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(54) **APPARATUS FOR MONITORING THE CONDITION OF A FETUS**

VORRICHTUNG ZUR BEOBACHTUNG DES ZUSTANDES EINES FÖTUS

APPAREIL DE CONTROLE DE L'ETAT D'UN FOETUS

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Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to electronic fetal monitoring and, more particularly, to a method and apparatus for classifying a fetal heart rate signal to assess a degree of risk for permanent neurological damage associated to the fetus.

BACKGROUND OF THE INVENTION

[0002] During labour, a fetus may experience oxygen deprivation that can produce permanent neurological damage. Cerebral palsy (CP) is a permanent neurological condition characterised by neuromotor spasticity and often associated with seizures and or mental retardation. In severe forms the child may be unable to crawl, have frequent seizures and severe mental handicap. Brain injury from insufficient oxygenation of the baby during labor leading to cerebral palsy is a condition obstetricians wish to avoid. Typically, since the fetus is not easily accessible and therefore evaluation is based on indirect observations, the medical team evaluates indirect signs of insufficient oxygenation of the baby during labour and may intervene with various diagnostic or therapeutic options to avoid serious fetal compromise.

[0003] One of the most commonly used methods to evaluate fetal tolerance to labour is analysis of the fetal heart rate by using electronic fetal monitors. These monitors measure both the fetal heart rate and the mother's uterine contraction pattern. They produce a paper print out of the tracing over time. Historically, the clinical staff used visual methods to study the tracings and from this deduce the degree of fetal well being in regards to tolerance to labour or pre-labour conditions. Abnormal patterns can lead to interventions such as more diagnostic tests, induced delivery of the baby or delivery by cesarean section. The features of the fetal heart rate that are used by clinicians include baseline, accelerations, deceleration and variability of the fetal heart rate.

[0004] A deficiency with the above described method is that it does not allow to objectively quantify multiple features of tracings over time since the analysis of the strip by the doctor or nurse is visual and therefore subject to imprecision and normal human biases. Physicians show great variation in how they measure, label and interpret fetal heart rate patterns, particularly when the patterns are measured only by visual inspection of the paper recording. While doctors and nurses are trained and presumably competent in their ability to assess the strip, there can be differences of opinion that may result in different interventions being done to the patient. There is often no suitable confirmation of the preoperative diagnosis that can be used to objectively validate the doctor's decision.

[0005] The issue of whether severe neurological damage could have been prevented with a suitable diagnosis is the issue of several lawsuits in the United Kingdom and in the United States. Due to the lack of objective and reliable data, the actions of the health care team are frequently considered not defensible and several cases are settled out of court. Irrespective of the exact proportions of preventable cases, the total malpractice cost born by obstetricians is staggering. Total annual estimated cost by the Florida Neurologic compensation Board for the labor & delivery related injuries or death was (no fault cost 27.5$ million per year). Births in Florida represent 4% of the total US births. Extrapolating these rates to the entire United States, the cost of birth related brain injury is approximately 650 million USD annually without accounting for the human cost. For additional information pertaining to the above, the reader is invited to refer to Frank A. Sloan, PhDa, Kathryn Whetten-Goldstein, PhDb, Gerald B. Hickson, MDc, The influence of obstetric no-fault compensation on obstetricians' practice patterns, American Journal of Obstetrics and Gynecology September 1998, part 1 • Volume 179 • Number 3 • p671 to p676.

[0006] A further difficulty in the study of this problem is the relative rarity of serious fetal compromise, both due to its natural low incidence and the fact that the medical team will intervene to prevent its full development whenever there is an indication of it beginning. The difficulty inherent in studying a rare event has been addressed by substituting more commonly observed early new-born outcome characteristics that are related to permanent birth related neurological damage. Examples of these more commonly observed outcomes are low Apgar scores, (a 10 point measure of vigor at birth), or rates of caesarean section for fetal distress. A further extension of this concept is to use even simpler measures such as a scoring of the fetal heart rate record and placing it in various categories based on the cumulative score (Krebs, Fischer scores).

[0007] A deficiency of methods of the type described above is that the prognosis of babies with these outcomes e.g. low Apgar scores, caesarean section for fetal distress, low Fisher or low Krebs scores, is generally very good. These tests do not allow an adequate level of discrimination between babies who have poor prognosis and those with a good prognosis.

[0008] In the context of the above, there is a need in the industry to provide a method and device for classifying a condition of a fetus that alleviates at least in part problems associated with the existing methods.

SUMMARY OF THE INVENTION

[0009] In accordance with a first broad aspect, the invention provides a method suitable for monitoring the condition of a fetus according to claim 34. A signal indicative of a fetal heart rate is received and processed to derive data indicative of a degree of risk of developing a permanent neurological condition. The data indicative of the degree of risk of developing a permanent neurological condition indicates a likelihood that the condition of the fetus belongs to a class in a group of classes, each class in the group of classes being associated with a pre-defined fetal condition. The data indicative of the degree of risk of developing a permanent neurological condition is then released.

[0010] An advantage of the present invention is that the degree of risk of developing a permanent neurological condition can be more objectively diagnosed.

[0011] Another advantage of the present invention is that by providing a more objective pre-delivery diagnosis, a later assessment regarding the issue of whether severe neurological damage could have been prevented can be more objectively assessed. For instance, in lawsuits the presence of objective and reliable data will allow the actions of the health care team to be considered and defended in a court of law.

[0012] In accordance with a non-limiting implementation, a signal indicative of uterine activity is also received and processed with the signal indicative of the fetal heart rate to derive the data indicative of a degree of risk of developing a permanent neurological condition.

[0013] In accordance with a specific implementation, each class in the group of classes is characterised by the presence or absence of new-born encephalopathy and according to the arterial cord blood gas base deficit, herein referred to as base deficit (BD), being above or below a pre-determined level.

[0014] In a specific implementation, the group of classes includes four classes namely:

- a first class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
- a second class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement below a pre-determined level;
- a third class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level; and
- a fourth class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

[0015] Advantageously, the invention allows classifying the condition of a fetus such as to indicate the presence or absence of new-born encephalopathy and the base deficit level being above or below a pre-determined level. When the baby is a fetus in-utero, the base deficit and the presence or absence of newborn encephalopathy cannot be directly assessed. The invention makes use of the fetal heart rate signal to classify the condition of the fetus according to the above-described classes.

[0016] Several mathematical techniques as well as rule-based techniques can be used to characterise the association of fetal heart rate patterns to the classes. Alternatively, artificial neural networks can be used to characterise the associations between fetal heart rate patterns and the classes described above.

[0017] In accordance with a specific implementation, the signal indicative of the fetal heart rate is processed using a neural network to derive a degree of risk of developing a permanent neurological condition related to hypoxic injury. The neural network includes a plurality of inputs and a set of outputs, the outputs corresponding to respective classes in the group of classes. The neural network is adapted to release at each of the outputs a likelihood value associated to a respective class in the group of classes indicating the likelihood that the condition of the fetus belongs to a given class.

[0018] In a non-limiting implementation, the signal indicative of a fetal heart rate is processed to derive a plurality of feature measures. These feature measures are provided to the plurality of inputs of the neural network. The signal indicative of a fetal heart rate includes heart rate information collected over a certain period of time. The certain period of time may have any suitable duration. In a specific non-limiting example, the certain period of time is in excess of 1 hour. In another specific non-limiting example, the certain period of time is in excess of 2 hours. In another specific non-limiting example, the certain period of time is in excess of 3 hours. In yet another specific non-limiting example, the certain period of time is in excess of 4 hours.

[0019] In accordance with yet another broad aspect, the invention provides a computer readable storage medium according to claim 32, which includes a program element suitable for execution by a computing apparatus for monitoring the condition of a fetus in accordance with the above described method.

[0020] In accordance with another broad aspect, the invention provides a fetal monitoring system according to claim 33.

[0021] In accordance with another broad aspect, the invention provides an apparatus for monitoring the condition of a fetus in accordance with the above-described method.

[0022] This apparatus is as defined in claims 1 to 31.

[0023] In particular, the apparatus can comprise a trained neural network for monitoring the condition of a fetus. The neural network comprises an input unit, a processing core and a set of outputs. The input unit is for receiving feature measures derived from a signal indicative of a fetal heart rate of a fetus. The set of outputs are associated to respective classes in a group of classes, each class in the group of classes being associated with a pre-defined fetal condition. The processing core processes the feature measures received at the input unit and releases at each output in the set of outputs data indicative of a likelihood that the condition of the fetus belongs to a respective class.

[0024] In accordance with a non-limiting implementation, the input unit also receives feature measures derived from a signal indicative of uterine activity.

[0025] In accordance with a specific implementation, each class in the group of classes is characterised by the presence or absence of new-born encephalopathy and according to the arterial cord blood gas base deficit, herein referred to as base deficit (BD), being above or below a pre-determined level. In a specific implementation, the group of classes includes the four classes described above.

[0026] In accordance with yet another broad aspect, the invention provides a computer readable storage medium including a program element suitable for execution by a computing apparatus for implementing the above described neural network.

[0027] A method for training a neural network suitable for monitoring the condition of a fetus can be implemented. The method includes receiving a plurality of records, each record comprising a first entry indicative of a fetal heart rate signal and a second entry indicative of a class selected from a group of classes, each class in the group of classes being indicative of a pre-defined fetal condition. The neural network is conditioned on the basis of the first and second entries of each record such as to enable the neural network, upon reception of a signal indicative of a fetal heart rate to derive a likelihood that the condition of the fetus belongs to a class in the group of classes.

[0028] In accordance with a specific implementation, each class in the group of classes is characterised by the presence or absence of new-born encephalopathy and according to the arterial cord blood gas base deficit, herein referred to as base deficit (BD), being above or below a pre-determined level. In a specific implementation, the group of classes includes the four classes described above.

[0029] In accordance with a specific implementation, the neural network assigns likelihood values to each class in the group of classes, at least in part on the basis of the signal indicative of a fetal heart rate. The neural network includes a plurality of inputs and a set of outputs, the outputs corresponding to respective classes in the group of classes. The signal indicative of a fetal heart rate is processed to derive a plurality of feature measures. The plurality of measures is then provided to the plurality of inputs of the neural network.

[0030] In accordance with another broad aspect, the invention provides an apparatus suitable for monitoring the condition of a fetus. The apparatus includes an input, a feature extraction unit, a neural network module and an output. The input is for receiving a signal indicative of a fetal heart rate. The feature extraction unit processes the signal indicative of the fetal heart rate to derive feature measures. The neural network module processes the feature measures to derive data indicative of a degree of risk of developing a permanent neurological condition. The data indicative of the degree of risk of developing a permanent neurological condition indicates a likelihood that the condition of the fetus belongs to a class in a group of classes, each class in the group of classes being associated with a pre-defined fetal condition. The output releases the data indicative of the degree of risk of developing a permanent neurological condition.

[0031] In accordance with a specific implementation, the feature extraction unit processes the fetal heart rate to identify a plurality of feature events. The feature extraction unit processes the plurality of feature events to generate a plurality of feature measures. The plurality of feature measures is then summarised to generate a compact representation of feature measures. The compact representation of feature measures is then release by the feature extraction unit for processing by the neural network module.

[0032] In a non-limiting implementation, the plurality of feature events includes at least some events selected from the set consisting of baseline, acceleration, deceleration and contraction events.

[0033] These and other aspects and features of the present invention will now become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] In the accompanying drawings:

Fig. 1 shows a high level block diagram of a fetal monitoring system in accordance with a specific example of implementation of the present invention;

Fig.2a, 2b, 2c and 2d show alternative specific examples of the output of the fetal monitoring system shown in figure 1;

Fig. 3 shows a block diagram of a processing unit operative to derive a degree of risk of developing a permanent neurological condition in accordance with a specific example of implementation of the present invention;

Fig. 4 shows a high level conceptual block diagram of a neural network implemented by the processing unit depicted in figure 3 in accordance with a non-limiting example of implementation of the invention;

Fig. 5 is a block diagram of a feature extraction unit implemented by the processing unit depicted in figure 3 in accordance with a non-limiting example of implementation of the invention;

Fig. 6 is a flow diagram of a process for generating a trained neural network of the type depicted in figure 4 in accordance with a non-limiting example of implementation of the invention;

Fig..7 is a block diagram depicted the classification scheme of a fetal condition on the basis of the presence/absence of neonatal encephalopathy and the base deficit level in accordance with a non-limiting example of implementation of the invention;

Fig. 8 shows a portion of a simplified fetal heart rate signal with labelled feature events in accordance with a non-limiting example of implementation of the invention;

Fig. 9a, 9b, 9c and 9d are graphs showing feature measures generated by the feature extraction unit in accordance with a non-limiting example of implementation of the present invention;

Fig. 10 is a block diagram of an apparatus for monitoring the condition of a fetus in accordance with a specific example of implementation of the present invention;

Fig. 11 a, 11b, 11c and 11d are graphs showing weighting windows for use in the decimation of sets of feature measures in accordance with non-limiting examples of implementation of the present invention.

[0035] Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

DETAILED DESCRIPTION

[0036] With reference to Fig. 1, there is shown a configuration of a fetal monitoring system comprising a fetal heart rate sensor 110, an apparatus suitable for monitoring the condition of a fetus 100 and an output unit 114.

[0037] The fetal heart rate sensor 110 is for detecting a fetal heart rate of a fetus in-utero, also referred to as a fetus in the womb. The fetal heart rate sensor 110 samples the fetal heart rate at a certain pre-determined frequency to generate the signal indicative of the fetal heart rate. Fetal heart rate sensors are well known in the art to which this invention pertains and any suitable sensor for detecting a fetal heart rate may be used and as such will not be described further here.

[0038] In a non-limiting implementation, the fetal monitoring system includes a sensor (not shown) for monitoring uterine activity (TOCO). The sensor samples the contraction pattern at a certain pre-determined frequency to generate the signal indicative of uterine activity. Sensors for monitoring uterine activity are well known in the art to which this invention pertains and any suitable sensor may be used and as such will not be described further here.

[0039] The signal indicative of the fetal heart rate and the signal indicative of uterine activity may be processed jointly or separately by processing unit 100 to derive data indicative of a degree of risk of developing a permanent neurological condition. For the purpose of simplicity and conciseness, the processing of the signal indicative of the fetal heart rate by apparatus 100 is described in detail herein below. It will be readily appreciated that similar processing may be applied to the signal indicative of uterine activity.

[0040] The apparatus suitable for monitoring the condition of a fetus 100 includes an input 102, a processing unit 106 and an output 108. The input 102 receives the signal indicative of the fetal heart rate from the fetal heart rate sensor 110. The processing unit 106 processes the signal received at input 102 to derive data indicative of a degree of risk of developing a permanent neurological condition. More specifically, the processing 106 unit derives a likelihood that the condition of the fetus belongs to a class in a group of classes, each class in the group of classes being associated with a pre-defined fetal condition. The likelihood may be in the form of a probability value, a ranking or any other value that allows ordering the classes on the basis of the confidence level that the condition of the fetus belong to the class.

[0041] In accordance with a specific implementation, each class in the group of classes is characterised by the presence or absence of new-born encephalopathy and according to the arterial cord blood gas base deficit, herein referred to as base deficit (BD), being above or below a pre-determined level. The pre-determined level of base deficit is selected such that infants having a base deficit level above the pre-determined level are associated to a higher degree of risk of developing cerebral palsy than children below the pre-determine level. In a non-limiting specific implementation, the pre-determined level of base deficit measurement is about 12 mmol/L. Alternatively, the pre-determined level of base deficit may be different for a fetal condition characterised by the presence of new-born encephalopathy and a foetal condition characterised by the absence of new-born encephalopathy. In a non-limiting specific implementation, the pre-determined level of base deficit measurement is about 12 mmol/L when the foetal condition is characterised by the presence of new-born encephalopathy and 8 mmol/L when the foetal condition is characterised by the absence of new-born encephalopathy. It will be appreciated that other suitable pre-determined levels of base deficit may be used.

[0042] Generally speaking, neonatal encephalopathy is a collection of neurologic signs typically including hypotonia, hypertonia, respiratory or feeding difficulty of central origin, seizures, coma. According to the American College of Obstetrics and Gynecology and the Society of Obstetricians and Gynecologists of Canada SOGC clinical guidelines, the characteristics of the newborn response to asphyxia of such a degree as to be likely to cause permanent harm include neonatal encephalopathy. The measure of base deficit is typically measured in the arterial blood of the umbilical cord. This is a measure of metabolic acidosis and is considered to be a direct consequence of fetal tissue oxygen deprivation. The level of base deficit measurement indicates whether the baby was exposed to substantial oxygen deprivation. Increasing degrees of metabolic acidosis with arterial cord base deficit levels over 12 mmol/L are highly correlated with neurological deficits later in their lives. For additional information regarding the above, the reader is invited to consult Low J.A., The role of blood gas and acid-base assessment in the diagnosis of intrapartum fetal asphyxia, Am J Obstet Genecol, 1988; 159:1234-40 and Low J.A. et al., Motor and cognitive deficits after intrapartum asphyxia in the mature fetus, Am J Obstet Gynecol. 1988 Feb;158(2):356-61.

[0043] Advantageously, by providing a classification of the condition of the fetus according to the measure of base deficit and the presence or absence of neonatal encephalopathy, a useful indication of the degree of risk of developing a permanent neurological condition related to hypoxic injury can be obtained.

[0044] In a specific implementation, the group of classes includes four classes namely:

- a first class, herein referred to as Class A, associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
- a second class, herein referred to as Class B, associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement below a pre-determined level;
- a third class, herein referred to as Class C, associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level; and
- a fourth class, herein referred to as Class D, associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

[0045] When the baby is a fetus in-utero, the base deficit and the presence or absence of newborn encephalopathy cannot be directly assessed. The processing unit 106 makes use of the fetal heart rate signal received from the fetal heart rate sensor 110 to classify the condition of the fetus according to the above described classes.

[0046] Advantageously, the above described classification provides intermediate risk classes where it is likely that intervention would prevent the baby from deteriorating into the category associated with a high likelihood of development of cerebral palsy. For example, a high likelihood of the condition of the fetus being classified in class A indicates to the physician or other health care professional that the fetus is in a high risk category for developing cerebral palsy. Alternatively, a high likelihood of the condition of the fetus being classified in classes B or C indicates to the physician or other health care professional that the condition fetus is in an intermediate risk category for developing cerebral palsy and that intervention may prevent the fetus from deteriorating in to a class having a greater risk for developing cerebral palsy such as class A. Finally, a high likelihood of the condition of the fetus being classified in class D indicates to the physician or other health care professional that the condition fetus is in a low risk category for developing cerebral palsy and the intervention on this basis may not be necessary.

[0047] The processing unit 106 releases at its output 108 data indicative of the degree of risk of developing a permanent neurological condition. In a first non-limiting example, the data is in the form of confidence levels associated to the respective classes in the group of classes indicating the likelihood of the condition of the fetus belonging to each class. In a second non-limiting example, the data includes an identifier associated to the class to which the condition of the fetus is most likely to belong.

[0048] The output unit 114 receives the data indicative of the degree of risk of developing a permanent neurological condition generated by the processing unit 106 and provides it to the physician or other health care professional in a visual and/or audio format. The output unit 114 may be in the form of a display screen, a paper print out or any other suitable device for conveying to the physician or other health care professional the data indicative of the degree of risk of developing a permanent neurological condition. In a first non-limiting implementation, as shown in figure 2a, the output unit 114 provides each class and its associated likelihood to the physician or other health care professional. In a second non-limiting example, as shown in figure 2b, the output unit 114 provides the class to which the condition of the fetus is most likely to belong and optionally associated likelihood to the physician or other health care professional. In a third non-limiting example, as shown in figure 2c, the output unit 114 provides a description of the condition of the fetus derived on the basis of the class the fetus is most likely to belong. The output unit 114 may provide the physician or other health care professional with data indicative of the degree of risk of developing a permanent neurological condition in a plurality of other suitable fashions, which will be readily apparent to the person skilled in the art in light of this description.

[0049] As shown in figure 2d, the output unit 114 may also display fetal heart rate patterns and other information in addition to the data indicative of the degree of risk of developing a permanent neurological condition.

[0050] The manner in which the processing unit 106 processes the fetal heart rate signal to classify the condition of the fetus in-utero is described in greater detail herein below.

Processing Unit 106

[0051] The processing unit 106 (shown in figure 1) implements an expert system to derive the degree of risk of developing a permanent neurological condition associated to the fetus. The expert system implemented by the processing unit 106 may be rule-based where the association of fetal heart rate and a class are expressed mathematically or through a logical/algorithmic association. Alternatively, trained artificial neural networks can be used to characterise the associations between fetal heart rate patterns and the classes described above. Advantageously, the use of a neural network allows modelling complex interrelated non-linear relationships between the fetal heart rate patterns and the above-described classes. In yet another alternative, the processing unit 106 makes use of a combination of an artificial neural network and a rule-based expert system.

[0052] As shown in figure 3, the processing unit 106 includes a feature extraction unit 300 and a trained artificial neural network module 302.

[0053] The feature extraction unit 300 processes the signal indicative of a fetal heart rate received at input 102 over a certain period of time to derive a plurality of feature measures characterising the signal indicative of the fetal heart rate.

[0054] The trained artificial neural network module 302 includes a plurality of inputs and a set of outputs, where the outputs correspond to respective classes in the group of classes. The neural network module 302 is adapted to process the plurality of feature measures received at its inputs to release at each of the outputs a likelihood value associated to a respective class.

[0055] The feature extraction unit 300 and the neural network module 302 are described in greater detail herein below.

Feature Extraction Unit 300

[0056] The feature extraction unit 300 processes the fetal heart rate signal over a certain period of time to generate a plurality of feature measures. The certain period of time may have any suitable duration. In a specific non-limiting example, the certain period of time is in excess of 1 hour. In another specific non-limiting example, the certain period of time is in excess of 2 hours. In another specific non-limiting example, the certain period of time is in excess of 3 hours. In yet another specific non-limiting example, the certain period of time is in excess of 4 hours. The time period used by the feature extraction unit has the same duration as the fetal heart rate signal on which the neural network was trained. Where the fetal heart rate signal, which is being processed, has a duration that is different from the duration of the signal on which the neural network was trained, extrapolation/truncation and compression methods may be used to expand or shorten the duration of the fetal heart rate signal. The feature extraction unit 300 releases the plurality of feature measures and provides them to the artificial trained neural network module 302.

[0057] The feature extraction unit 300 is shown in greater detail in figure 5 and includes three functional modules namely a feature detection module 500, a feature measurement module 502 and a feature summary module 504.

[0058] The feature detection module 500 processes the fetal heart rate signal and performs a time-domain segmentation of the fetal heart rate signal to locate feature events of interest. In a non-limiting example of implementation, the feature detection module 500 detects features events including without being limited to baseline, deceleration, acceleration and contraction feature events. Any suitable method for detecting baseline, deceleration, acceleration and contraction events may be used here. For additional information, the reader is invited to refer to Mantel R, Van Geijn HP, Caron FJM, Swartjes JM, Van Woerden EE, Jongsma HW: Computer analysis of antepartum fetal heart rate: 1. baseline determination. 2. detection of accelerations and decelerations. Int J Biomed Comput 25, 261 (1990). A simplified representation of a portion of a fetal heart rate signal where the baseline, deceleration, acceleration events are labelled is shown in figure 8. Figure 8 shows a portion 800 of a fetal heart signal having a duration of about 3-minutes. The portion 800 has been segmented by the feature detection module 500 such as to indicate a deceleration feature event 802, a baseline feature event 806 and an acceleration feature event 804. For each feature event, a determination of its temporal location within the fetal heart rate signal, namely the beginning and ending time of the feature event, is made. Although figure 8 shows the time-domain segmentation performed by the feature detection module 500 for a 3-minute segment, the above process is performed for the entire fetal heart rate signal being processed. The feature detection module 500 releases a list of feature events with their beginning and ending times.

[0059] The feature measurement module 502 receives the list of feature events with their beginning and ending times from the feature detection module 500. For each feature event, measures are generated describing characteristics of the feature event. In a non-limiting specific implementation, for a baseline feature event, feature measures describing the mean, frequency, length, variability and sinusoidal pattern of the baseline feature event are calculated. For a deceleration or acceleration feature event, feature measures describing the mean, frequency, length, variability and area of the deceleration or acceleration feature event are calculated. For a contraction feature event, feature measures describing

the frequency and deceleration recovery time of the contraction feature event are calculated. The time sequence of certain feature events with respect to other feature events, which can be of clinical significance (e.g. deceleration recovery time following contraction), may be included in the feature measures. The table below illustrates a non-limiting example of various feature measures used for certain feature events. It will be readily apparent to the person skilled in the art that other feature measures may be used in addition to the feature measures identified below and certain feature measure may be omitted.

Table 1Example of feature measures

Baseline	Deceleration	Acceleration	Contraction
Mean	Mean	Mean	Deceleration recovery time
Frequency	Frequency	Frequency	Frequency
Length	Length	Length	
Variability	Variability	Variability	
Sinusoidal pattern	Area	Area	

[0060] The computation of the various feature measures may be effected using any suitable technique. Such techniques are well known in the art of signal processing and as such will not be described further here. Generally, where the fetal heart rate signal is processed over a long period of time, several thousands of features measures are obtained.

[0061] The feature measurement module 502 releases a plurality of sets of feature measures, each set of feature measures includes feature measures describing a given characteristic of a feature event. For example, a first set of feature measures will include all the features measures for the mean values of baseline feature events. A second set of feature measures will include all the features measures for the frequency values of baseline feature events. A third set of feature measures will include all the features measures for the mean values of acceleration feature events and so on. Generally speaking, the sets of feature measures characterise feature events that are irregularly spaced in time. Figure 9a shows in simplified form the set of feature measures for the baseline mean values over a 4-hour time period. As shown, the fourteen feature measures labelled M_1 to M_{14} are irregularly spaced in the time domain.

[0062] The feature summary module 504 receives the sets of feature measures from the feature measurement module 502. For each set of feature measure, the feature summary module 504 processes the feature measures in the set to obtained a set of feature measures which is compact and regularly spaced in the time domain.

[0063] In a non-limiting example, this process is effected in two steps. The first step involves interpolating the feature measures in each set onto a sampling grid to generate a plurality of feature measures where the sampling grid has a certain frequency. Any suitable type of interpolation may be used including linear, spline or cubic interpolation. In a specific non-limiting implementation, the sampling grid has a frequency equal to the frequency of the fetal heart rate signal. Figure 9b shows in simplified form the set of feature measures for the baseline mean over a 4-hour time period interpolated at the frequency of the fetal heart rate signal. The signal depicted is labelled b_{INTER} and forms the interpolated set of feature measures for the mean values of baseline feature events.

[0064] Optionally, following the interpolation of the feature measures and in order to reduce the amount of data to be processed by the neural network module 302 (shown in figure 3), the interpolated set of feature measures b_{INTER} is decimated at a desired sampling rate by a low-pass filter to generate a compact representation of the set of feature measures. The desired sampling rate may be different for each set of feature measures. For example, feature measures that change more rapidly can be given a time resolution that adequately describes them. For example, the features measures for the variability values of baseline feature events may be sampled to get a value at each 60 minute interval while the features measures for the mean values of baseline feature events may be sampled to get a value at each 15 minute interval. Figure 9c shows in simplified form the set of feature measures for the baseline mean over a 4-hour time period decimated to obtain a sample at every hour. As shown, the baseline feature measures for the mean are summarised as four feature measures labelled B_{m1}, B_{m2}, B_{m3} and B_{m4} respectively in figure 9c. Feature measures labelled B_{m1}, B_{m2}, B_{m3} and B_{m4} form a compact representation of the set of feature measures for the mean values of baseline feature events for the four-hour time period.

[0065] Many decimation techniques for reducing the number of feature measures in the interpolated set of feature measures b_{INTER} may be used here for reducing the number of feature measures. In a non-limiting implementation, a weighted average of the feature measures in the interpolated set of feature measures b_{INTER} is used to obtain the feature measure value sampled at the decimated frequency. Figure 9d illustrated a set of weighting windows applied to the interpolated signal b_{INTER} shown in figure 9b to obtain the samples of figure 9c. In figure 9d, the weighting windows are labelled w[1], w[2], w[3] and w[4] and are associated to samples B_{m1}, B_{m2}, B_{m3} and B_{m4} respectively. Each weighting

windows w[k] is selected such as to weigh more heavily feature measures in the interpolated set of feature measures b_{INTER} occurring closer to sample B_{mk} and to weigh less heavily feature measures in the interpolated set of feature measures b_{INTER} occurring further sample B_{mk}. Mathematically, the computation of samples B_{m1}, B_{m2}, B_{m3} and B_{m4} can be expressed as follows:

Equation 1

$$B_{m1} = \frac{1}{2N}\sum_{i=0}^{N-1} w[1]_i * b_{INTER}[i]$$

$$B_{m2} = \frac{1}{2N}\sum_{i=N}^{2N-1} w[2]_i * b_{INTER}[i]$$

$$B_{m3} = \frac{1}{2N}\sum_{i=2N}^{3N-1} w[3]_i * b_{INTER}[i]$$

$$B_{m4} = \frac{1}{2N}\sum_{i=3N}^{4N-1} w[4]_i * b_{INTER}[i]$$

where N is the number of features measures at the interpolated frequency between the desired samples of the compact representation; w[k] is the weighting window associated to sample B_{mk}; and $b_{INTER}[k]$ is the kth feature measure the set of feature measures b_{INTER}.

[0066] In an alternative form, let be signal $b_{INTER}(n)$ include M samples (in the example shown in the figures M=4N). For the purpose of simplicity, we set $b_{INTER}(n)$ to zero outside the area of interest. Mathematically, this can be expressed as follows:

$$b_{INTER}(n) = b_{INTER}(n) \quad \text{for } 0 \le n < M$$

$$b_{INTER}(n) = 0 \text{ for } n < 0 \text{ and } n \ge M$$

[0067] Let $v(n)$ be the output of a low-pass decimation filter (or "weighting function") $w(n)$ where:

$$v(n) = \sum_{k=-\infty}^{\infty} b_{INTER}(k)w(n-k), \quad 0 \le n < M$$

[0068] In a first non-limiting implementation, the compact representation of the set of feature measures is a regularly sampled signal (e.g. samples once per hour). The output signal is downsampled by a factor D. The output is every D^{th} sample of $v(n)$ and can be expressed as follows:

$$y(m) = v(mD), \qquad 0 \le m < P, \quad \text{where } P = \frac{M}{D}$$

$$= \sum_{k=-\infty}^{\infty} b_{INTER}(k)w(mD-k)$$

where y(m) is the mth output sample of the compact representation of the set of feature measures.

[0069] A non-limiting example of the signal v(m) is shown in figure 11 b). The weighting function w(n), shown in figure 11 a), is defined as:

$$w(n) = \frac{\overline{w}(n)}{\sum_{i=-D}^{D} \overline{w}(n)}$$

where $\overline{w}(n)$ is a raised cosine of limited extent:

$$\overline{w}(n) = 1 + \cos\left[\frac{(n-1)\pi}{D-1}\right], \quad -D \le n \le D$$
$$= 0, \quad |n| > D$$

and the denominator of *w(n)* is a normalizing factor.

[0070] Alternatively, the compact representation of the set of feature measures is a signal sampled with irregularly spaced samples. ·Advantageously, sampling with irregular intervals allows higher sampling during time intervals considered most information-critical (e.g. the last hour of labour) than during intervals considered to be less information-critical.

[0071] In a non-limiting implementation, a local weighting function $w_m(n)$, of the type shown in figure 11 c), is applied at each sample of b_{INTER}. For example, if the sample spacing before and after sample m are D_{m-1} and D_m respectively, the weighting function before normalization can be expressed as follows:

$$\overline{w}_m(n) = 0, \quad n < -D_{m-1}$$
$$= 1 + \cos\left[\frac{(n-1)\pi}{D_{m-1}-1}\right], \quad -D_{m-1} \le n < 0$$
$$= 1 + \cos\left[\frac{(n-1)\pi}{D_m-1}\right], \quad 0 \le n \le D_m$$
$$= 0, \quad n > D_m$$

[0072] The output of the low-pass decimating filter, an example of which is shown in figure 11 d), can be expressed in a mathematical format as follows:

$$v(n) = \sum_{k=-\infty}^{\infty} b_{INTER}(k) w_m(n-k), \quad 0 \le n < M$$

and the downsampled output signal is:

$$y(m) = v[i(m)]$$
$$= \sum_{k=-\infty}^{\infty} b_{INTER}(k) w_m(i(m)-k), \quad 0 \le m < P$$

where *i(m)* is the set of *P* indices into *v(n)* of the irregularly spaced sample points.

[0073] It will be appreciated that other methods for decimating signal b_{INTER} may be used without detracting from the spirit of the invention.

[0074] For each set of feature measures, the above describe process of interpolation and decimation is effected by the feature summary module 504. The feature summary module 504 releases for each set of feature measures, the compact representation of the set of feature measures for processing by the neural network module 302 (shown in figure 3). Advantageously, by interpolating and decimating each set of feature measures, the feature summary module 502 presents feature measures to the neural network in a compact but representative fashion.

Artificial Trained Neural Network 302

[0075] A functional representation of the trained neural network module 302 is shown in figure 4 of drawings. As depicted, the trained neural network 302 includes an input unit 400, a processing core 402 and a set of outputs 404 406 408 410. The input unit 400 includes a plurality of inputs for receiving respective feature measures received from the feature extraction unit 300 (shown in figure 3).

[0076] Each output in the set of outputs 404 406 408 410 is associated to a respective class in the group of classes described above. In the non-limiting representation depicted in figure 4, output 404 is associated to class A, output 406 is associated to class B, output 408 is associated to class C and output 410 is associated to class D. The processing core 402 processes the feature measures received at the input unit 400 to release at each output data indicative of a likelihood that the condition of the fetus belongs to a respective class. In the non-limiting specific implementation, the neural network module 302 includes a multilayer perceptron (MLP) network trained by back propagation. The training of the artificial neural network is described herein below.

THE TRAINING PROCESS FOR THE ARTIFICIAL NEURAL NETWORK

[0077] Generally speaking, a neural network is a mathematical process capable of performing a large number of "experiments" based on observations to determine or "learn" the best way of mathematically representing the association between a given set of observations and an outcome. The neural network determines this association by processing a "training set" of data where it is given observations associated to respective actual outcomes in a set of pre-defined outcomes. The neural network is conditioned such that when the given observations are applied to its inputs, the corresponding actual outcome is released at the outputs. Conditioning a neural network in the basis of observations associated to respective actual pre-defined outcomes is known in the art and as such will not be described in further detail here. Once the neural network has been conditioned on the basis of the training set, when new observations are applied to the inputs of the neural network, likelihood values are released associated to the outcomes in the set of pre-defined outcomes indicating likelihood values that the new observations are associated to each pre-defined outcome. In this specific implementation, the observations are derived from fetal heart rate signals and are the feature measures and the set of pre-defined outcomes are the four classes (Class A; Class B; Class C and Class D) determined in the basis of the base deficit level and the presence or absence of neonatal encephalopathy.

[0078] The training of the artificial neural network 302 is described herein below with reference to figure 6 of the drawings. The training process can be divided into three distinct steps namely training set generation 600, feature extraction 602 and conditioning of the neural network 604.

[0079] In the training set generation step 600, a pool of baby health profiles including a plurality of entries is processed. Each entry in the pool corresponds to a respective baby and describes a health profile associated to the baby including a fetal heart rate signal, a base deficit measure and data indicating the presence/absence of neonatal encephalopathy.

[0080] Typically, the base deficit is measured in a newborn blood sample, which usually taken from the umbilical cord just after the cord is cut. This is a measure of metabolic acidosis and is considered to be a consequence of fetal tissue oxygen deprivation. The base deficit measures the total concentration of blood buffer base in units of equivalents/L. The presence/absence of neonatal encephalopathy is a clinical assessment based on the presence of certain criteria well known in the field of obstetrics and as such will not be described in further detail here. For additional information on this topic, the reader is invited to refer to Sarnat, HB. & Sarnat, MS. Neonatal encephalopathy following fetal distress. Arch Neurol 1976; 33: 696-705 and Badawi, N., Kurinczuk, JJ., Keogh, JM., Alessandri, LM., O'Sullivan, F., & Burton, PR. Antepartum risk factors for newborn encephalopathy: the Western Australian case-control study. BMJ 1998; 317: 15491553.

[0081] The presence of presence/absence of neonatal encephalopathy and the base deficit in each entry are used to classify the baby's condition into one of four classes. The classification scheme is shown in figure 7 of the drawings. Each entry in the pool of baby health profiles 700 is first classified into one of two groups where a first group 702 includes babies exhibiting neonatal encephalopathy and the second group 704 includes babies exhibiting an absence of neonatal encephalopathy 704. Following this, the entries in each group 702 704 are further divided into two groups wherein first groups 706 710 include babies exhibiting base deficit levels above a predetermined threshold and the second groups 708 718 including babies exhibiting base deficit levels below a predetermined threshold. It will readily be appreciated that the order of classification may be reversed such that each entry in the pool of baby health profiles 700 is first classified on the basis of the base deficit level and then classified on the basis of the presence or absence of neonatal encephalopathy. The entries in group 706 are associated to class A, the entries in group 708 are associated to class B, the entries in group 710 are associated to class C and the entries in group 712 are associated to class D.

[0082] For each entry in the pool of baby health profiles 700, a record is generated including a first member indicative of a fetal heart rate signal and a second member indicative of the class assigned by the above described processed. Preferably, several entries in the pool of baby health profiles are associated to each of the classes such as to provide

a suitable representation and observation set for the training of the artificial neural network. Generally, the fetal heart rate signals in the records have the same time duration. Extrapolation methods may be used to extend/shorter the length of a fetal heart rate signal where the signal does not have the desired time duration. The plurality of records generated in the above described manner forms the training set for the artificial neural network where the observations are derived from the fetal heart rate signal and the pre-defined outcomes are the assigned classes.

[0083] In the feature extraction step 602, for each record in the training set, the fetal heart rate signal is processed to derive a plurality of feature measures. In a non-limiting implementation, a feature extraction unit of the type described in connection with unit 300 (shown in figure 5 of the drawings) is used to generate a plurality of feature measures. The same feature measures used in the training of the neural network will be used when the neural network is used in the apparatus for monitoring the condition of a fetus 100.

[0084] In the conditioning of the neural network step 604, for each record in the training set, the plurality of feature measures are provided to respective inputs of the neural network. A simplified representation of the neural network is shown in figure 4. The input unit 400 of the network receives the feature measures. Each output in the set of outputs 404 406 408 410 is associated to a respective class. In non-limiting implementation, the neural network is a multilayer perceptron (MLP) network trained by backpropagation. For each record in the training set, the feature measures are presented to the input unit 400 of the network, the resulting outputs released by the set of outputs 404 406 408 410 are compared to the class in the record, and an error signal is generated. Using a standard backpropagation algorithm, this error is used to update the weights of the neural network such as to cause the output to reflect the class in the record. The training of a neural network in well known in the art an will not be described in further detail here.

SPECIFIC PHYSICAL IMPLEMENTATION

[0085] Those skilled in the art should appreciate that in some embodiments of the invention, all or part of the functionality previously described herein with respect to the apparatus for monitoring the condition of a fetus may be implemented as preprogrammed hardware or firmware elements (e.g., application specific integrated circuits (ASICs), electrically erasable programmable read-only memories (EEPROMs), etc.), or other related components.

[0086] In other embodiments of the invention, all or part of the functionality previously described herein with respect to the apparatus for monitoring the condition of a fetus may be implemented as software consisting of a series of instructions for execution by a computing unit. The series of instructions could be stored on a medium which is fixed, tangible and readable directly by the computing unit, (e.g., removable diskette, CD-ROM, ROM, PROM, EPROM or fixed disk), or the instructions could be stored remotely but transmittable to the computing unit via a modem or other interface device (e.g., a communications adapter) connected to a network over a transmission medium. The transmission medium may be either a tangible medium (e.g., optical or analog communications lines) or a medium implemented using wireless techniques (e.g., microwave, infrared or other transmission schemes).

[0087] The computing unit implementing the apparatus for monitoring the condition of a fetus may be configured as a computing unit of the type depicted in figure 10, including a processing unit 1002 and a memory 1002 connected by a communication bus 1008. The memory includes data 1010 and program instructions 1006. The processing unit 1002 is adapted to process the data 1010 and the program instructions 1006 in order to implement the functional blocks described in the specification and depicted in the drawings. In a non-limiting implementation, the program instructions 1006 implement the functionality of processing unit 106 described above. The computing unit 1002 may also comprise a number of interfaces 1012 1016 for receiving or sending data elements to external devices. For example, interface 1012 may be used for receiving data streams indicative of a fetal heart rate signal and interface 1012 may be for releasing a signal causing a display unit to display of the results of the method implemented by program instructions 1006. An interface for receiving a signal indicative of uterine activity (not shown) may also be provided.

[0088] Those skilled in the art should further appreciate that the program instructions 1006 may be written in a number of programming languages for use with many computer architectures or operating systems. For example, some embodiments may be implemented in a procedural programming language (e.g., "C") or an object oriented programming language (e.g., "C++" or "JAVA").

[0089] It will be appreciated that the system for monitoring the condition of a fetus may be of a distributed nature where the fetal heart rate signal is collected at one location by a fetal heart rate sense and transmitted to a computing unit implementing the apparatus 100 over a network. The network may be any suitable network including but not limited to a global public network such as the Intranet, a private network and a wireless network. In addition, the computing unit implementing the apparatus 100 may be adapted to process multiple fetal heart rates originating from multiple fetuses concurrently using suitable methods known in the computer related arts.

[0090] Although the present invention has been described in considerable detail with reference to certain preferred embodiments thereof, variations and refinements are possible within the scope of the appended claims.

Claims

1. An apparatus (100) suitable for monitoring the condition of a fetus, said apparatus (100) comprising:

   a) an input (102) for receiving a signal indicative of a fetal heart rate;
   b) a processing unit (106) coupled to said input (102), said processing unit (106) being operative for processing said signal indicative of the fetal heart rate to derive data indicative of a degree of risk of developing a permanent neurological condition related to hypoxic injury, the data indicative of the degree of risk of developing a permanent neurological condition indicating a likelihood that the condition of the fetus belongs to a class in a group of classes, each class in the group of classes being associated with a pre-defined fetal condition characterised at least in part by:

      i. a measure of base deficit being above or below a pre-defined level; and
      ii. a presence or absence of new-born encephalopathy;

   c) an output (108) for releasing the data indicative of the degree of risk of developing a permanent neurological condition.

2. An apparatus as defined in claim 1, wherein said input (102) is a first input, said apparatus (100) comprising a second input for receiving a signal indicative of uterine activity, said processing unit (106) being coupled to said first (102) and second inputs and being operative for processing said signal indicative of the fetal heart rate and said signal indicative of uterine activity to derive the data indicative of a degree of risk of developing a permanent neurological condition.

3. An apparatus as defined in claim 1, wherein for each class in the group of classes, the data indicates a likelihood value that the condition of the fetus belongs to the corresponding class.

4. An apparatus as defined in claim 1, wherein said group of classes includes at least four classes comprising:

   a) a first class and a second class associated to respective pre-defined fetal conditions indicative of a presence of new-born encephalopathy; and
   b) a third class and a fourth class associated to respective pre-defined fetal conditions indicative of an absence of new-born encephalopathy.

5. An apparatus as defined in claim 4, wherein said first class is associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a measure of base deficit above a pre-determined level.

6. An apparatus as defined in claim 4, wherein said second class is associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a measure of base deficit below a pre-determined level.

7. An apparatus as defined in claim 4, wherein said third class is associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level.

8. An apparatus as defined in claim 4, wherein said fourth class is associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

9. An apparatus as defined in claim 1, wherein said group of classes includes at least four classes comprising:

   a) a first class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
   b) a second class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement below a pre-determined level;
   c) a third class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
   d) a fourth class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

10. An apparatus as defined in claim 1, wherein said processing unit (106) includes a neural network (302).

11. An apparatus as defined in claim 10, wherein said neural network (302) includes an input unit (400) and a set of outputs (404 406 408 410), the outputs (404 406 408 410) corresponding to respective classes in the group of classes, said neural network (302) being adapted to release at each of said outputs (404 406 408 410) a likelihood value associated to a respective class in the group of classes.

12. An apparatus as defined in claim 11, wherein said processing unit (106) includes a pre-processing unit (300) operative to:

a) process the signal indicative of a fetal heart rate to derive a plurality of feature measures;
b) providing said plurality of feature measures to the input unit (400) of said neural network (302).

13. An apparatus as defined in claim 12, wherein said signal indicative of a fetal heart rate include heart rate information collected over a certain period of time.

14. An apparatus as defined in claim 13, wherein the certain period of time is in excess of 1 hour.

15. An apparatus as defined in claim 13, wherein the certain period of time is in excess of 2 hour.

16. An apparatus as defined in claim 13, wherein the certain period of time is in excess of 3 hour.

17. An apparatus as defined in claim 13, wherein the certain period of time is in excess of 4 hour.

18. An apparatus as defined in claim 1, wherein said processing unit (106) includes a neural network (302), said neural network (302) including:

a) an input unit (400) for receiving feature measures derived from the signal indicative of the fetal heart rate; and
b) a set of outputs (404 406 408 410) associated to respective classes in the group of classes;
c) a processing core (402) coupled to said input unit (400) and to said set of outputs (404 406 408 410), said processing core (402) being operative to release at each output (404 406 408 410) data indicative of a likelihood that the condition of the fetus belongs to a respective class on the basis of the feature measures received at said input unit (400).

19. An apparatus as defined in claim 18, wherein said group of classes includes at least four classes comprising:

a) a first class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
b) a second class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement below a pre-determined level;
c) a third class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
d) a fourth class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

20. An apparatus as defined in claim 1, wherein said processing unit comprises:

a) a feature extraction unit (300) coupled to said input (102), said feature extraction unit (300) being operative for processing the signal indicative of the fetal heart rate to derive feature measures;
b) a neural network module (302) coupled to said feature extraction unit (300), said neural network module (302) being operative to process the feature measures to derive data indicative of a degree of risk of developing a permanent neurological condition.

21. An apparatus as defined in claim 20, wherein said feature extraction unit (300) is operative for:

a) processing said fetal heart rate to identifying a plurality of feature events;
b) generating a plurality of feature measures for the plurality of feature events identified in a);
c) summarising said plurality of feature measures to generate a compact representation of feature measures;
d) providing the compact representation of feature measures to said neural network module (302).

22. An apparatus as defined in claim 21, wherein summarising said plurality of feature measures to generate a compact representation of feature measures includes:

a) processing the plurality of feature measures to generate at least one interpolated feature measure signal;
b) decimating the interpolated feature measure signal such as to generate the compact representation of feature measures.

23. An apparatus as defined in claim 22, wherein decimating the interpolated feature measure signal is effected on the basis of regular sampling intervals.

24. An apparatus as defined in claim 22, wherein decimating the interpolated feature measure signal is effected on the basis of irregular sampling intervals.

25. An apparatus as defined in claim 21, wherein the plurality of feature events includes at least some events selected from the set consisting of baseline, acceleration, deceleration and contraction events.

26. An apparatus as defined in claim 25, wherein subsets of the plurality of feature measures are associated to respective feature events, at least one subset being associated to a baseline feature event, said at least one subset including feature measures selected from the set consisting of mean value, frequency, length, variability and sinusoidal pattern.

27. An apparatus as defined in claim 25, wherein subsets of the plurality of feature measures are associated to respective feature events, at least one subset being associated to an acceleration feature event, said at least one subset including feature measures selected from the set consisting of mean value, frequency, length, variability and area.

28. An apparatus as defined in claim 25, wherein subsets of the plurality of feature measures are associated to respective feature events, at least one subset being associated to a contraction feature event, said at least one subset including a feature measure selected from the set consisting of frequency and deceleration recovery time.

29. An apparatus as defined in claim 21, wherein said group of classes includes at least four classes comprising:

a) a first class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
b) a second class associated to a pre-determined fetal condition indicative of the presence of new-born encephalopathy and a base deficit measurement below a pre-determined level;
c) a third class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement above a pre-determined level;
d) a fourth class associated to a pre-determined fetal condition indicative of the absence of new-born encephalopathy and a base deficit measurement below a pre-determined level.

30. An apparatus as defined in claim 21, wherein said neural network module (302) includes an input unit (400) and a set of outputs (404 406 408 410), the outputs (404 406 408 410) corresponding to respective classes in the group of classes, said neural network module (302) being adapted to release at each of said outputs (404 406 408 410) a likelihood value associated to a respective class in the group of classes.

31. An apparatus as defined in claim 30, wherein the compact representation of feature measures is provided to the input unit (400) of said neural network module (302).

32. A computer readable storage medium including a program element suitable for execution by a computing apparatus (1000) for monitoring the condition of a fetus, said computing apparatus (1000) comprising

a) a memory unit (1004);
b) a processor (1002) operatively connected to said memory unit (1004), said program element when executing on said processor (1002) being operative for execution by an apparatus for monitoring the condition of a fetus in accordance with any one of claims 1 to 31.

33. A fetal monitoring system comprising:

a) a sensor (110) for receiving a signal indicative of a fetal heart rate;

b) an apparatus (100) for monitoring the condition of a fetus according to any one of claims 1 to 31;
c) an output unit (114) in communication with said apparatus (100), said output unit (114) being adapted for displaying information conveying a degree of risk of developing a permanent neurological condition related to hypoxic injury.

34. A method suitable for monitoring the condition of a fetus, said method comprising:

a) receiving a signal indicative of a fetal heart rate;
b) transmitting said signal to an apparatus (100) for monitoring the condition of a fetus according to any one of claims 1 to 31;
c) receiving data indicative of a degree of risk of developing a permanent neurological condition related to hypoxic injury from the apparatus (100);
d) conveying the data indicative of the degree of risk of developing a permanent neurological condition to a user.

Patentansprüche

1. Vorrichtung (100), die zur Beobachtung des Zustandes eines Fötus geeignet ist, wobei die Vorrichtung (100) umfasst:

a) einen Eingang (102) für den Empfang eines Signals, das eine fötale Herzschlagfrequenz angibt;
b) eine Verarbeitungseinheit (106), die an den Eingang (102) gekoppelt ist, wobei die Verarbeitungseinheit (106) zur Verarbeitung des Signals betriebsbereit ist, das die fötale Herzschlagfrequenz angibt, um Daten zu erlangen, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln, der mit einer hypoxischen Verletzung in Zusammenhang steht, wobei die Daten, die das Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln, eine Wahrscheinlichkeit angeben, dass der Zustand des Fötus zu einer Klasse in einer Gruppe von Klassen gehört, wobei jede Klasse in der Gruppe von Klassen einem vordefinierten fötalen Zustand zugeordnet ist, zumindest teilweise **gekennzeichnet durch**:

i. einen Messwert eines Basendefizits, der über oder unter einem vorbestimmten Wert liegt; und
ii. ein Vorhandensein oder Fehlen einer Enzephalopathie beim Neugeborenen;

c) einen Ausgang (108) zur Ausgabe der Daten, die das Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln.

2. Vorrichtung nach Anspruch 1, wobei der Eingang (102) ein erster Eingang ist, wobei die Vorrichtung (100) einen zweiten Eingang zum Empfangen eines Signals umfasst, das die Uterusaktivität angibt, wobei die Verarbeitungseinheit (106) an den ersten (102) und den zweiten Eingang gekoppelt ist und zur Verarbeitung des Signals, das die fötale Herzschlagfrequenz angibt, und des Signals, das die Uterusaktivität angibt, betriebsbereit ist, um die Daten zu erlangen, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln.

3. Vorrichtung nach Anspruch 1, wobei für jede Klasse in der Gruppe von Klassen die Daten einen Wahrscheinlichkeitswert angeben, dass der Zustand des Fötus zu der entsprechenden Klasse gehört.

4. Vorrichtung nach Anspruch 1, wobei die Gruppe von Klassen mindestens vier Klassen enthält, umfassend:

a) eine erste Klasse und eine zweite Klasse, die jeweiligen vordefinierten fötalen Zuständen zugeordnet sind, die ein Vorhandensein einer Enzephalopathie beim Neugeborenen angegeben; und
b) eine dritte Klasse und eine vierte Klasse, die jeweiligen vordefinierten fötalen Zuständen zugeordnet sind, die ein Fehlen einer Enzephalopathie beim Neugeborenen angegeben.

5. Vorrichtung nach Anspruch 4, wobei die erste Klasse einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist.

6. Vorrichtung nach Anspruch 4, wobei die zweite Klasse einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist.

7. Vorrichtung nach Anspruch 4, wobei die dritte Klasse einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist.

8. Vorrichtung nach Anspruch 4, wobei die vierte Klasse einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist.

9. Vorrichtung nach Anspruch 1, wobei die Gruppe von Klassen mindestens vier Klassen enthält, umfassend:

a) eine erste Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
b) eine zweite Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist;
c) eine dritte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
d) eine vierte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist.

10. Vorrichtung nach Anspruch 1, wobei die Verarbeitungseinheit (106) ein neuronales Netzwerk (302) enthält.

11. Vorrichtung nach Anspruch 10, wobei das neuronale Netzwerk (302) eine Eingangseinheit (400) und einen Satz von Ausgängen (404, 406, 408, 410) enthält, wobei die Ausgänge (404, 406, 408, 410) jeweiligen Klassen in der Gruppe von Klassen entsprechen, wobei das neuronale Netzwerk (302) zum Ausgeben eines Wahrscheinlichkeitswertes, der einer jeweiligen Klasse in der Gruppe von Klassen zugeordnet ist, an jedem der Ausgänge (404, 406, 408, 410) ausgebildet ist.

12. Vorrichtung nach Anspruch 11, wobei die Verarbeitungseinheit (106) eine Vorverarbeitungseinheit (300) enthält, die betriebsbereit ist zum:

a) Verarbeiten des Signals, das eine fötale Herzschlagfrequenz angibt, um mehrere Messungen charakteristischer Merkmale zu erlangen;
b) Leiten der mehreren Messungen charakteristischer Merkmale zu der Eingangseinheit (400) des neuronalen Netzwerkes (302).

13. Vorrichtung nach Anspruch 12, wobei das Signal, das eine fötale Herzschlagfrequenz angibt, Herzschlagfrequenzinformationen enthält, die über eine gewisse Zeitperiode gesammelt wurden.

14. Vorrichtung nach Anspruch 13, wobei die gewisse Zeitperiode mehr als 1 Stunde beträgt.

15. Vorrichtung nach Anspruch 13, wobei die gewisse Zeitperiode mehr als 2 Stunden beträgt.

16. Vorrichtung nach Anspruch 13, wobei die gewisse Zeitperiode mehr als 3 Stunden beträgt.

17. Vorrichtung nach Anspruch 13, wobei die gewisse Zeitperiode mehr als 4 Stunden beträgt.

18. Vorrichtung nach Anspruch 1, wobei die Verarbeitungseinheit (106) ein neuronales Netzwerk (302) enthält, wobei das neuronale Netzwerk (302) enthält:

a) eine Eingangseinheit (400) zum Empfangen von Messungen charakteristischer Merkmale, die aus dem Signal erlangt werden, das die fötale Herzschlagfrequenz angibt;
b) einen Satz von Ausgängen (404, 406, 408, 410), die jeweiligen Klassen in der Gruppe von Klassen zugeordnet sind;
c) einen Verarbeitungskern (402), der an die Eingangseinheit (400) und den Satz von Ausgängen (404, 406,

408, 410) gekoppelt ist, wobei der Verarbeitungskern (402) auf der Basis der Messungen charakteristischer Merkmale, die an der Eingangseinheit (400) empfangen werden, zum Ausgeben von Daten an jedem Ausgang (404, 406, 408, 410) betriebsbereit ist, die eine Wahrscheinlichkeit angeben, dass der Zustand des Fötus zu einer jeweiligen Klasse gehört.

19. Vorrichtung nach Anspruch 18, wobei die Gruppe von Klassen mindestens vier Klassen enthält, umfassend:

a) eine erste Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
b) eine zweite Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist;
c) eine dritte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
d) eine vierte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist.

20. Vorrichtung nach Anspruch 1, wobei die Verarbeitungseinheit umfasst:

a) eine Einheit (300) zur Extraktion charakteristischer Merkmale, die an den Eingang (102) gekoppelt ist, wobei die Einheit (300) zur Extraktion charakteristischer Merkmale betriebsbereit ist, das Signal zu verarbeiten, das die fötale Herzschlagfrequenz angibt, um Messungen charakteristischer Merkmale zu erlangen;
b) ein neuronales Netzwerkmodul (302), das an die Einheit (300) zur Extraktion charakteristischer Merkmale gekoppelt ist, wobei das neuronale Netzwerkmodul (302) zum Verarbeiten der Messungen charakteristischer Merkmale betriebsbereit ist, um Daten zu erlangen, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln.

21. Vorrichtung nach Anspruch 20, wobei die Einheit (300) zur Extraktion charakteristischer Merkmale betriebsbereit ist zum:

a) Verarbeiten der fötalen Herzschlagfrequenz zur Identifizierung mehrerer Vorkommnisse charakteristischer Merkmale;
b) Generieren mehrerer Messungen charakteristischer Merkmale für die mehreren in a) identifizierten Vorkommnisse charakteristischer Merkmale;
c) Zusammenfassen der mehreren Messungen charakteristischer Merkmale zum Generieren einer kompakten Darstellung von Messungen charakteristischer Merkmale;
d) Leiten der kompakten Darstellung von Messungen charakteristischer Merkmale zu dem neuronalen Netzwerkmodul (302).

22. Vorrichtung nach Anspruch 21, wobei das Zusammenfassen der mehreren Messungen charakteristischer Merkmale zum Generieren einer kompakten Darstellung von Messungen charakteristischer Merkmale enthält:

a) Verarbeiten der mehreren Messungen charakteristischer Merkmale zum Generieren mindestens eines interpolierten Messsignals charakteristischer Merkmale;
b) Dezimieren des interpolierten Messsignals charakteristischer Merkmale zum Generieren der kompakten Darstellung von Messungen charakteristischer Merkmale.

23. Vorrichtung nach Anspruch 22, wobei das Dezimieren des interpolierten Messsignals charakteristischer Merkmale auf der Basis von regelmäßigen Abtastintervallen erfolgt.

24. Vorrichtung nach Anspruch 22, wobei das Dezimieren des interpolierten Messsignals charakteristischer Merkmale auf der Basis von unregelmäßigen Abtastintervallen erfolgt.

25. Vorrichtung nach Anspruch 21, wobei die mehreren Vorkommnisse charakteristischer Merkmale mindestens einige Vorkommnisse erhalten, die ausgewählt sind aus dem Satz bestehend aus Grundlinien-, Beschleunigungs-, Ver-

langsamungs- und Kontraktionsvorkommnissen.

26. Vorrichtung nach Anspruch 25, wobei Teilsätze der mehreren Messungen charakteristischer Merkmale entsprechenden Vorkommnissen charakteristischer Merkmale zugeordnet sind, wobei mindestens ein Teilsatz einem Vorkommnis eines charakteristischen Merkmals an der Grundlinie zugeordnet ist, wobei der mindestens eine Teilsatz Messungen charakteristischer Merkmale enthält, die ausgewählt sind aus dem Satz bestehend aus Mittelwert, Frequenz, Länge, Variabilität und sinusoidalem Muster.

27. Vorrichtung nach Anspruch 25, wobei Teilsätze der mehreren Messungen charakteristischer Merkmale entsprechenden Vorkommnissen charakteristischer Merkmale zugeordnet sind, wobei mindestens ein Teilsatz einem Vorkommnis eines charakteristischen Merkmals in der Beschleunigung zugeordnet ist, wobei der mindestens eine Teilsatz Messungen charakteristischer Merkmale enthält, die ausgewählt sind aus dem Satz bestehend aus Mittelwert, Frequenz, Länge, Variabilität und Fläche.

28. Vorrichtung nach Anspruch 25, wobei Teilsätze der mehreren Messungen charakteristischer Merkmale entsprechenden Vorkommnissen charakteristischer Merkmale zugeordnet sind, wobei mindestens ein Teilsatz einem Vorkommnis eines charakteristischen Merkmals in der Kontraktion zugeordnet ist, wobei der mindestens eine Teilsatz Messungen charakteristischer Merkmale enthält, die ausgewählt sind aus dem Satz bestehend aus Frequenz und Verlangsamungserholungszeit.

29. Vorrichtung nach Anspruch 21, wobei die Gruppe von Klassen mindestens vier Klassen enthält, umfassend:

a) eine erste Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
b) eine zweite Klasse, die einem vorbestimmten fötalen Zustand, der das Vorhandensein einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist;
c) eine dritte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits über einem vorbestimmten Wert zugeordnet ist;
d) eine vierte Klasse, die einem vorbestimmten fötalen Zustand, der das Fehlen einer Enzephalopathie beim Neugeborenen angibt, sowie einem Messwert eines Basendefizits unter einem vorbestimmten Wert zugeordnet ist.

30. Vorrichtung nach Anspruch 21, wobei das neuronale Netzwerkmodul (302) eine Eingangseinheit (400) und einen Satz von Ausgängen (404, 406, 408, 410) enthält, wobei die Ausgänge (404, 406, 408, 410) jeweiligen Klassen in der Gruppe von Klassen entsprechen, wobei das neuronale Netzwerkmodul (302) zum Ausgeben eines Wahrscheinlichkeitswertes, der einer jeweiligen Klasse in der Gruppe von Klassen zugeordnet ist, an jedem der Ausgänge (404, 406, 408, 410) ausgebildet ist.

31. Vorrichtung nach Anspruch 30, wobei die kompakte Darstellung der Messungen charakteristischer Merkmale zu der Eingangseinheit (400) des neuronalen Netzwerkmoduls (302) geleitet wird.

32. Computerlesbares Speichermedium, enthaltend ein Programmelement, das zur Ausführung durch eine Rechnervorrichtung (1000) zur Beobachtung des Zustandes eines Fötus geeignet ist, wobei die Rechnervorrichtung (1000) umfasst:

a) eine Speichereinheit (1004);
b) einen Prozessor (1002), der betriebsbereit an die Speichereinheit (1004) angeschlossen ist, wobei das Programmelement, wenn es auf dem Prozessor (1002) ausgeführt wird, zum Ausführen durch eine Vorrichtung zur Beobachtung des Zustandes eines Fötus nach einem der Ansprüche 1 bis 31 betriebsbereit ist.

33. System zum Beobachten eines Fötus, umfassend:

a) einen Sensor (110) zum Empfangen eines Signals, das eine fötale Herzschlagfrequenz angibt;
b) eine Vorrichtung (100) zur Beobachtung des Zustandes eines Fötus nach einem der Ansprüche 1 bis 31;
c) eine Ausgabeeinheit (114), die mit der Vorrichtung (100) verbunden ist, wobei die Ausgabeeinheit (114) zum

Anzeigen von Informationen ausgebildet ist, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln, der mit einer hypoxischen Verletzung in Zusammenhang steht.

34. Verfahren, das zur Beobachtung des Zustandes eines Fötus geeignet ist, wobei das Verfahren umfasst:

a) Empfangen eines Signals, das eine fötale Herzschlagfrequenz angibt;
b) Senden des Signals zu einer Vorrichtung (100) zur Beobachtung des Zustandes eines Fötus nach einem der Ansprüche 1 bis 31;
c) Empfangen von Daten, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln, der mit einer hypoxischen Verletzung in Zusammenhang steht, von der Vorrichtung (100);
d) Leiten der Daten, die ein Ausmaß eines Risikos angeben, einen permanenten neurologischen Zustand zu entwickeln, zu einem Anwender.

Revendications

1. Appareil (100) apte à contrôler l'état d'un foetus, ledit appareil (100) comprenant :

a) une entrée (102) pour recevoir un signal indiquant la fréquence cardiaque d'un foetus ;
b) une unité de traitement (106) couplée à ladite entrée (102), ladite unité de traitement (106) permettant de traiter ledit signal indiquant la fréquence cardiaque du foetus pour obtenir des données indiquant un degré de risque de développer une affection neurologique permanente en rapport avec une lésion hypoxique, les données indiquant le degré de risque de développer une affection neurologique permanente indiquant une probabilité que l'affection du foetus appartienne à une classe dans un groupe de classes, chaque classe dans le groupe de classes étant associée à une affection foetale prédéfinie caractérisée au moins en partie par :

i. une mesure d'un déficit de base d'une valeur supérieure ou inférieure à une valeur prédéfinie ; et
ii. une présence ou absence d'encéphalopathie du nouveau-né ;

c) une sortie (108) pour fournir les données indiquant le degré de risque de développer une affection neurologique permanente.

2. Appareil selon la revendication 1, dans lequel ladite entrée (102) est une première entrée, ledit appareil (100) comprenant une seconde entrée pour recevoir un signal indiquant l'activité utérine, ladite unité de traitement (106) étant couplée auxdites première (102) et seconde entrées et permettant de traiter ledit signal indiquant la fréquence cardiaque du foetus et ledit signal indiquant l'activité utérine pour obtenir les données indiquant un degré de risque de développer une affection neurologique permanente

3. Appareil selon la revendication 1, dans lequel, pour chaque classe dans le groupe de classes, les données indiquent une valeur de probabilité que l'affection du foetus appartienne à la classe correspondante.

4. Appareil selon la revendication 1, dans lequel ledit groupe de classes comprend au moins quatre classes comprenant :

a) une première classe et une deuxième classe associées à des conditions foetales prédéfinies respectives indiquant la présence d'une encépha-lopathie du nouveau-né ; et
b) une troisième classe et une quatrième classe associées à des conditions foetales prédéfinies respectives indiquant l'absence d'encéphalopathie du nouveau-né.

5. Appareil selon la revendication 4, dans lequel ladite première classe est associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure d'un déficit de base d'une valeur supérieure à une valeur prédéterminée.

6. Appareil selon la revendication 4, dans lequel ladite deuxième classe est associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure d'un déficit de base d'une valeur inférieure à une valeur prédéterminée.

7. Appareil selon la revendication 4, dans lequel ladite troisième classe est associée à une condition foetale prédé-

terminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée.

8. Appareil selon la revendication 4, dans lequel ladite quatrième classe est associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée.

9. Appareil selon la revendication 1, dans lequel ledit groupe de classes comprend au moins quatre classes comprenant :

a) une première classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
b) une deuxième classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée ;
c) une troisième classe associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
d) une quatrième classe associée à une condition foetale prédéterminée indiquant l'absence d'encépha-lopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée.

10. Appareil selon la revendication 1, dans lequel ladite unité de traitement (106) comprend un réseau neuronal (302).

11. Appareil selon la revendication 10, dans lequel ledit réseau neuronal (302) comprend une unité d'entrée (400) et une série de sorties (404, 406, 408, 410), les sorties (404, 406, 408, 410) correspondant à des classes respectives dans le groupe de classes, ledit réseau neuronal (302) étant adapté à fournir à chacune desdites sorties (404, 406, 408, 410) une valeur de probabilité associée à une classe respective dans le groupe de classes.

12. Appareil selon la revendication 11, dans lequel ladite unité de traitement (106) comprend une unité de pré-traitement (300) permettant :

a) de traiter le signal indiquant la fréquence cardiaque d'un foetus pour en déduire une pluralité de mesures de caractéristiques ;
b) de fournir ladite pluralité de mesures de caractéristiques à l'unité d'entrée (400) dudit réseau neuronal (302).

13. Appareil selon la revendication 12, dans lequel ledit signal indiquant la fréquence cardiaque d'un foetus comprend l'information de fréquence cardiaque collectée pendant une certaine période de temps.

14. Appareil selon la revendication 13, dans lequel la certaine période de temps est supérieure à une heure.

15. Appareil selon la revendication 13, dans lequel la certaine période de temps est supérieure à deux heures.

16. Appareil selon la revendication 13, dans lequel la certaine période de temps est supérieure à trois heures.

17. Appareil selon la revendication 13, dans lequel la certaine période de temps est supérieure à quatre heures.

18. Appareil selon la revendication 1, dans lequel ladite unité de traitement (106) comprend un réseau neuronal (302), ledit réseau neuronal (302) comprenant :

a) une unité d'entrée (400) pour recevoir des mesures de caractéristiques déduites du signal indiquant la fréquence cardiaque du foetus ; et
b) une série de sorties (404, 406, 408, 410), associées à des classes respectives dans le groupe de classes ;
c) un centre de traitement (402) couplé à ladite unité d'entrée (400) et à ladite série de sorties (404, 406, 408, 410), ledit centre de traitement (402) permettant de fournir à chaque sortie (404, 406, 408, 410) des données indiquant une probabilité que l'état du foetus appartienne à une classe respective sur la base des mesures de caractéristiques reçues au niveau de ladite unité d'entrée (400).

19. Appareil selon la revendication 18, dans lequel ledit groupe de classes comprend au moins quatre classes comprenant :

a) une première classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
b) une deuxième classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée ;
c) une troisième classe associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
d) une quatrième classe associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée.

20. Appareil selon la revendication 1, dans lequel ladite unité de traitement comprend :

a) une unité d'extraction de caractéristiques (300) couplée à ladite entrée (102), ladite unité d'extraction de caractéristiques (300) permettant le traitement du signal indiquant la fréquence cardiaque du foetus pour en déduire des mesures de caractéristiques ;
b) un module de réseau neuronal (302) couplé à ladite unité d'extraction de caractéristiques (300), ledit module de réseau neuronal (302) permettant le traitement des mesures de caractéristiques pour en déduire des données indiquant un degré de risque de développement d'une affection neurologique permanente.

21. Appareil selon la revendication 20, dans lequel ladite unité d'extraction de caractéristiques (300) permet :

a) de traiter ladite fréquence cardiaque du foetus pour identifier une pluralité d'événements de caractéristiques ;
b) d'engendrer une pluralité de mesures de caractéristiques pour la pluralité d'événements de caractéristiques identifiée en a) ;
c) de récapituler ladite pluralité de mesures de caractéristiques pour engendrer une représentation compacte de mesures de caractéristiques ;
d) de fournir la représentation compacte de mesures des caractéristiques audit module de réseau neuronal (302).

22. Appareil selon la revendication 21, dans lequel le récapitulé de ladite pluralité de mesures de caractéristiques pour engendrer une représentation compacte de mesures de caractéristiques comprend :

a) le traitement de la pluralité de mesures de caractéristiques pour engendrer au moins un signal de mesure de caractéristique interpolé;
b) la décimation du signal de mesure de caractéristique interpolé de manière à engendrer la représentation compacte de mesures de caractéristiques.

23. Appareil selon la revendication 22, dans lequel la décimation du signal de mesure de caractéristique interpolé est effectuée sur la base d'intervalles d'échantillonnage réguliers.

24. Appareil selon la revendication 22, dans lequel la décimation du signal de mesure de caractéristique interpolé est effectuée sur la base d'intervalles d'échantillonnage irréguliers.

25. Appareil selon la revendication 21, dans lequel la pluralité d'événements de caractéristiques comprend au moins certains événements choisis dans la série consistant en des événements de ligne de base, d'accélération, de décélération et de contraction.

26. Appareil selon la revendication 25, dans lequel des sous-catégories de la pluralité de mesures de caractéristiques sont associées à des événements de caractéristiques respectifs, au moins une sous-catégorie étant associée à un événement de caractéristique de ligne de base, ladite au moins une sous-catégorie comprenant des mesures de caractéristiques choisies dans la série consistant en une valeur moyenne, une fréquence, une longueur, une variabilité et un motif sinusoïdal.

27. Appareil selon la revendication 25, dans lequel des sous-catégories de la pluralité de mesures de caractéristiques sont associées à des événements de caractéristiques respectifs, au moins une sous-catégorie étant associée à un événement de caractéristique d'accélération, ladite au moins une sous-catégorie comprenant des mesures de caractéristiques choisies dans la série consistant en une valeur moyenne, une fréquence, une longueur, une variabilité et une aire.

28. Appareil selon la revendication 25, dans lequel des sous-catégories de la pluralité de mesures de caractéristiques

sont associées à des événements de caractéristiques respectifs, au moins une sous-catégorie étant associée à un événement de caractéristique de contraction, ladite au moins une sous-catégorie comprenant une mesure de caractéristique choisie dans la série consistant en la fréquence et le temps de rétablissement de décélération.

29. Appareil selon la revendication 21, dans lequel ledit groupe de classes comprend au moins quatre classes comprenant :

a) une première classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
b) une deuxième classe associée à une condition foetale prédéterminée indiquant la présence d'une encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée ;
c) une troisième classe associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur supérieure à une valeur prédéterminée ;
d) une quatrième classe associée à une condition foetale prédéterminée indiquant l'absence d'encéphalopathie du nouveau-né et une mesure de déficit de base d'une valeur inférieure à une valeur prédéterminée.

30. Appareil selon la revendication 21, dans lequel ledit module de réseau neuronal (302) comprend une unité d'entrée (400) et une série de sorties (404, 406, 408, 410), les sorties (404, 406, 408, 410) correspondant à des classes respectives dans le groupe de classes, ledit module de réseau neuronal (302) étant adapté à fournir à chacune desdites sorties (404, 406, 408, 410), une valeur de probabilité associée à une classe respective dans le groupe de classes.

31. Appareil selon la revendication 30, dans lequel la représentation compacte de mesures de caractéristiques est fournie à l'unité d'entrée (400) dudit module de réseau neuronal (302).

32. Support d'informations à lecture informatique, comprenant un élément de programme convenable pour exécution par un appareil informatique (1000) pour contrôler l'état d'un foetus, ledit appareil informatique (1000) comprenant :

a) une unité à mémoire (1004) ;
b) un processeur (1002) connecté de manière fonctionnelle à ladite unité à mémoire (1004), ledit élément de programme, lors de l'exécution sur le processeur (1002), étant apte à l'exécution par un appareil pour contrôler l'état d'un foetus selon l'une quelconque des revendications 1 à 31.

33. Système de contrôle de foetus, comprenant :

a) un capteur (110) pour recevoir un signal indiquant la fréquence cardiaque d'un foetus ;
b) un appareil (100) pour contrôler l'état d'un foetus selon l'une quelconque des revendications 1 à 31 ;
c) une unité de sortie (114) en communication avec ledit appareil (100), ladite unité de sortie (114) étant adaptée à représenter l'information véhiculant un degré de risque de développer une affection neurologique permanente en rapport avec une lésion hypoxique.

34. Procédé permettant de contrôler l'état d'un foetus, ledit procédé comprenant les étapes de :

a) réception d'un signal indiquant la fréquence cardiaque d'un foetus ;
b) transmission dudit signal à un appareil (100) pour contrôler l'état d'un foetus selon l'une quelconque des revendications 1 à 31 ;
c) réception des données indiquant un degré de risque de développer une affection neurologique permanente en rapport avec une lésion hypoxique en provenance de l'appareil (100) ;
d) transmission à un utilisateur des données indiquant le degré de risque de développer une affection neurologique permanente.

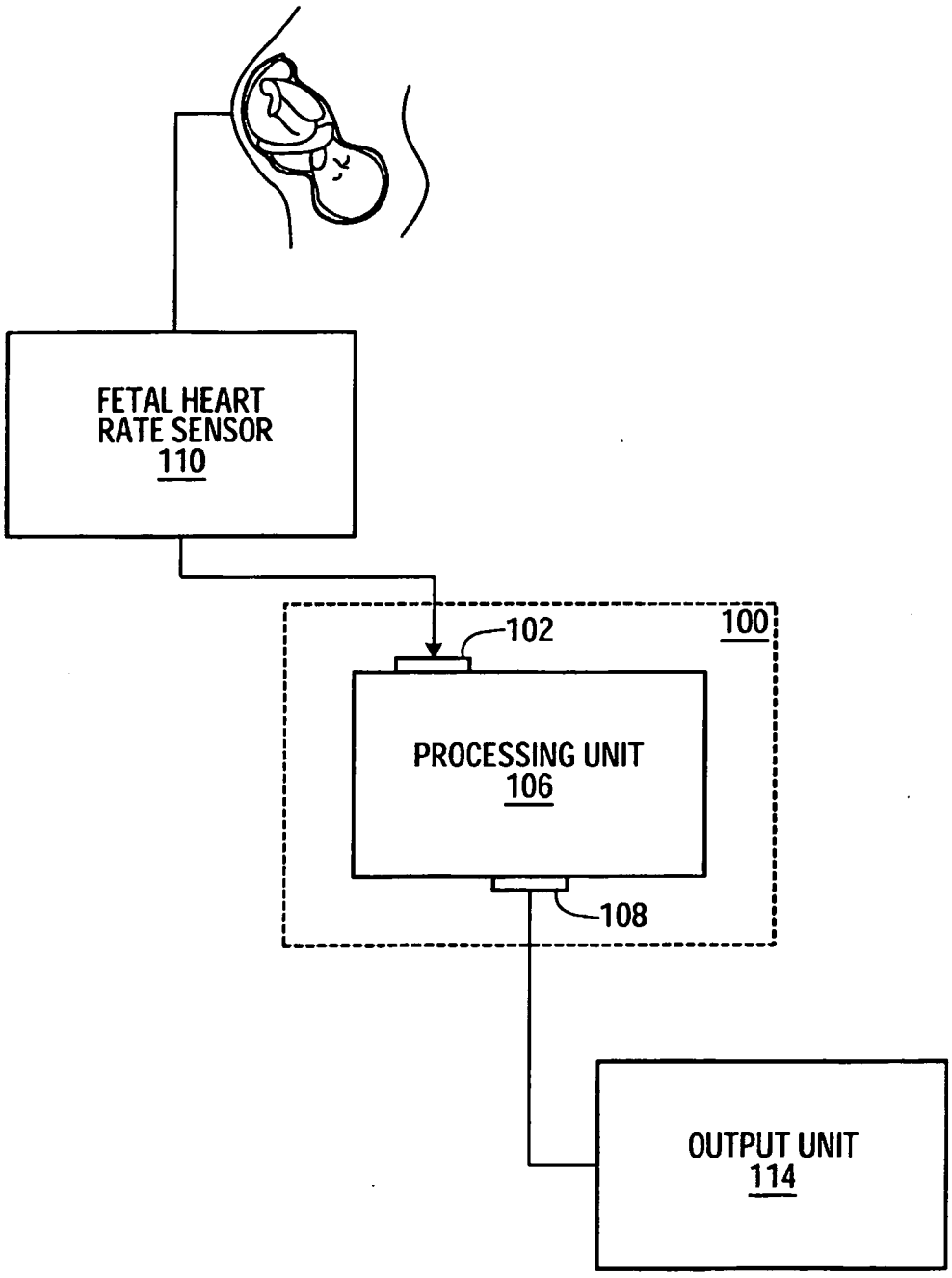
FETAL HEART
RATE SENSOR
110
100
102
PROCESSING UNIT
106
108
OUTPUT UNIT
114

FIG. 1

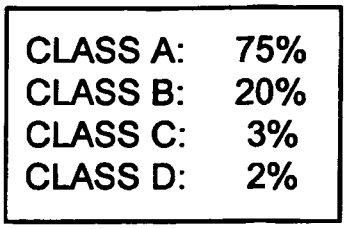

FIG. 2A

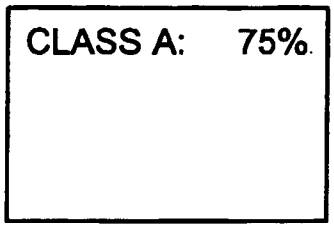

FIG. 2B

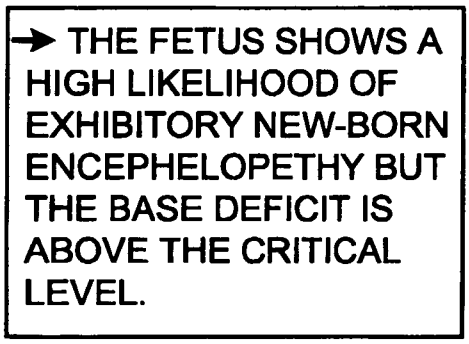

FIG. 2C

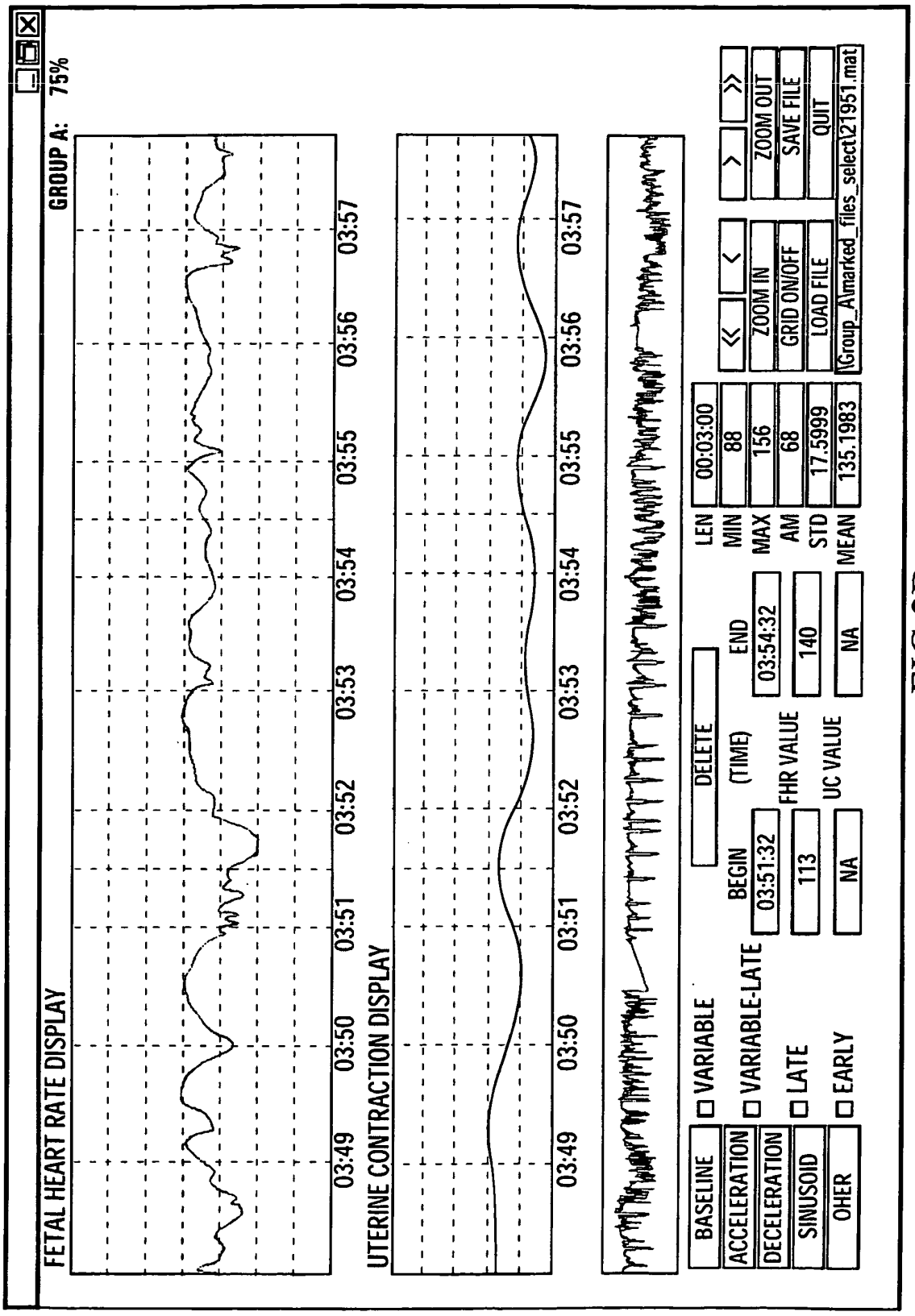
FETAL HEART RATE DISPLAY
GROUP A: 75%
03:49
03:50
03:51
03:52
03:53
03:54
03:55
03:56
03:57
UTERINE CONTRACTION DISPLAY
BASELINE
ACCELERATION
DECELERATION
SINUSOID
OHER
VARIABLE
VARIABLE-LATE
LATE
EARLY
DELETE
BEGIN
(TIME)
03:51:32
FHR VALUE
113
UC VALUE
NA
END
03:54:32
140
NA
LEN
MIN
MAX
AM
STD
MEAN
00:03:00
88
156
68
17.5999
135.1983
ZOOM IN
GRID ON/OFF
LOAD FILE
ZOOM OUT
SAVE FILE
QUIT
\Group_A\marked_files_select\21951.mat

FIG.2D

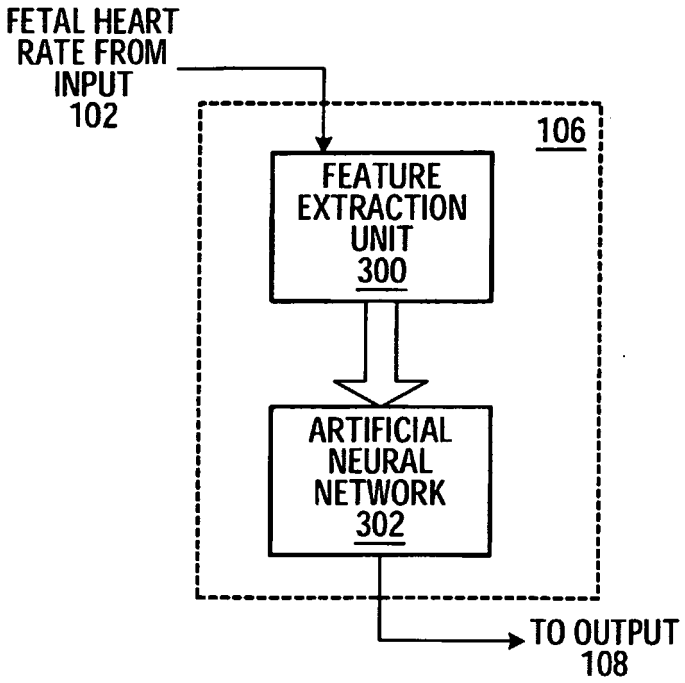
FETAL HEART RATE FROM INPUT 102
106
FEATURE EXTRACTION UNIT 300
ARTIFICIAL NEURAL NETWORK 302
TO OUTPUT 108

FIG. 3

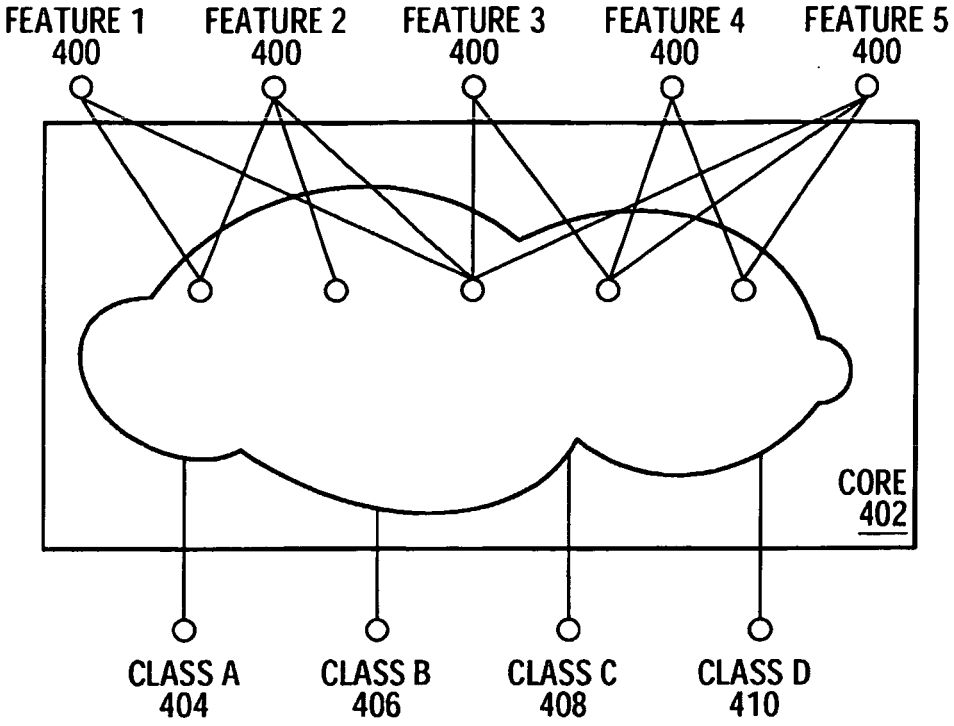
FEATURE 1
400
FEATURE 2
400
FEATURE 3
400
FEATURE 4
400
FEATURE 5
400
CORE
402
CLASS A
404
CLASS B
406
CLASS C
408
CLASS D
410

FIG. 4

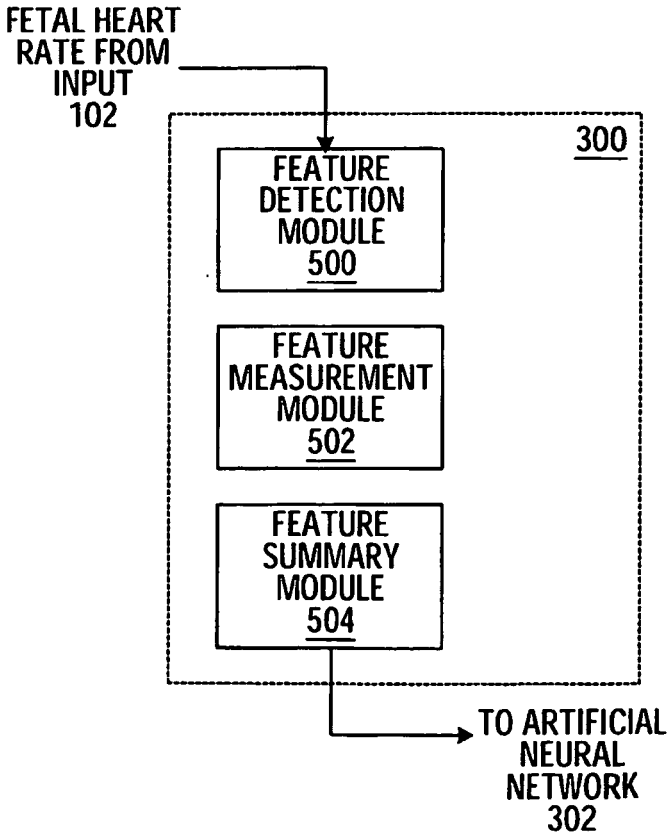
FETAL HEART RATE FROM INPUT
102
300
FEATURE DETECTION MODULE
500
FEATURE MEASUREMENT MODULE
502
FEATURE SUMMARY MODULE
504
TO ARTIFICIAL NEURAL NETWORK
302

FIG. 5

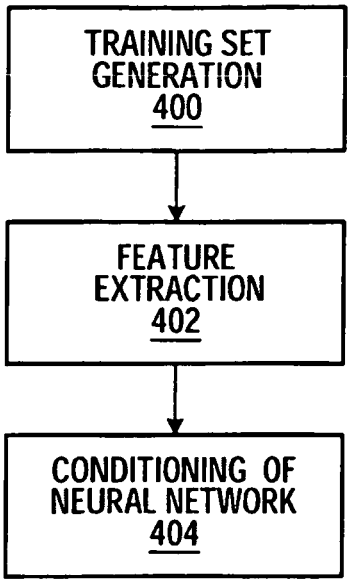
TRAINING SET GENERATION 400
FEATURE EXTRACTION 402
CONDITIONING OF NEURAL NETWORK 404

FIG. 6

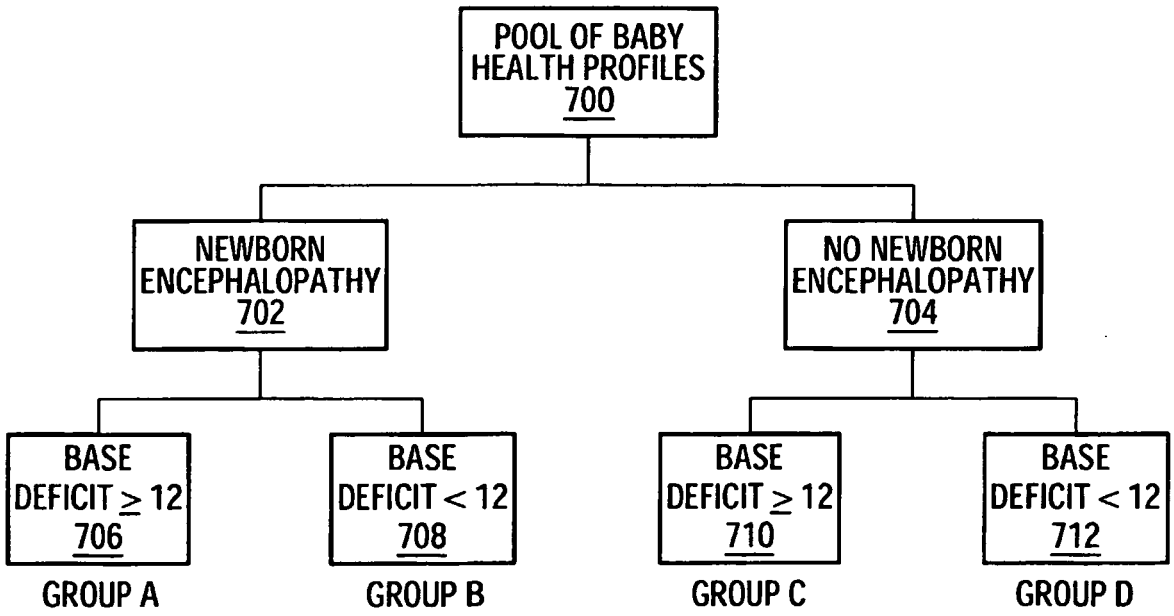
POOL OF BABY HEALTH PROFILES 700
NEWBORN ENCEPHALOPATHY 702
NO NEWBORN ENCEPHALOPATHY 704
BASE DEFICIT ≥ 12 706
BASE DEFICIT < 12 708
BASE DEFICIT ≥ 12 710
BASE DEFICIT < 12 712
GROUP A
GROUP B
GROUP C
GROUP D

FIG. 7

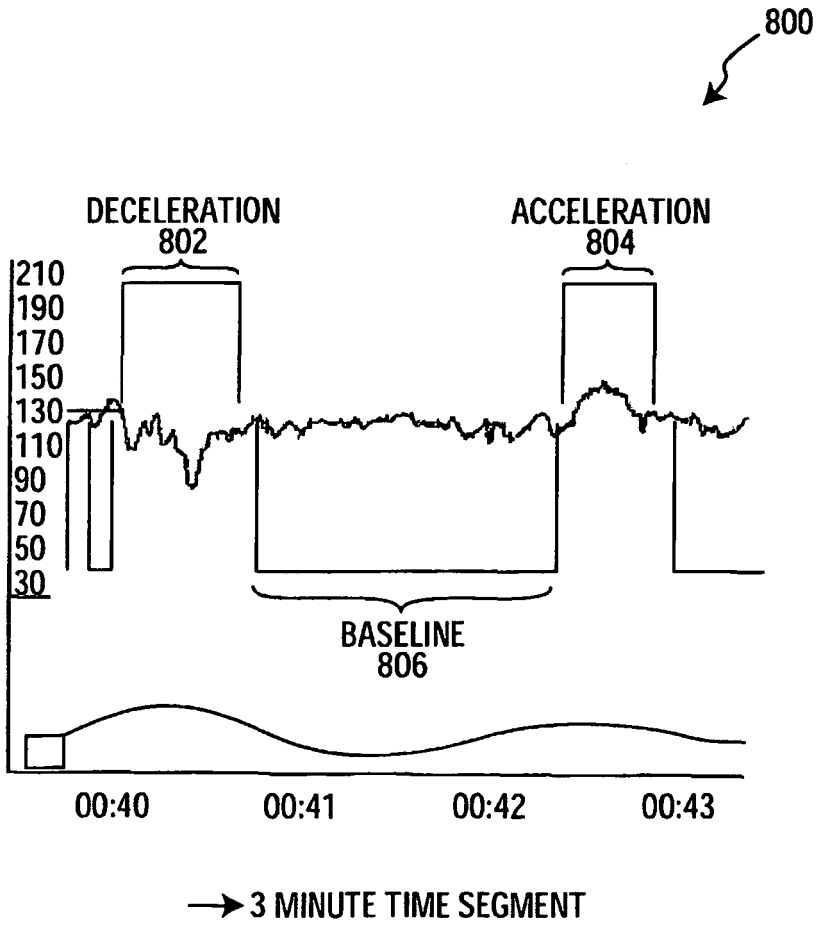
800
DECELERATION
802
ACCELERATION
804
210
190
170
150
130
110
90
70
50
30
BASELINE
806
00:40
00:41
00:42
00:43
3 MINUTE TIME SEGMENT

FIG. 8

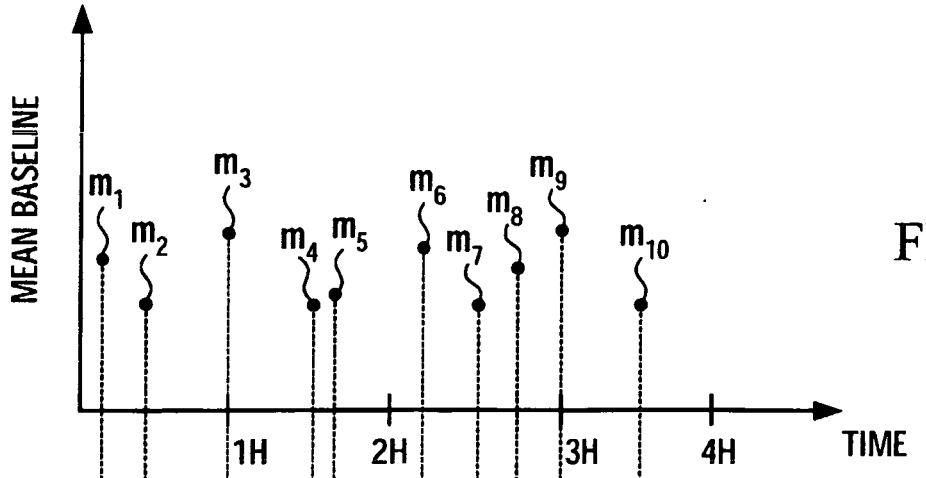

FIG. 9A

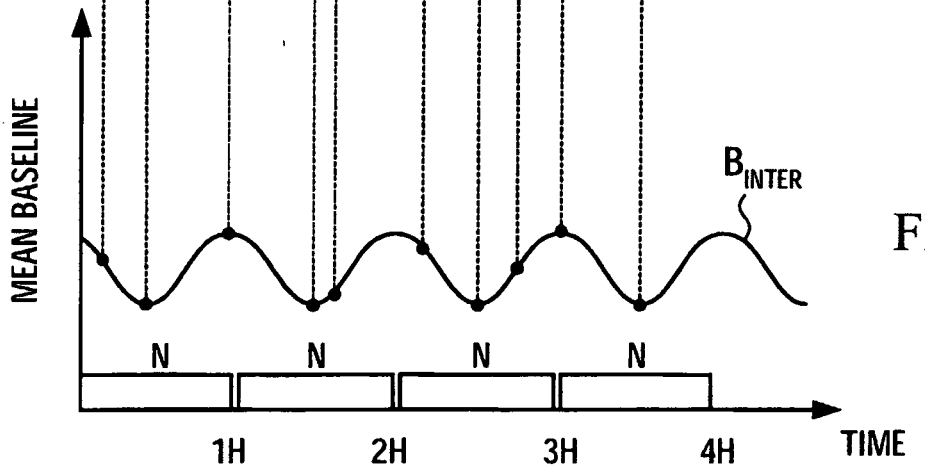

FIG. 9B

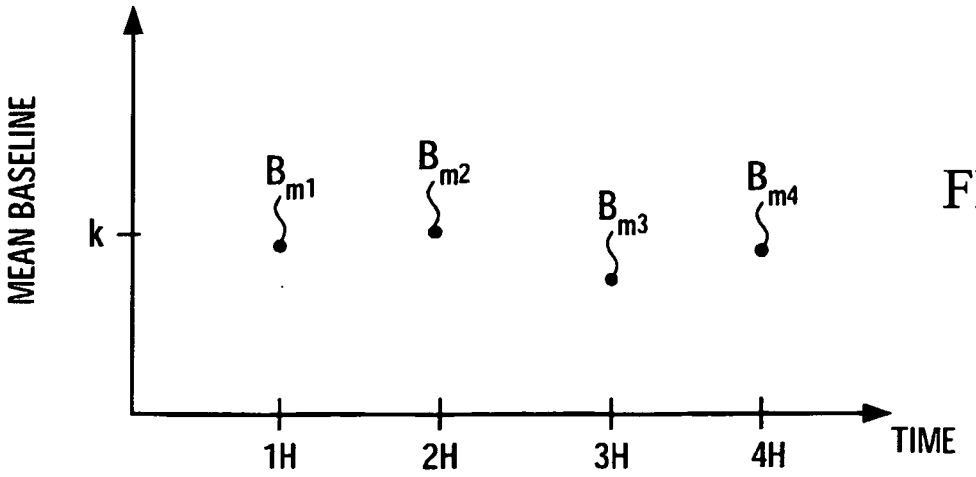

FIG. 9C

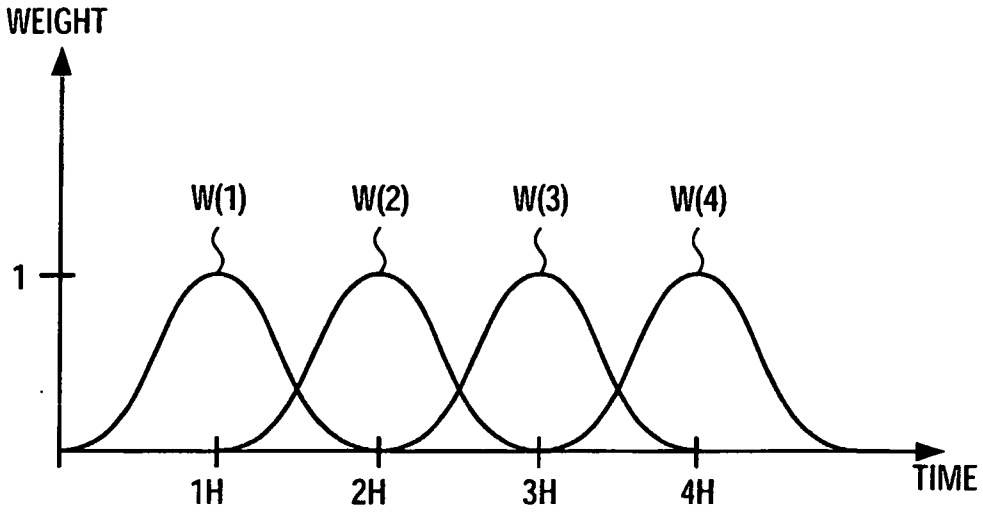
WEIGHT
W(1)
W(2)
W(3)
W(4)
1
1H
2H
3H
4H
TIME

FIG. 9D

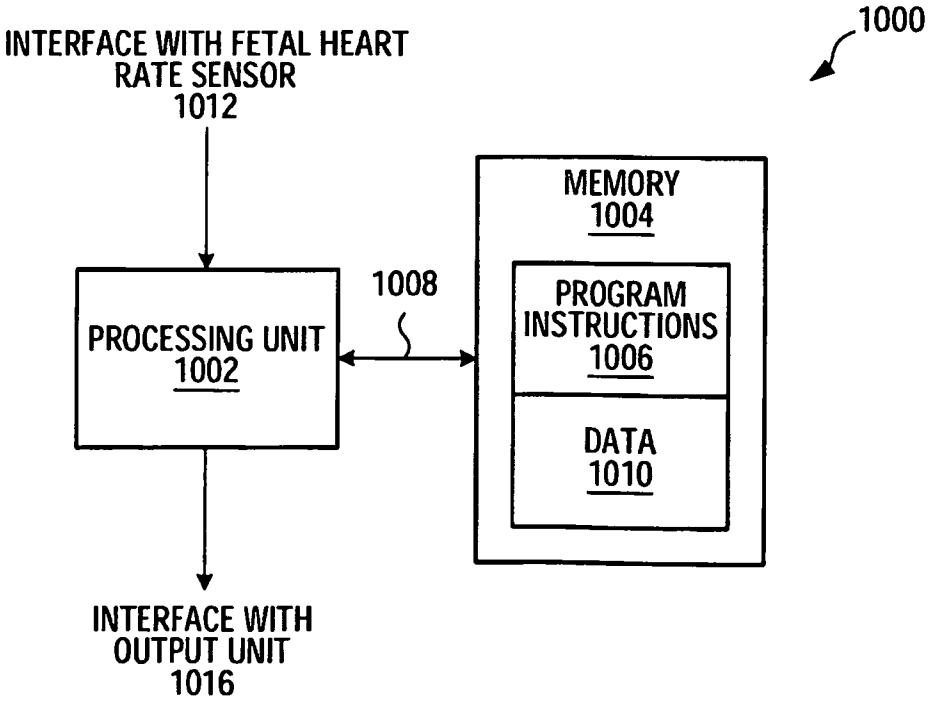
1000
INTERFACE WITH FETAL HEART RATE SENSOR 1012
MEMORY 1004
PROGRAM INSTRUCTIONS 1006
DATA 1010
1008
PROCESSING UNIT 1002
INTERFACE WITH OUTPUT UNIT 1016

FIG. 10

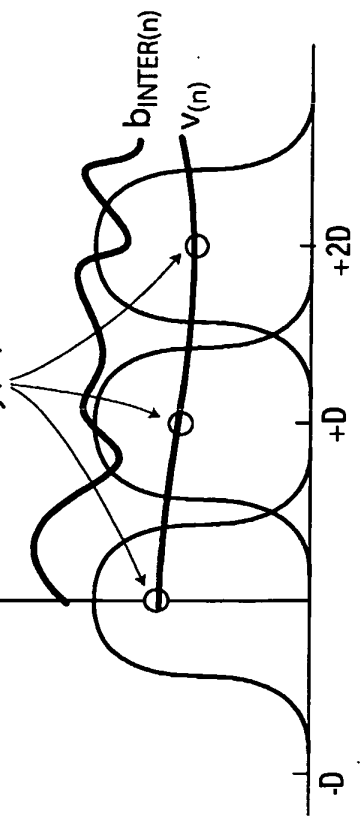

FIG. 11B

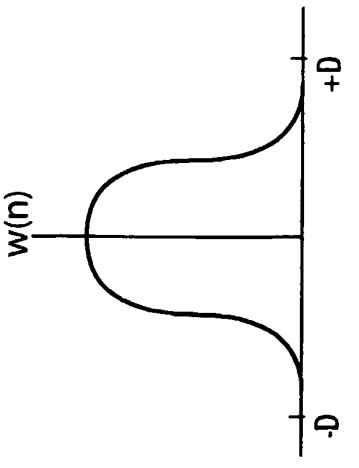

FIG. 11A

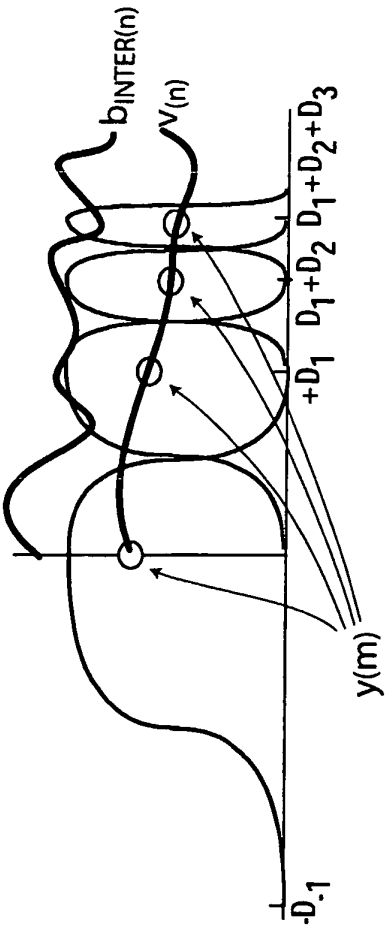

FIG. 11D

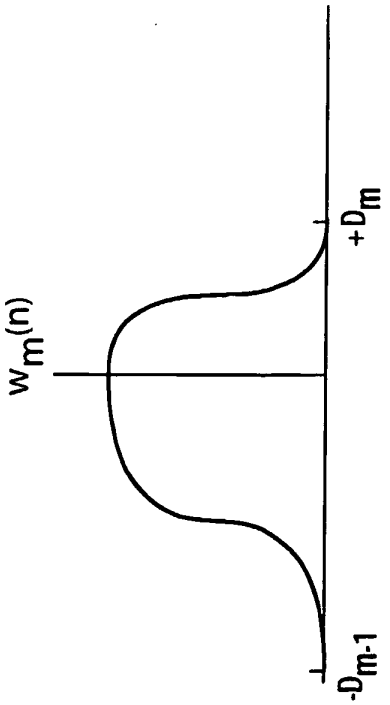

FIG. 11C

REFERENCES CITED IN THE DESCRIPTION

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- **LOW J.A.** The role of blood gas and acid-base assessment in the diagnosis of intrapartum fetal asphyxia,. *Am J Obstet Genecol,* 1988, vol. 159, 1234-40 **[0042]**
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- **SARNAT, HB. ; SARNAT, MS.** Neonatal encephalopathy following fetal distress. *Arch Neurol,* 1976, vol. 33, 696-705 **[0080]**
- **BADAWI, N. ; KURINCZUK, JJ. ; KEOGH, JM. ; ALESSANDRI, LM. ; O'SULLIVAN, F. ; BURTON, PR.** Antepartum risk factors for newborn encephalopathy: the Western Australian case-control study. *BMJ,* 1998, vol. 317, 15491553 **[0080]**

专利名称(译)	用于监测胎儿状况的装置		
公开(公告)号	EP1489960B1	公开(公告)日	2012-12-19
申请号	EP2003709501	申请日	2003-03-31
[标]申请(专利权)人(译)	LMS医疗SYST		
申请(专利权)人(译)	LMS医疗系统，LTD.		
当前申请(专利权)人(译)	PERIGEN INC.		
[标]发明人	HAMILTON EMILY F GLAUDE MICHAEL C MACIESZCZAK MACIEJ WARRICK PHILIP A		
发明人	HAMILTON, EMILY, F. GLAUDE, MICHAEL, C. MACIESZCZAK, MACIEJ WARRICK, PHILIP, A.		
IPC分类号	A61B5/00 A61B5/0444 A61B5/024		
CPC分类号	A61B5/4362 A61B5/0011 A61B5/02411 A61B5/0444 A61B5/7267		
优先权	10/113788 2002-04-01 US 2379733 2002-04-02 CA		
其他公开文献	EP1489960A2		
外部链接	Espacenet		

摘要(译)

提供了一种用于监测胎儿状况以评估发展永久性神经病症的风险程度的方法和设备。处理指示胎儿心脏的信号以获得发展永久性神经病症的风险程度。指示发展永久性神经病症的风险程度的数据表明胎儿的状况属于一组类别中的类别的可能性，其中该类别组中的每个类别与预定义的胎儿状况相关联。 。然后释放指示发展永久性神经病症的风险程度的数据。在一个示例中，神经网络用于获得指示胎儿的状况属于类组中的类的可能性的数据。

Equation 1

$$B_{m1} = \frac{1}{2N}\sum_{i=0}^{N-1} w[1]_i * b_{INTER}[i]$$

$$B_{m2} = \frac{1}{2N}\sum_{i=N}^{2N-1} w[2]_i * b_{INTER}[i]$$

$$B_{m3} = \frac{1}{2N}\sum_{i=2N}^{3N-1} w[3]_i * b_{INTER}[i]$$

$$B_{m4} = \frac{1}{2N}\sum_{i=3N}^{4N-1} w[4]_i * b_{INTER}[i]$$