Enhancing the Accuracy of Cardiotocogram Analysis by Fuzzy Logic System

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***Abstract*— This paper focuses on the enhancement of the accuracy of Cardiotocogram analysis by Fuzzy Logic System. Electronic fetal monitoring is based almost entirely on the Cardiotocogram (CTG), which is a continuous display of the fetal heart rate (FHR) pattern together with contraction of the womb. The Cardiotocogram machine and fuzzy system with five patients were used in the analysis to determine the accuracy of fetal heart rate (FHR). The result shows that the Cardiotocogram machine gave an accuracy of ±3.9%, ±4.3%, ±4.7%, ±4.8%, ±5.3%, while the fuzzy logic system gave an accuracy of ±1.47%, ±3.73, ±3.73%, ±3.73% and ±1.52%, respectively. The results obtained confirmed that the fuzzy logic system has provided significant method of enhancing the Cardiotocogram analysis with a higher degree of accuracy between 0.6% - 3.8% and makes the system less sensitive to noise or error.**

***Index Terms*— Cardiotocogram, Fuzzy logic system, fetal heart rate, Accuracy, enhancement.**

I. INTRODUCTION

Childbirth is a critical period for the foetus and the mother. A good outcome of child labour is generally desired but sometimes problems occur that may lead to injury like fetal brain damage, other abnormalities or even death. The most common monitoring method is based on a continuous trace of the fetal heart rate pattern and maternal contractions, known as the cardiotocogram (CTG). Difficulties in the interpretation of the cardiotocogram have led to unnecessary medical intervention and failure to intervene when necessary may lead to injuries and deaths [1]. These problems have led to the development of a number of computerized systems to assist with the analysis and interpretation of CTG data.

There is no significant improvement in fetal outcomes; the progress in computerized cardiotocogram analysis has been impeded by several factors. There are inherent problems of imprecision and uncertainty in the clinical data and the interpretation methods used. The solutions to this problem are yet to be addressed in computerized cardiotocogram system. Cardiotocogram does not contain sufficient information accurate for assessment of the fetal condition [2]. Additional information may be obtained by a proper analysis of changes in the fetal electrocardiogram (ECG), but the problems of uncertainty and imprecision also exist in fetal electrocardiogram analysis.

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Fetal distress occurs when a foetus can no longer compensate for the effects of stress in labour, which can quickly lead to fetal injury. If continuous information on the fetal condition is available then the clinician is in a position to improve on the level of care by making more accurate and timely decisions. Thus the clinician could respond to appropriate signs of fetal distress to prevent fetal injury and at the same time avoid unnecessary intervention [3].

The assessment of the fetal condition depends on the growth of the uterus and its contents, the movements of the foetus perceived by the mother and the listening of the fetal heart beat with a stethoscope. Absence of fetal movements during pregnancy is a serious diagnostic problem. The decision to assist the delivery of the baby by artificial means depends on information gathered through the application of cardiotocography [4].

Much of the knowledge relating to CTG interpretation is based on empirical observations made in the 1960s that certain heart rate features are associated with poor fetal outcome [5]. An example of 15-minutes of CTG trace, with the important features labeled is shown in Fig.1.

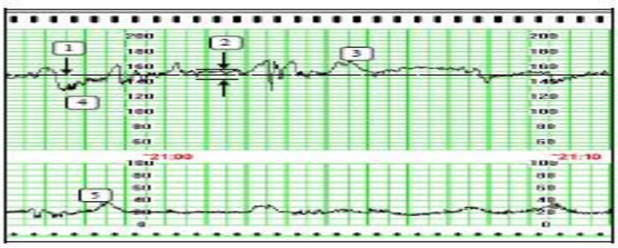


Fig.1. An example 15 minute segment of cardiotocogram with important features. The top trace is fetal heart rate and the bottom trace is maternal contractions. The key features are: (1) Baseline, (2) Variability (3) Acceleration (4) Deceleration (5) Contractions

II. METHODS

The fuzzy model for Cardiotocogram analysis that incorporates a fuzzy sets and fuzzy rules is shown in figure 2. The features of the fetal heart rate (Baseline, variability, accelerations and decelerations) are identified using numerical algorithms and then fuzzified. The fuzzified feature set is then used to produce accuracy classification. Mamdani inference is used to apply the rules and the accuracy classification output set is defuzzified using the centre of gravity method to give a scalar value [6]. The two key parameters of the fuzzy model are the fuzzy sets and fuzzy rules. In the design of fuzzy sets, it is necessary to first describe the features and facts using linguistic variables. The fuzzy sets are used to represent the four features of the Cardiotocogram (baseline, variability, accelerations and decelerations) and the Cardiotocogram accuracy.

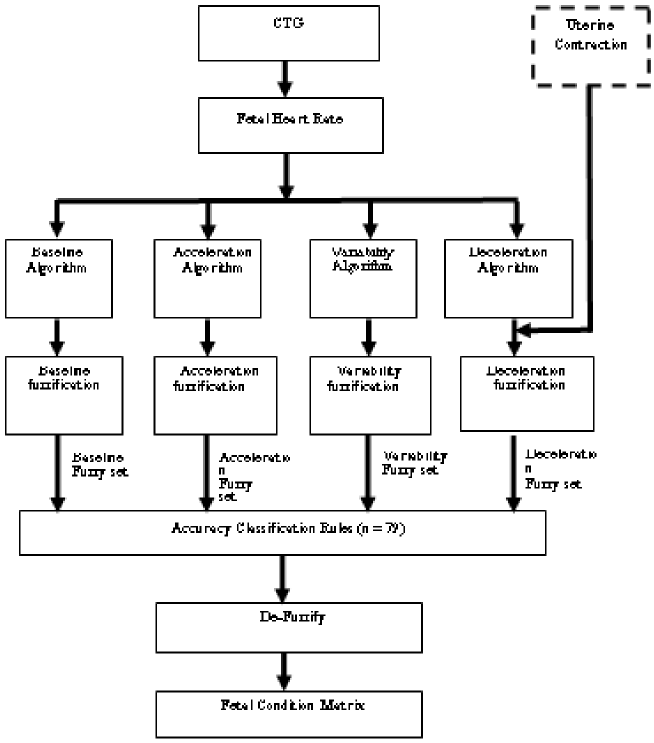


Fig.2. Fuzzy model for CTG analysis

In Cardiotocogram (CTG) system analysis, several Cardiotocogram features have been identified to provide clinicians with a method of predicting the condition of the foetus and outcome of child labour [7]. These features include the heart rate baseline, acceleration and deceleration in heart rate, heart rate variability and uterine contractions.
Each feature is classified using rules derived from certain guidelines as shown in Tables 1 and Table 2.

Table 1: Classification of baseline heart rate

Baseline value (beats per minute)	Linguistic Classification
< 90	Low
90 – 109	Slightly low
110 – 159	Normal
160 – 179	Slightly high
> 180	High

Table 2: Classification of heart rate variability

Variability value (beats per minute)	Linguistic Classification
< 2	Absent
2 – 5	Reduced
6 – 25	Normal
> 25	Increased

A. Fuzzy Logic System

Fuzzy logic system is the process of formulating the mapping from a given input set to an output set using fuzzy logic [8]. This mapping process provides the basis from which the inference or conclusion can be made. Features identified by the crisp system are fuzzified and assessed using new rule sets. The values of baseline variability calculated by the existing algorithms are fuzzified onto their respective term sets:

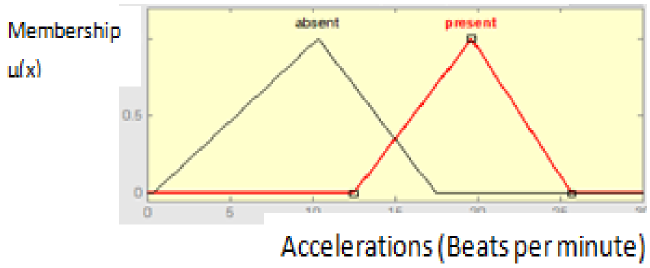
Baseline = {Low, Sightly low, Normal, Slightly high, High}
Variability = {Absent, Reduced, Normal, Increased}

These fuzzy sets are based on the existing crisp classification sets. (See Table 1 and Fig. 3 for the relationship between crisp fuzzy and baseline).

Fig. 3: Fuzzy membership sets for baseline heart rate

The fuzzy classification of accelerations is found by considering the total duration of identified accelerations as a proportion of the segment length. The acceleration classification set is:

Accelerations = {Absent, Present}



4. Fuzzy membership sets for accelerations.

The fuzzy classification of decelerations is found by considering the total duration of identified decelerations as a proportion of the segment length. The deceleration classification set is:

Decelerations = {Absent, Present}

B. Testing

Five patients (pregnant women) were used for the experiment to determine the fetal heart rate of the foetus and uterine contraction of the mothers. Each patient lay on top of the bed, facing up, and the clinician either placed or tied the toco-probe at the right side of the mother's abdomen.

The Cardiotocogram tracing was then monitored on the monitor, and the readings of the parameters under investigation included the baseline rate, baseline variability, accelerations and decelerations were recorded [9]. These results were also sent to the printer to obtain a hard copy.

Cardiotocography segments of about 15 minutes, read from five patients were interpreted with the help of an expert and the accuracy was computed using MATLAB 7.5 functions for the measured values.

To establish whether the fuzzy system enhance the accuracy of Cardiotocogram, a comparison was made between the computed accuracy values obtained from the Cardiotocogram tracings and the accuracy obtained from the designed fuzzy inference system (FIS).

III. THE RESULTS

Table 3 shows the measured values obtained from the Cardiotocogram machine and Table 3 shows the accuracy of the measured values using Cardiotocogram and Fuzzy Inference System

Table 3: Experimental results obtained from Cardiotocography machine (CTG)

Class of patient	Baseline rate (bpm)	Baseline variability (bpm)	Accelerations (bpm)	Decelerations (bpm)
One	140	6	22	20
Two	140	10	10	6
Three	150	10	18	10
Four	148	7	10	12
Five	160	6	20	20

Table 4: Analysis of the accuracy of the measured values using Cardiotocogram and Fuzzy Inference System

Class of patient	**Accuracy of fetal heart rate (%)**				
	Cardiotocogram (%)	**Fuzzy system (%)**	**Degree of error (%)**	**Percentage error (%)**	**Efficiency (%)**
One	0.039	0.0147	2.4	62.3	97.6
Two	0.043	0.0373	0.6	13.3	99.4
Three	0.047	0.0373	0.9	20.6	99.1
Four	0.048	0.0373	1.1	22.3	98.9
Five	0.053	0.0152	3.8	71.3	96.2

IV. ANALYSIS OF RESULTS AND DISCUSSIONS

The overall accuracy of the measured values for the Cardiotocogram was ±3.9%, ±4.3%, ±4.7%, ±4.8%, and ±5.3% respectively. The overall accuracy of the fuzzy system was ±1.47%, ±3.73%, ±3.73%, ±3.73%, and ±1.52% respectively.The degree of accuracy between the Cardiotocogram and the fuzzy system was ±2.4%, ±0.6%, ±0.9%, ±1.1%, and ±3.8%, respectively.

The percentage efficiency of the system was 97.6%, 99.4%, 99.1%, 98.9%, and 96.2%.

The result shows that the accuracy of the fuzzy logic system was compared favorably than the measured values of the Cardiotocogram.

This shows that the Fuzzy logic system can be used to improve the efficiency of the clinician position for making accurate diagnosis.

V. CONCLUSION

The Fuzzy expert system concepts are re- examined, refined and developed further to include knowledge on the CTG. The performance of CTG assessment totally depends on the clinical knowledge employed to interpret it. Presently, automated methods possess limited clinical applications in Cardiotocography. A greater percentage of this unsatisfactory performance rests on the weakness of methods employed for classifying fetal condition that generates risk alarms during pregnancy.

The researchers have developed a fuzzy logic inference system, and have derived rules directly from practical observations, which gave greater flexibility to the classification criteria, and widened knowledge acquisition through training. The simulation of the theoretical guidelines was also carried out to further determine the optimality conditions of the fuzzy system. The researchers observed that the measured readings produced higher classification errors compared to the fuzzy system.

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