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Models for Handling Uncertainty in Fetal Heart Rate and Cardiotocogram (Ctg) Analysis

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Abstract -This paper concerns the models for handling uncertainty in fetal heart rate and Cardiotocogram (CTG) analysis. Methods for handling imprecision and uncertainty in computer- based analysis of fetal heart rate patterns and CTG wave shape during child labour are presented. The ability to handle imprecision and uncertainty in clinical data and method of interpretation is vital to remove a key obstacle in electronic fetal monitoring. The results obtained from the fuzzy system shows that fuzzy logic system offers an improvement in Cardiotocogram analysis over the crisp expert system.
Index Terms: Cardiotocogram, Electronic fetal monitoring, Fuzzy logic, Fetal heart rate, imprecision and uncertainty.

I. INTRODUCTION

Childbirth is a critical time for foetus and mother. Clinical outcome is usually good for both foetus and mother but problems may occur that result in permanent fetal organ damage or even death. A number of fetal monitoring technologies have been developed which seek to assist clinical decision making during labour. The most common of this is the cardiotocogram (CTG), which consists of a continuous recording of fetal heart rate and maternal contractions.

Changes in the fetal heart rate pattern relative to contractions provide an indication of fetal condition which can be used to identify those cases needing intervention. Cardiotocogram interpretation is a difficult task, requiring clinical experience and significant expertise. Studies have shown that this expertise is often lacking in delivering units, with Cardiotocogram misinterpretation implicated in a large number of preventable fetal deaths and unnecessary operative interventions [1].

Progress in computerised Cardiotocogram analysis has been impeded by several factors. First, there are significant inherent problems of imprecision and uncertainty in the clinical data and the interpretation methods used. These problems have yet to be addressed in computerised CTG systems. Secondly, the CTG does not contain sufficient information for accurate assessment of the fetal condition. 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 [2].

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 [3].

A. Uncertainty and imprecision in fetal heart rate analysis

In the past, several Cardiotocogram features have been identified and basic guidelines for their interpretation established to provide clinicians with a method of predicting the condition of the foetus and outcome of labour. The five key features in the CTG are heart rate baseline, acceleration and deceleration in heart rate, heart rate variability and uterine contractions as shown in figure 1

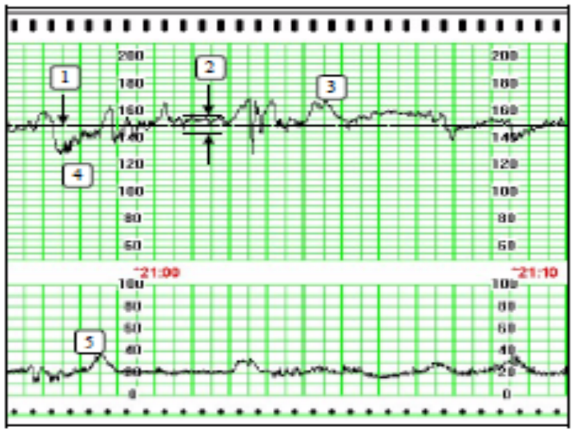

Figure.**1.** An example 15 minute segment of Cardiotocogram with important features.

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

In CTG analysis systems, each feature is identified and then classified using rules derived from the guidelines as shown in Tables 1 and 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

The problem is that the guidelines are based on empirical observations and lacks precision because of the high false positive abnormality rate of the Cardiotocogram. This has led to a situation where two experts can give different interpretations of the same Cardiotogram trace.

Again, there are no precise expected outcomes for a given set of features even when interpreted consistently. A reason for this is that the CTG features alone are insufficient to give an accurate indication of fetal condition. More clinical information is needed for a realistic interpretation of data. In addition, methods used to identify CTG features are inexact and vary from system to system [4].

Most current computerized intelligent CTG systems use crisp models, despite the imprecision and uncertainties in the clinical knowledge and data. The crisp rule does not capture the obvious vagueness inherent in the clinician's model of CTG interpretation. A variety of different techniques may be used to handle the imprecision and uncertainty in CTG analysis but fuzzy logic fuzzy set theory offer the most comprehensive and flexible framework to address the problems [5].

II. MATERIALS AND METHODS

A. Fuzzy model for Cardiotocogram (CTG) analysis

The two key parameters of a fuzzy model are the fuzzy sets and fuzzy rules. The main issues in the design of the fuzzy sets for Cardiotocogram analysis include the choice of the shape of membership functions for the sets, set names, number of sets, position and universe of discourses for the sets [6]. The fuzzy model that incorporates the fuzzy sets and fuzzy rules is shown in figure 2.

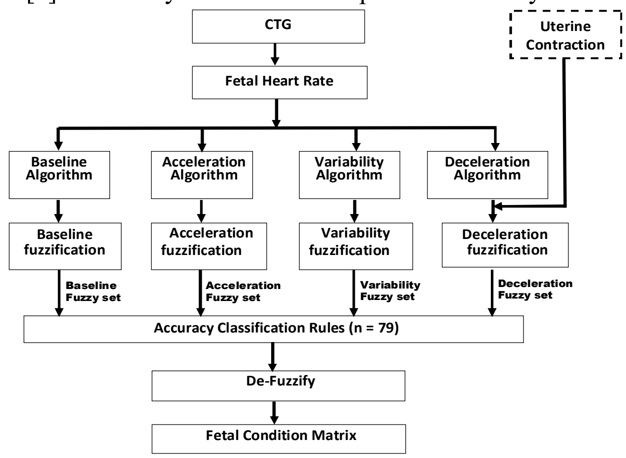

Figure 2: Fuzzy model for CTG analysis

The fuzzy sets are used to represent the four features of the Cardiotocogram (CTG) (baseline, variability, accelerations and decelerations) and the CTG segment. They model the linguistic classification of the features and the classification of Cardiotocogram segments. The linguistic terms and classifications for the CTG features are:

Baseline {Low, Slightly Low, Normal, Slightly High, High}

Variability {Absent, Reduced, Normal, Increased}

Accelerations {Absent, Present}

Decelerations {Absent, Present}

The linguistic terms for the CTG features are a natural choice for fuzzy set names. Triangular membership curves are used for the membership functions as they represent clinical model for CTG analysis. There are two sets of rules for Cardiotocogram analysis:

A set of rules for classifying each of the four CTG features-Baseline, Variability, Accelerations and Decelerations.

A rule set to provide an overall classification for the segment.

The features of heart rate and contractions are first identified using numerical algorithms and then fuzzified. Mamdani's inference is used to apply the rules. The segment classification output set is defuzzified using the centroid method to give a scalar value [7].

B. Fuzzy model for Electrocardiogram (ECG) analysis

The two primary design parameters in the fuzzy ECG model are the fuzzy sets and the fuzzy rules [8]. In the design of fuzzy sets, it is necessary to first describe the features and facts using linguistic variables. The important linguistic terms used in the clinical guidelines are given below. The words in brackets are the different categories.

1) T/QRS Ratio: {Constant, Increasing, Rising, Rapidly Increasing, Negative, Positive, High, Normal}
2) ST Waveform: {Normal, Depressed, Negative, Elevated, Raised, Bi-Phasic, Changing, Acute change}
3) CTG Pattern: {Normal reactive, Intermediate, Abnormal, Normal, Pre-terminal}
4) Heart Rate Decelerations: {Increased, bradycardia, Low, tachycardia, High, Normal, Rapid return}
5) Heart rate variability: {Increased, Decreased, Normal, Undulating}

In the design of the fuzzy sets, we have used the linguistic terms as set names to keep close to the language of the clinicians [9]. Triangular membership functions are used and the fuzzy rules are derived from the clinical guidelines and from formal and informal consultation with expert clinicians. The four categories of rules used are stated below:

1) Rule for CTG analysis and interpretation. ECG features can only be properly interpreted if this is carried out in association with CTG analysis.
2) Rules for assessing the quality of ECG data. Fetal ECG features are susceptible to distortion and need to be interpreted in

proper context.

3) Rules for Static Pattern Recognition-These are rules for the recognition and classification of important changes in the T complex shape and ST shape.
4) Rules for Dynamic Pattern Recognition- These are rules for managing the progressive changes in ECG wave shape and for keeping track of past events.

The fuzzy model that embodies the fuzzy sets and rules is shown in figure 3.

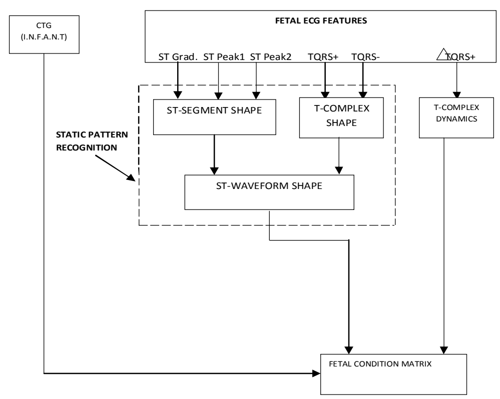

Figure 3: Fuzzy model for ECG analysis

III. THE RESULTS

The results obtained from the measured values and the fuzzy inference system for the accuracy of the fetal heart rate is presented in Table 3.

Table 3: 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

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

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the mother's abdomen.

The CTG 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. 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.

V. CONCLUSION

The fuzzy model for Cardiotocogram (CTG) analysis to handle the imprecision and uncertainty in the clinical data and knowledge during labour has been presented. The model for CTG analysis was compared to the fuzzy logic system and the results indicates that the fuzzy logic approach gives improved performance.

The fuzzy model for Electrocardiogram (ECG) includes a method based on finite state machine concepts for handling the sequences of events during the course of labour [10]. This is an important aspect of the model as there are many situations during labour in which the expert's interpretation of the CTG is informed by previous events and their sequence.

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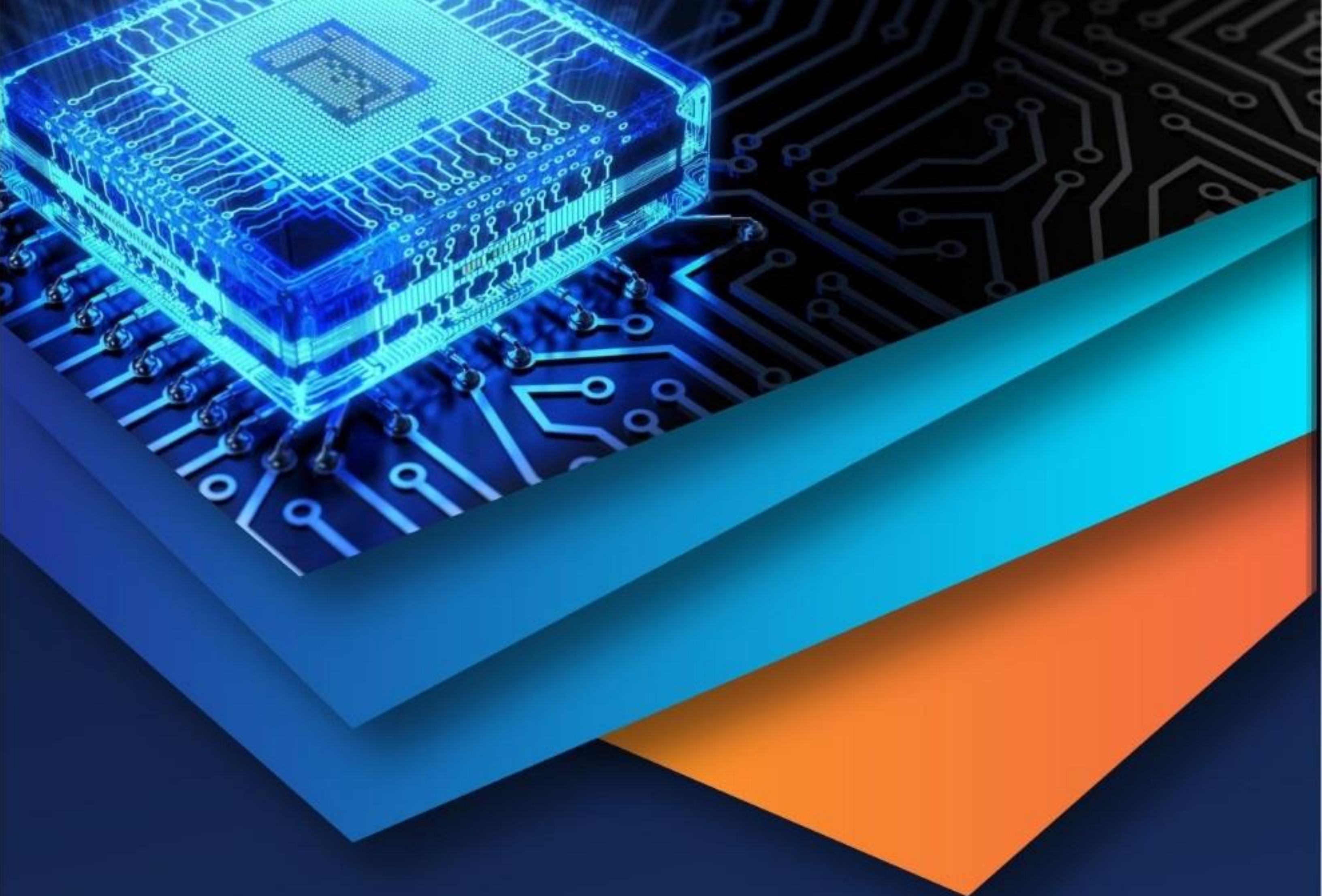

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