the null hypothesis that data in the vector x are a random sample from a normal distribution with mean 0 and unknown variance, against the alternative that the mean is not 0. The result of the test is returned in h. h = 1 indicates a rejection of the null hypothesis at the 5% significance level. h = 0 indicates a failure to reject the null hypothesis at the 5% significance level. The p-value is the probability, under the null hypothesis, of observing a value as extreme or more extreme of the test statistic where the sample mean, μ= 0 (or m) is the hypothesized population mean, s is the sample standard deviation, and n is the sample size. Under the null hypothesis, the test statistic will have Student's t distribution with n – 1 degrees of freedom.
Pearson's test was used to test goodness of fit of the distribution function.For linear correlation, the Pearson correlation coefficient was calculated for the two variables x (week number) and y (FHR index), it reflects the tendency for the x' s and y's to be close to straight line and it is denoted by ρ .
It is a population measure of the strength of a linear relationship. For a random sample (x1, y1), , (xN,yN), the usual estimator for is r,where

$$r = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \quad (8)$$

If there is perfect linear relationship between x and y, that is, x and y are always on a straight line, then r = +1 or r = -1 depending on whether the relationship is direct or inverse if x and y increase together or if an increase in x is associated with a decrease in y, respectively. In estimator eq.(7), x and y are the usual sample means of x and y. If r = 0 in eq.(6) then there is no linear relationship [14, 15].
After implementation of the Biorthogonal wavelet analysis method and making use of statistical methods used to identify the most suitable index to identify fetus condition for each week of gestation (28-38) weeks. The resulted a is used to built a system to identify sick fetuses by comparing the value of a calculated of FHR recorded on CTG paper of a fetus whose condition not identified with the a value for the same week of the gestation from normal fetuses that were associated with uncomplicated pregnancies and uneventful perinatal periods. When analyzing fetal heart rate of 18 fetuses from pregnant women with pregnancy-induced hypertension the system succeed to identify the presence of a problem in 6 fetuses.

3. Computer Simulation Results

It is obvious from table1& 2 that D, a value decrease as week of gestation increases for both normal and fetuses from pregnant women with pregnancy-induced hypertension. When examine Table 3 the indices D,a showed a strong negative linear correlation .showed that the null hypothesis can be rejected at 0.05 significant level for each of the 2 weeks period, i.e. the average values of indices at all gestational weeks were significantly (p=0) larger than zero.

Table (1) Mean *a*, D values For normal fetuses (*n*=12)

week	*a*	D
28	1.9048	18.262
30	1.8154	16.699
32	1.7236	15.234
34	1.6573	14.258
36	1.4528	11.621
38	1.3324	10.303

Table (2) Mean *a*, D values For fetuses from pregnant women with pregnancy-induced hypertension (*n*=18)

week	*a*	D
26	3.1652	64.404
28	2.7104	40.869
30	2.5472	34.717
32	2.4436	31.299
34	2.3989	29.932
36	2.1912	24.316
38	2.0831	21.826

Table (3) The correlation analysis of heart rate indices with gestational weeks (*n*=30)

FHR indices	Correlation coefficient(r)	*p*
D	-0.9833	0
a	-0.9722	0
D, abnormal	-0.872	0
a abnormal	-0.9406	0

When Kruskal-Wallis test was used to assess significant differences in each heart rate index between the gestational weeks the results (p=0) are shown in Table 4 &5. (Fig. 8,9,10,11).

Table (4) Kruskal-Wallis Table for D ,a for normal fetuses

Source	SS	MS	Chi-sq	Prob> Chi-sq
Groups	140	28	10.81	0.0553
Error	2.5	0.4167		
Total	142.5			

For t test of heart rate indices shown in Table 6, h =0 for all indices indicates a failure to reject null hypothesis at the 5% significance level. For all indices p = 1

Table (5) Kruskal-Wallis Table for D, *a* for abnormal fetuses

Source	SS	MS	Chi-sq	Prob> Chi-sq
Groups	400	66.67	15.7055	0.01543
Error	7.5	0.75		
Total	407.5			

Table (6) The Results for t test of heart rate indices with gestational weeks (*n*=30)

FHR indices	**h**	**p**	**standard deviation**
D	**0**	**1**	**3.0650**
a	**0**	**1**	**0.2223**
D, abnormal	**0**	**1**	**10.7985**
***a* abnormal**	**0**	**1**	**0.2970**

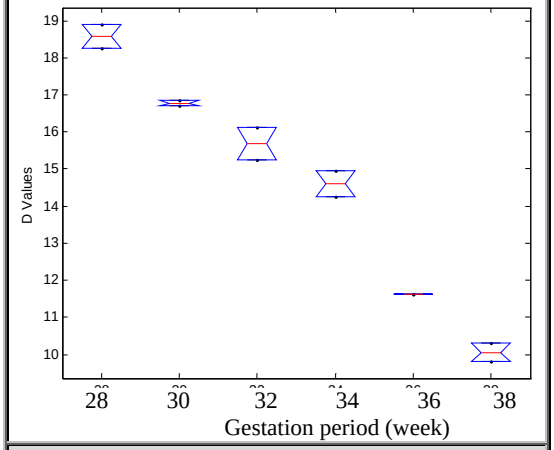

Figure (8) Kruskal-Wallis box plot for D of normal fetuses

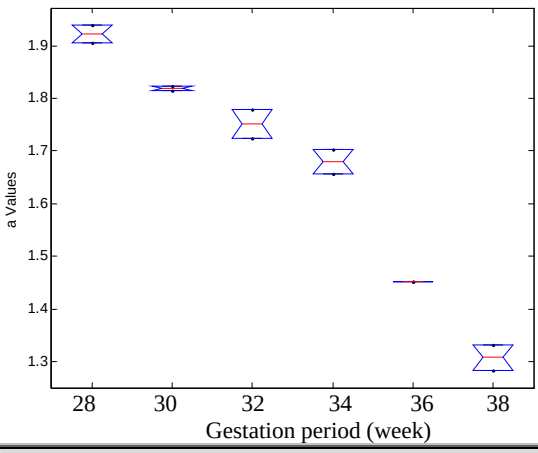

Figure (9) Kruskal-Wallis box plot for *a* of normal fetuses

4. Conclusions

We analyze FHR using Biorthogonal wavelet transform because FHR is nonlinear; the characteristic which make it useless to use FFT, DFT, PSD and other similar analysis methods. The shape of amplitude distribution of FHR was pointed out which was chi-square distribution. This distribution exists from 28 week of gestation onward.

In Table 1 we noticed that a value remained almost constant with slight decrease as

gestational age of the fetus increase, that means a value is less than 2 for normal fetuses. a value won't exceed 2 unless fetus is abnormal as in Table 2.

In Table 3 we noticed that a, D values for both normal and abnormal fetuses has negative correlation which implies decreased of both indices with increase in week of gestation no matter the fetus is normal or abnormal.

The cause of a behavior mentioned above is that FHR is under constant variation from the baseline. This variability reflects a healthy nervous system, chemoreceptors, baroreceptors and cardiac Prematurity decreases variability; therefore, there is little rate fluctuation before 28 weeks. Variability should be normal after 32 weeks.

Fetal hypoxia, congenital heart anomalies and fetal tachycardia also cause decreased variability. This is why a value in abnormal fetuses is greater than a value for normal fetus in same week of gestation.

The difference in a, D for normal and abnormal fetuses are significant with a significance level of 0.05 as shown in Table 4 and 5, so we can't set single value for a in all weeks of gestation.

Constant a value means Loss of variability in FHR. This may be uncomplicated and may be the result of fetal quiescence (rest-activity cycle or behavior state), in this case the variability usually increases spontaneously within 30 to 40 minutes. Uncomplicated loss of variability may also be caused by central nervous system depressants.

Table 6 shows that a value has less deviation with weeks of gestation than D for the same reasons mentioned above.

The difference in a, D values between weeks is maximum between 34 and 36 week of gestation for normal fetuses as shown in Fig. 8,9. This difference is maximum between 28 and 30 week of gestation for abnormal fetuses as shown in Fig. 10 and 11.

Calculating a value for gestational weeks 28 onward for normal and abnormal fetuses will provide effective way to detect abnormality such as in fetal distress make it easer and less cost to monitor fetal condition.

Further development for program can be made using neural net work to provide a system capable of not only identify normal or abnormal fetuses but identify the abnormal fetuses condition and show if it is dangerous or not.

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الكشف عن الأجنة الغير طبيعية باستخدام تحليل المويجة ثنائي التعامد

رند قاسم محمد
مدرس مساعد (ماجستير في الهندسة الطبية)
كلية الطب / جامعة ديالى
بريد الكتروني:randkasim_09@yahoo.com

الخلاصة:

الموجات الطب-حياتية تتولد بواسطة أنظمة معقدة ذاتية الضبط تعالج الإدخالات بواسطة مدى واسع من الخصائص .العديد من السلاسل الزمنية الوظائفية، مثل معدل نبض قلب الجنين،غير متجانسة إلى ابعد حد وغير ثابتة، تتموج بأسلوب معقد وغير منتظم.

في هذا المشروع، قيمة تموج التردد المنخفض من ترددات معدل نبض قلب الجنين تمت دراسته باستخدام تحليل يدعى تحليل المويجة. طبيعة وتغيرات النضج لتموج التردد المنخفض لمعدل نبض قلب الجنين في الأجنة الطبيعية تم التحقق منها واحتمالية توزيع معاملات المويجة لمعدل نبض قلب الجنين تم دراستها من الأسبوع الثامن والعشرين للحمل فأكثر.

قيمة المعامل a بالنسبة لهذا التوزيع لم تتجاوز ١.٩٣٩ بغض النظر عن مدة الحمل في الحالات الطبيعية. قيمة a تتراوح بين ٢.١٥٨٥ حتى ٣.١٦٥٢ لأجنه من نساء حوامل مصابات بارتفاع ضغط الدم الناتج عن الحمل.

هذا المشروع يقدم أيضا نظام قادر على حساب مؤشر لقيمة تموج توزيع التردد المنخفض لمعدل نبض قلب الجنين واستخدامها لتعيين حالة الجنين باستخدام برنامج مختبر المصفوفات ٧.٣.

لقد قمنا بدراسة بيانات معدل نبض قلب الجنين لاثنى عشر جنينا طبيعيا وثمانية عشر جنينا من نساء حوامل مصابات بارتفاع ضغط الدم الناتج عن الحمل جميعها بين ثمان وعشرين وثمان وثلاثين اسبوعا للحمل.

أولا، تم تحويل تخطيط قلب الأجنة من صور لأوراق التخطيط CTG إلى متسلسله رقمية باستخدام معالجة الصورة ليتمكن النظام من تحليلها ثم تم تحويل معدل نبض قلب الجنين إلى متسلسله زمنية للزمن مابين نبض القلب.

تم استخدام تحليل المويجة ثنائي التعامد لتحليل المتسلسله الزمنية للزمن مابين نبض القلب. تم تحليل الرسم البياني العمودي للقيم المطلقة لمعاملات المويجة الناتجة ثم تم استخدام توزيع الاحتمالية لتردد معاملات المويجة لحساب معامل التموج a .

تم استخدام طرق تحليل إحصائية للمقارنة بين النتائج. استخدم اختبار كرسكال-والاس لاختبار وجود فرق ذي أهمية بين المعاملات الناتجة؛ كما استخدم اختبار بيرسون لاختبار جودة ملائمة معادلة التوزيع.إضافة إلى ذلك ، تم استخدام اختبار - ت للإحصائيات الاخرى٠تم استخدام قيمة a لتعيين الأجنة الغير طبيعية٠ عند تحليل معدل نبض قلب الجنين لثمانية عشر جنينا من نساء حوامل مصابات بارتفاع ضغط الدم الناتج عن الحمل تمكن البرنامج من الكشف عن وجود مشكلة في ست من هذه الأجنة.