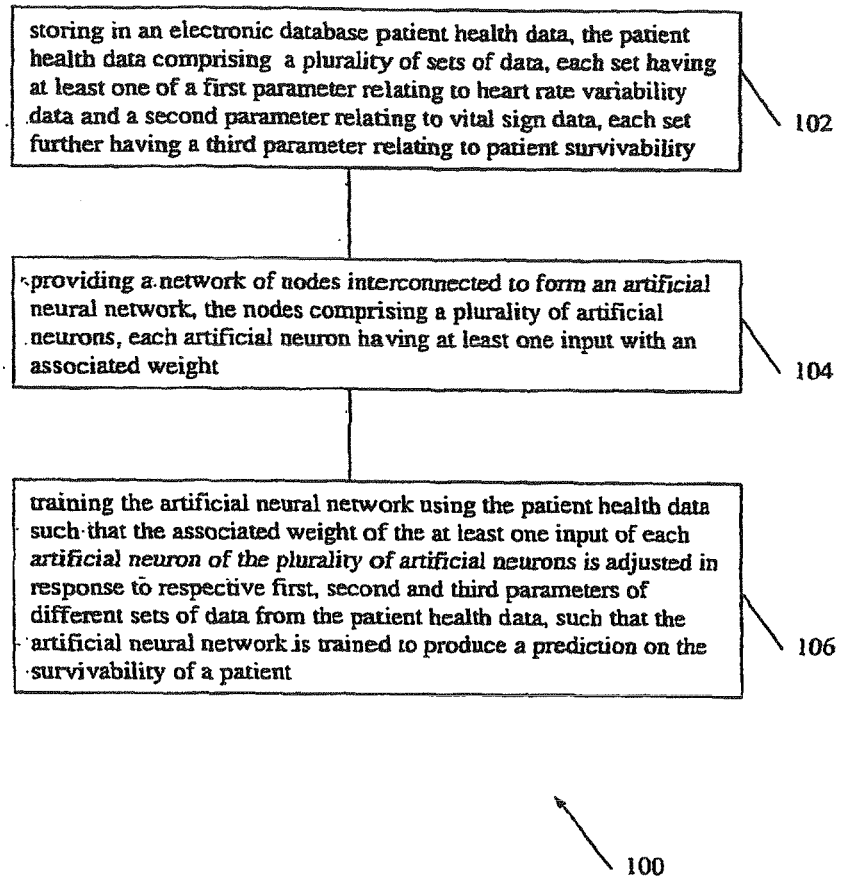

storing in an electronic database patient health data, the patient health data comprising a plurality of sets of data, each set having at least one of a first parameter relating to heart rate variability data and a second parameter relating to vital sign data, each set further having a third parameter relating to patient survivability
102
providing a network of nodes interconnected to form an artificial neural network, the nodes comprising a plurality of artificial neurons, each artificial neuron having at least one input with an associated weight
104
training the artificial neural network using the patient health data such that the associated weight of the at least one input of each artificial neuron of the plurality of artificial neurons is adjusted in response to respective first, second and third parameters of different sets of data from the patient health data, such that the artificial neural network is trained to produce a prediction on the survivability of a patient
106
100

Figure 1

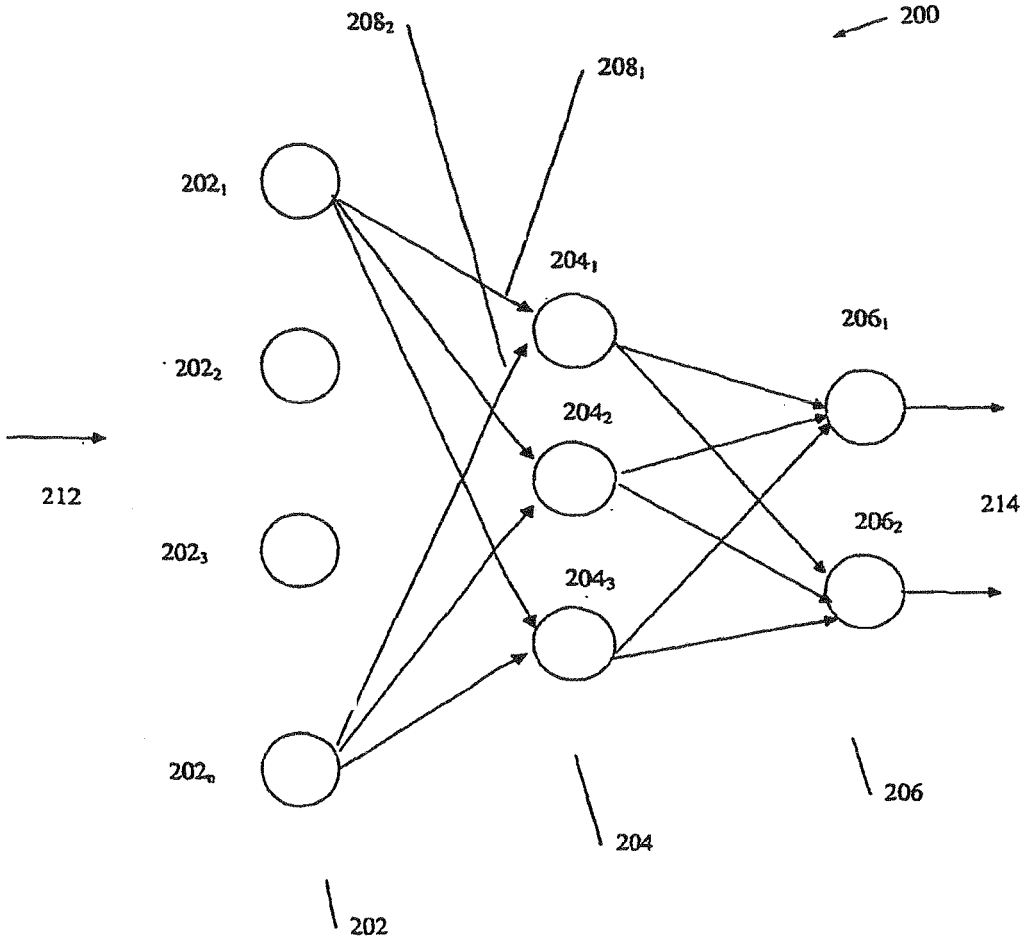

200
208_2
208_1
202_1
204_1
206_1
202_2
204_2
212
214
206_2
202_3
204_3
202_n
206
204
202

Figure 2

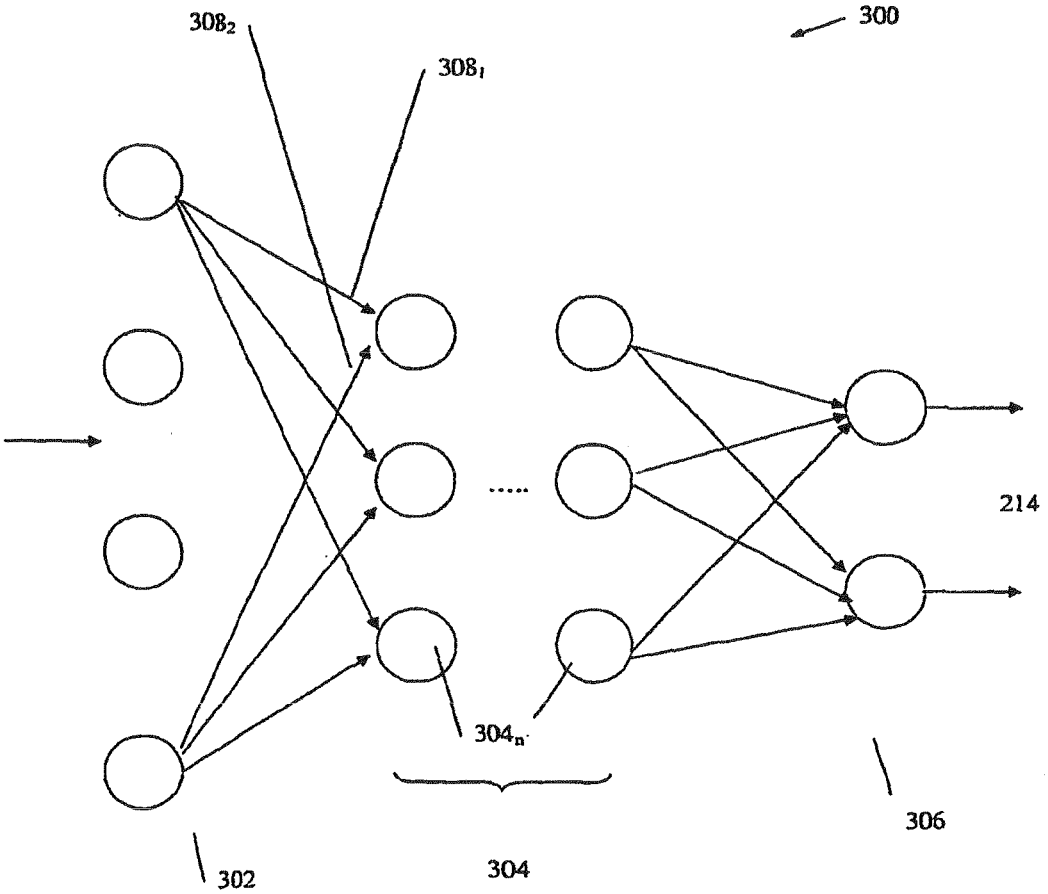


Figure 3

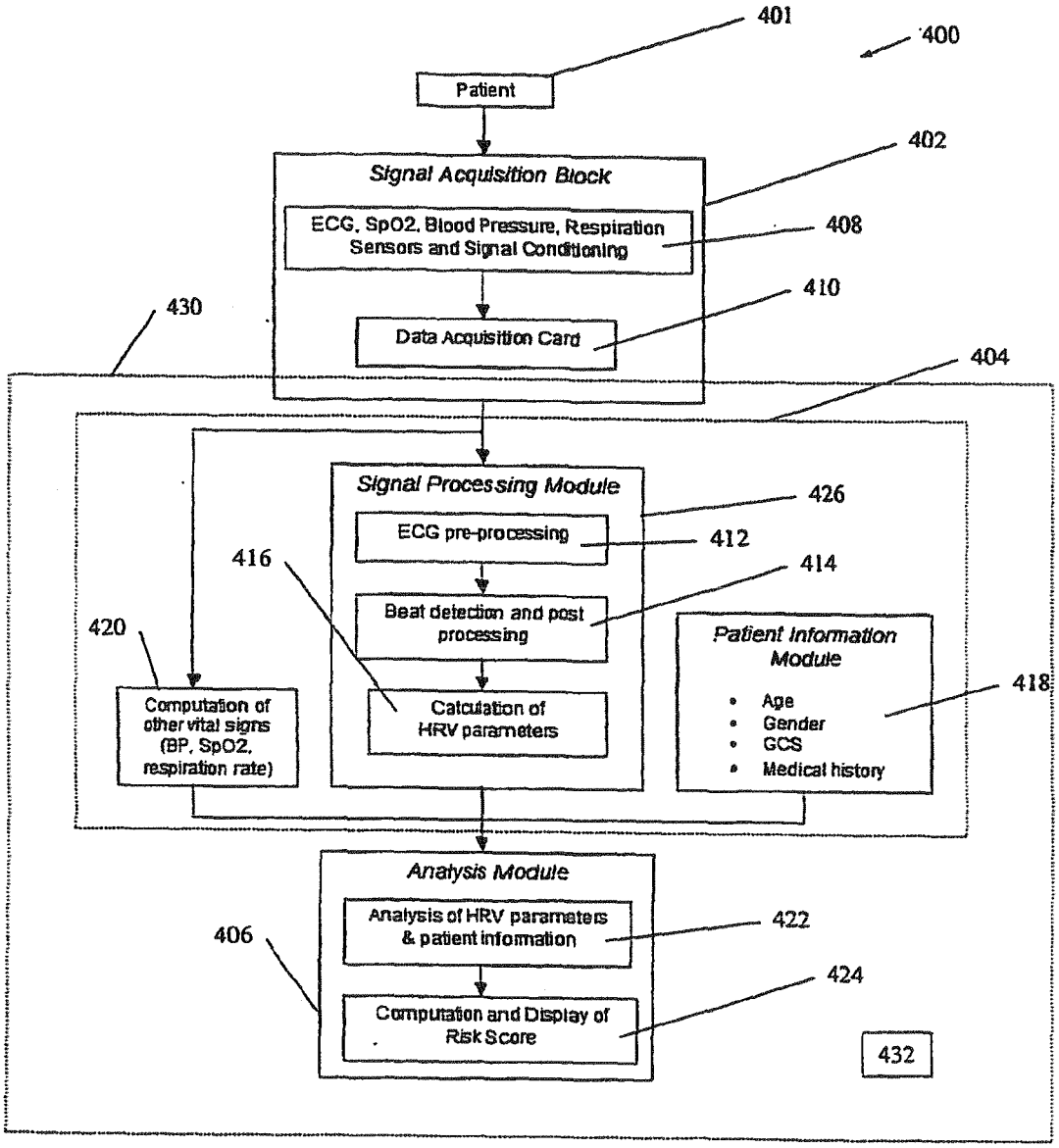

401
400
Patient
402
Signal Acquisition Block
ECG, SpO2, Blood Pressure, Respiration Sensors and Signal Conditioning
408
410
Data Acquisition Card
430
404
Signal Processing Module
426
ECG pre-processing
412
416
414
Beat detection and post processing
420
Patient Information Module
Age
Gender
GCS
Medical history
418
Computation of other vital signs (BP, SpO2, respiration rate)
Calculation of HRV parameters
Analysis Module
406
Analysis of HRV parameters & patient information
422
424
Computation and Display of Risk Score
432

Figure 4

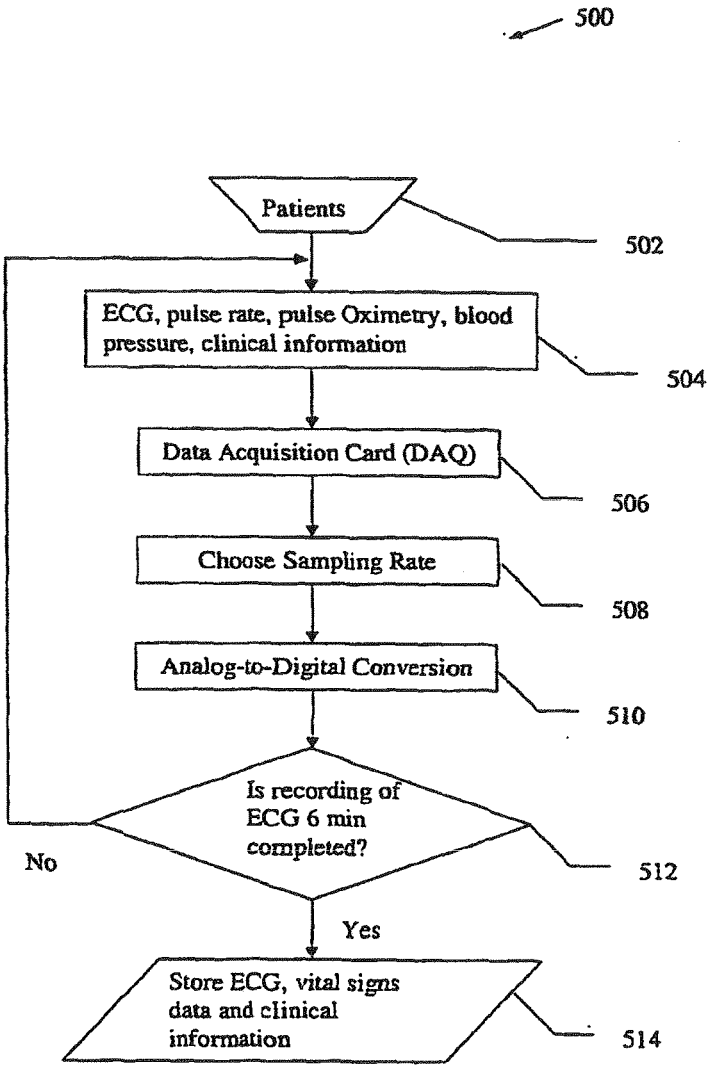

500
Patients
502
ECG, pulse rate, pulse Oximetry, blood pressure, clinical information
504
Data Acquisition Card (DAQ)
506
Choose Sampling Rate
508
Analog-to-Digital Conversion
510
Is recording of ECG 6 min completed?
512
No
Yes
Store ECG, vital signs data and clinical information
514

Figure 5

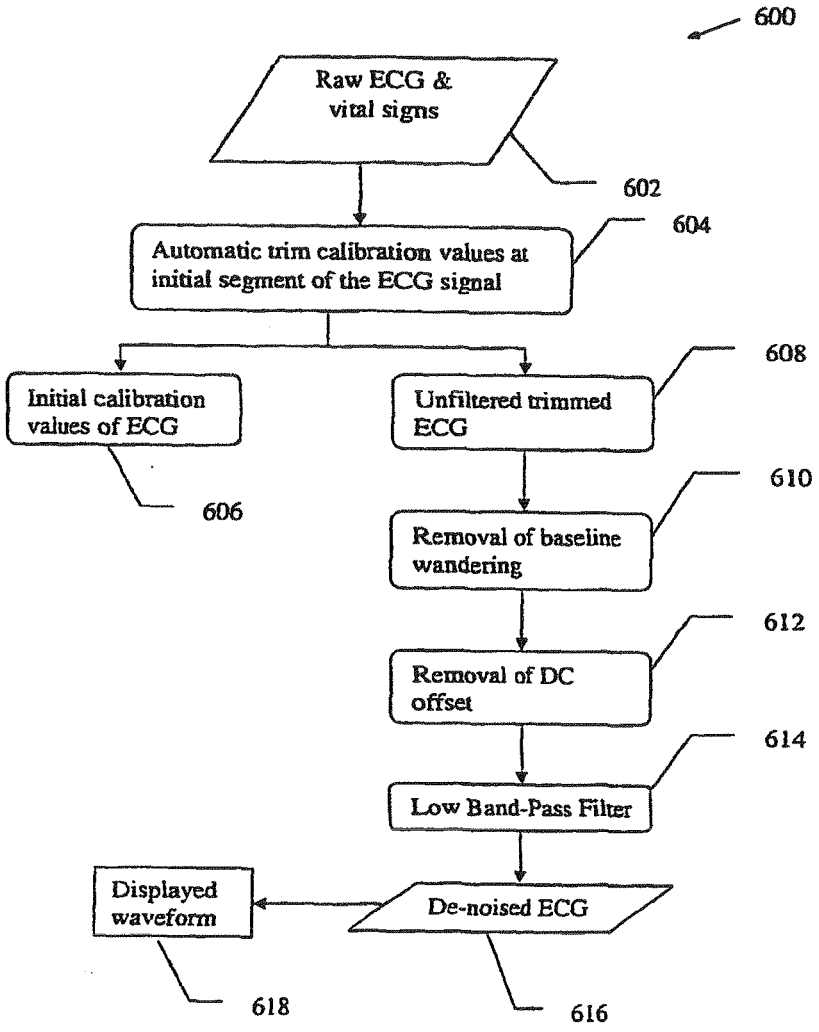

600
Raw ECG & vital signs
602
Automatic trim calibration values at initial segment of the ECG signal
604
Initial calibration values of ECG
606
Unfiltered trimmed ECG
608
Removal of baseline wandering
610
Removal of DC offset
612
Low Band-Pass Filter
614
De-noised ECG
616
Displayed waveform
618

Figure 6

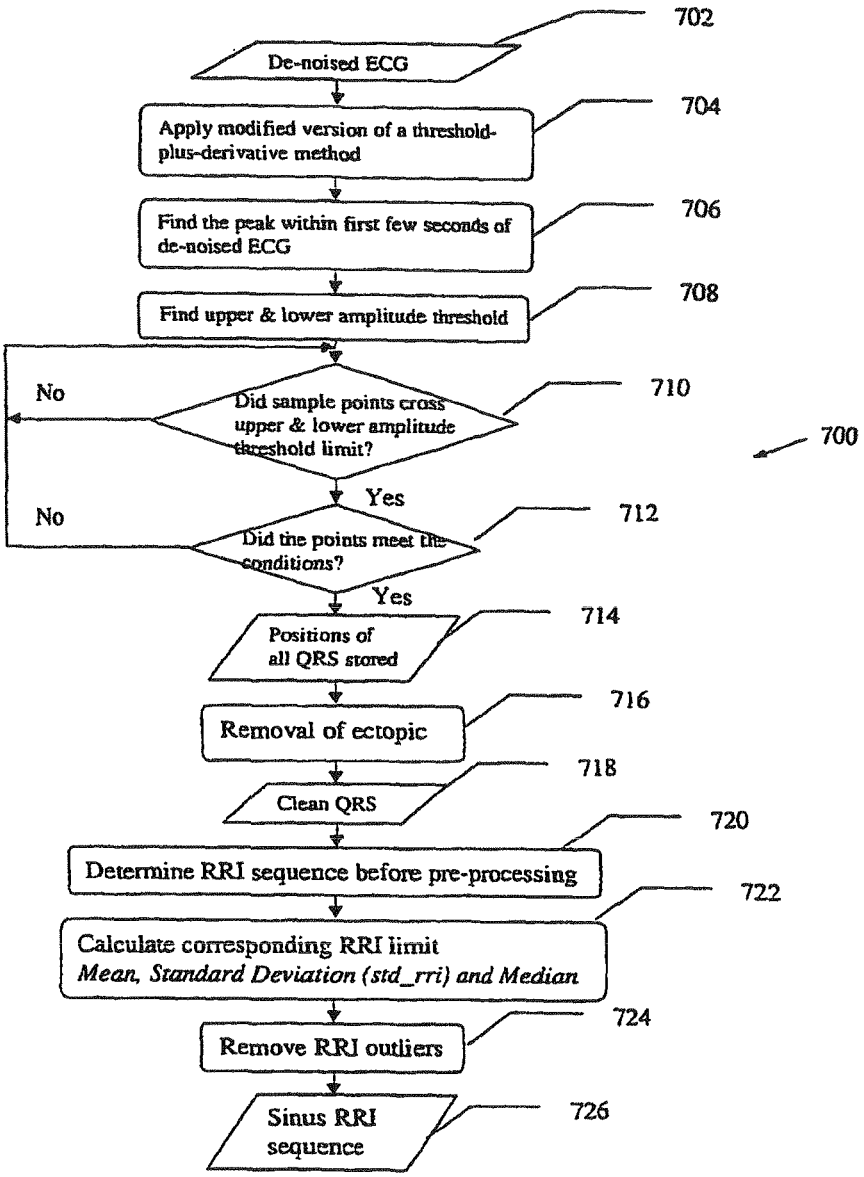

702
De-noised ECG
704
Apply modified version of a threshold-plus-derivative method
706
Find the peak within first few seconds of de-noised ECG
708
Find upper & lower amplitude threshold
710
No
Did sample points cross upper & lower amplitude threshold limit?
700
Yes
712
No
Did the points meet the conditions?
Yes
714
Positions of all QRS stored
716
Removal of ectopic
718
Clean QRS
720
Determine RRI sequence before pre-processing
722
Calculate corresponding RRI limit
Mean, Standard Deviation (std_rri) and Median
724
Remove RRI outliers
726
Sinus RRI sequence

Figure 7

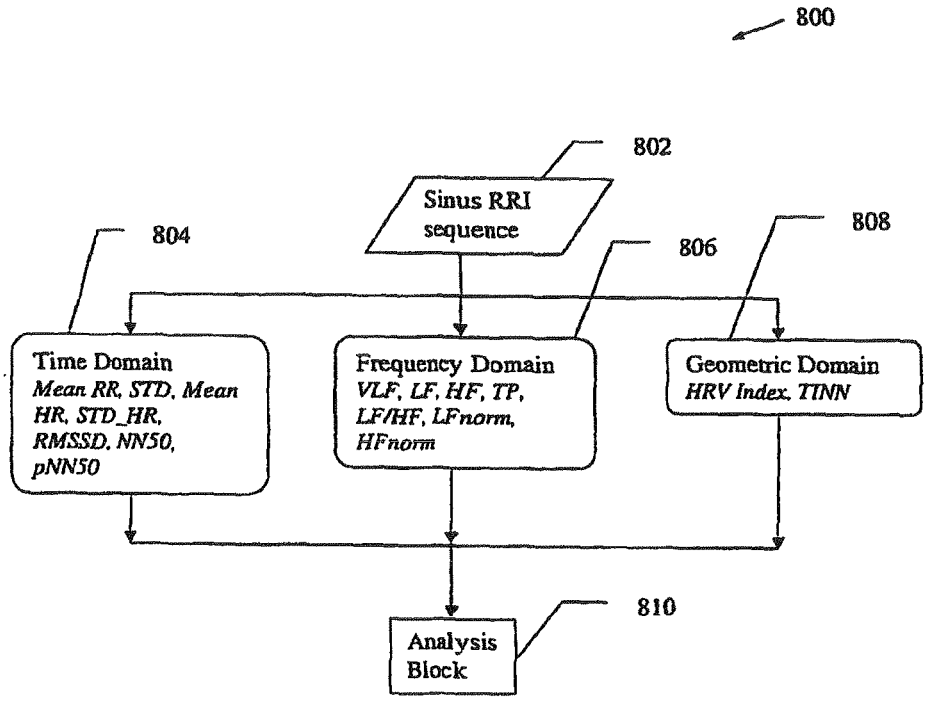

800
802
Sinus RRI sequence
804
806
808
Time Domain
Mean RR, STD, Mean HR, STD_HR, RMSSD, NN50, pNN50
Frequency Domain
VLF, LF, HF, TP, LF/HF, LFnorm, HFnorm
Geometric Domain
HRV Index, TINN
810
Analysis Block

Figure 8

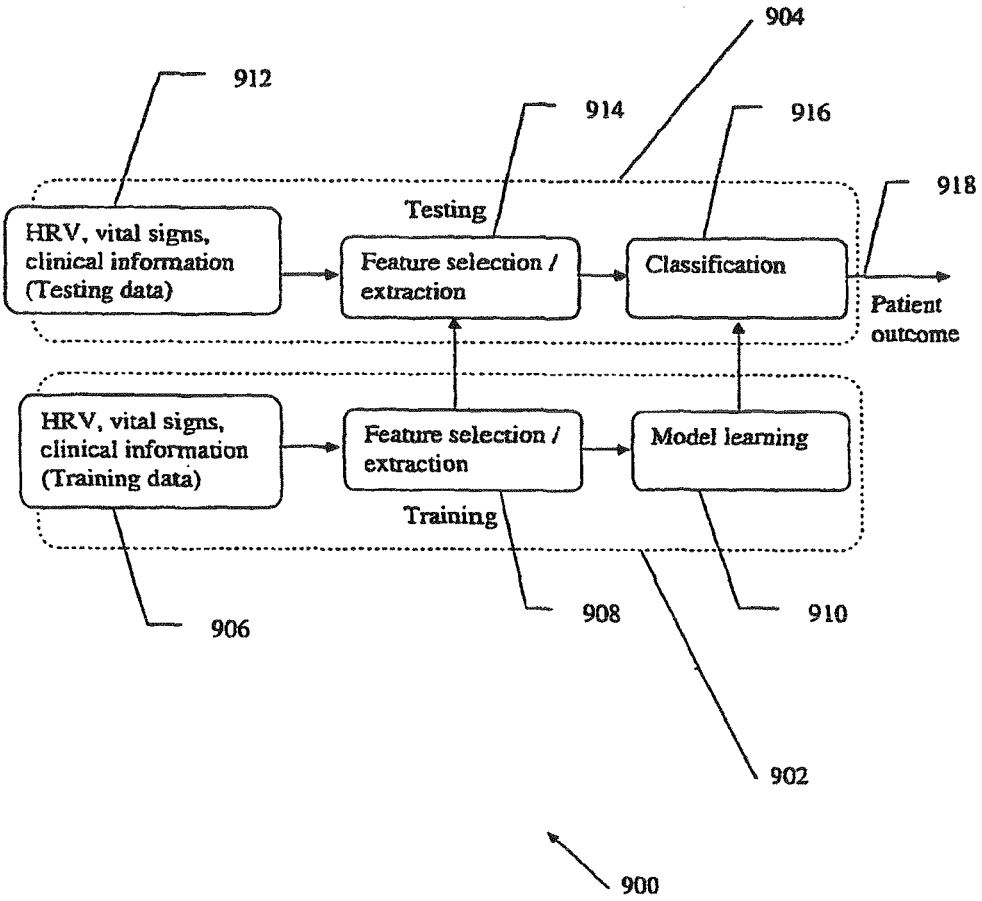

904
912
914
916
918
Testing
HRV, vital signs, clinical information (Testing data)
Feature selection / extraction
Classification
Patient outcome
HRV, vital signs, clinical information (Training data)
Feature selection / extraction
Model learning
Training
906
908
910
902
900

Figure 9

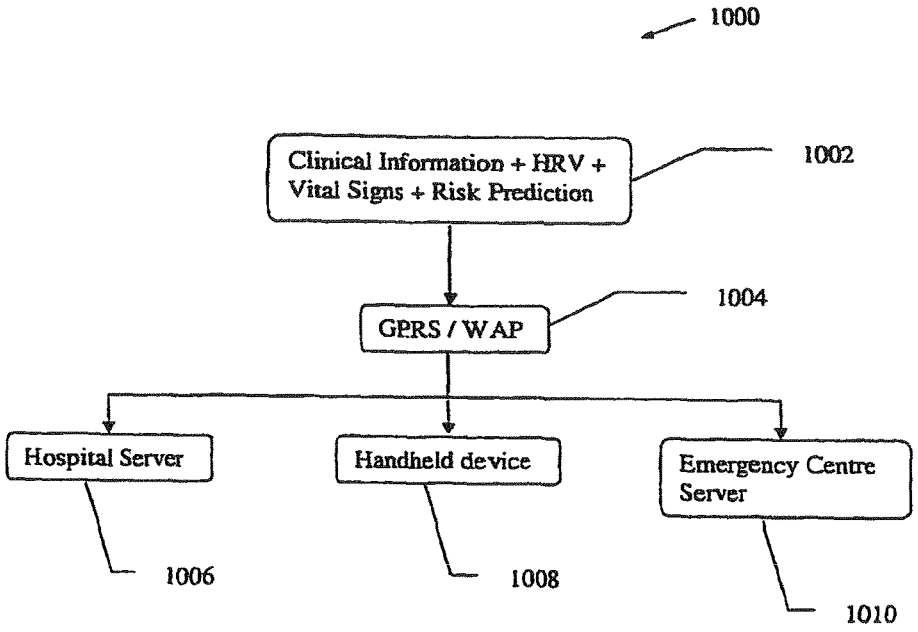

1000
Clinical Information + HRV + Vital Signs + Risk Prediction
1002
GPRS / WAP
1004
Hospital Server
Handheld device
Emergency Centre Server
1006
1008
1010

Figure 10

Characteristics	(N=100)
Mean age (SD)	65.21 (15.95)
Female (%)	37 (37.00)
Ethnicity (%)	
Chinese	73 (73.00)
Malay	15 (15.00)
Indian	7 (7.00)
Other	5 (5.00)
Priority class (%)	
P1	87 (87.00)
p2	13 (13.00)
Vital Signs (SD)	
Temperature (°C)	36.81 (0.75)
Resp rate (/min)	19.47 (4.34)
Pulse (/min)	91.82 (27.35)
SBP (mmHG)	135.99 (37.80)
DBP (mmHG)	75.94 (20.89)
SpO_2	95.19 (7.12)
GCS	14.01 (2.77)
Pain Score	1.84 (3.15)
Patient outcome (%)	
Died	40 (40.00)
Survived	60 (60.00)
ECG characteristics (SD)	
Mean length (min)	207.52 (102.07)
% sinus rhythm	89.64 (13.99)

FIG. 11

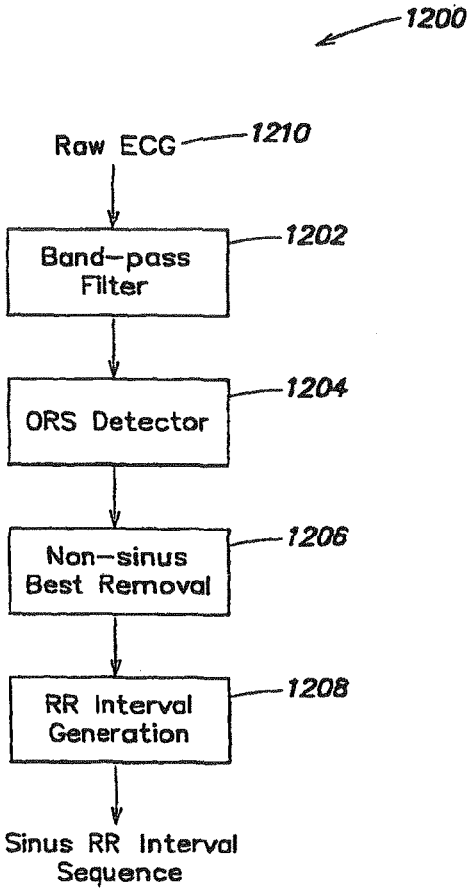

1200
Raw ECG
1210
Band-pass Filter
1202
QRS Detector
1204
Non-sinus Best Removal
1206
RR Interval Generation
1208
Sinus RR Interval Sequence

FIG. 12

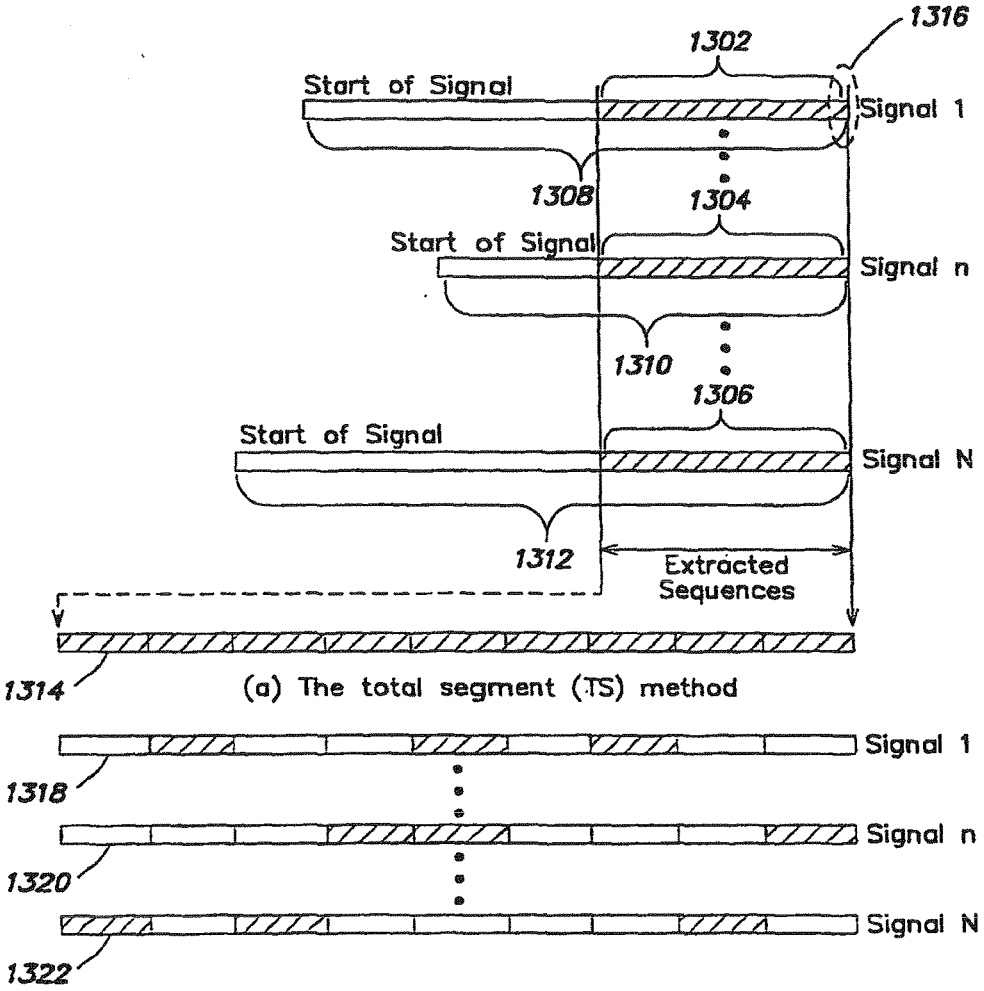

1316
1302
Start of Signal
Signal 1
1308
1304
Start of Signal
Signal n
1310
1306
Start of Signal
Signal N
1312
Extracted Sequences
1314
(a) The total segment (TS) method
Signal 1
1318
Signal n
1320
Signal N
1322

FIG. 13

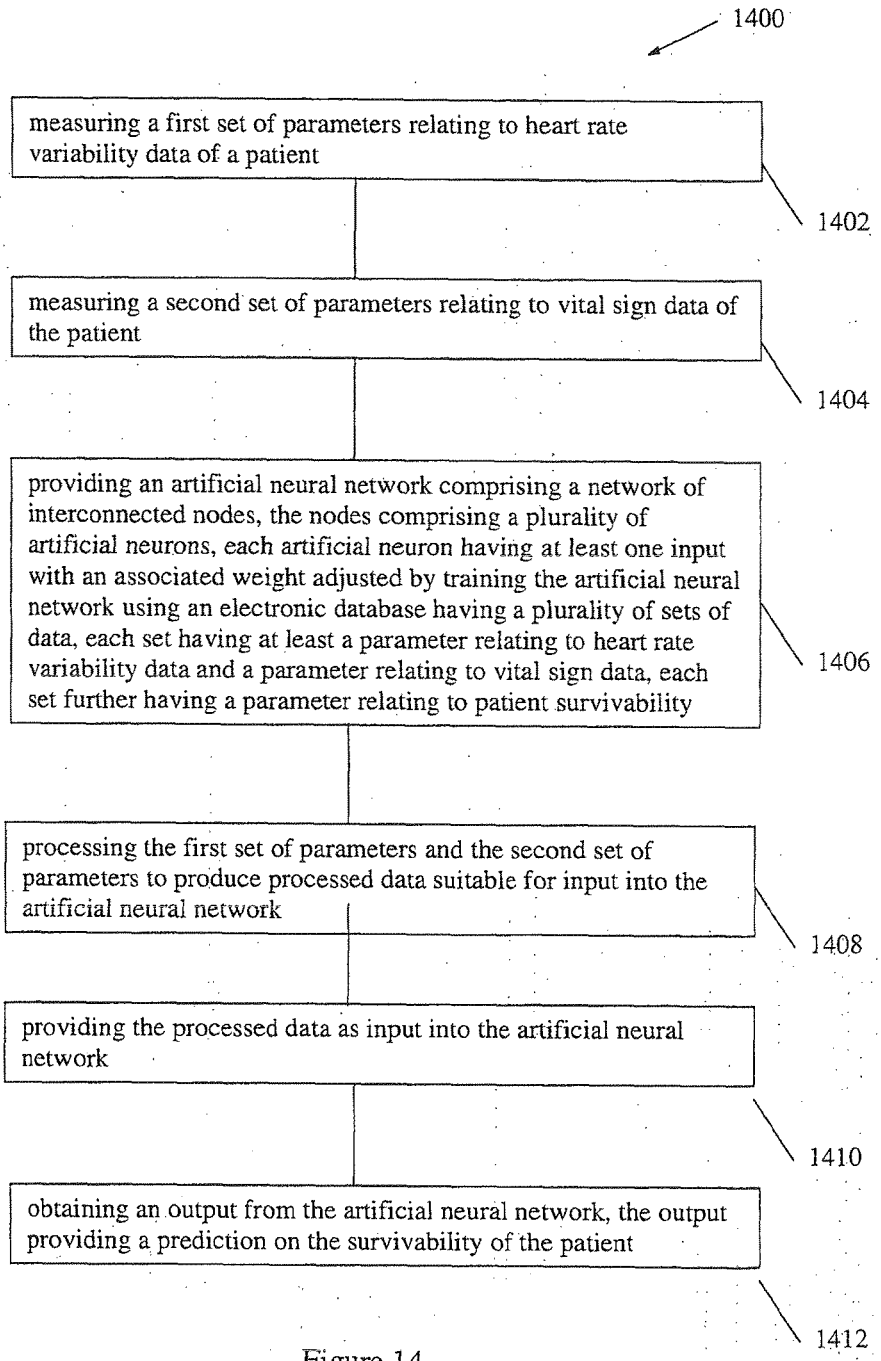

1400
measuring a first set of parameters relating to heart rate variability data of a patient
1402
measuring a second set of parameters relating to vital sign data of the patient
1404
providing an artificial neural network comprising a network of interconnected nodes, the nodes comprising a plurality of artificial neurons, each artificial neuron having at least one input with an associated weight adjusted by training the artificial neural network using an electronic database having a plurality of sets of data, each set having at least a parameter relating to heart rate variability data and a parameter relating to vital sign data, each set further having a parameter relating to patient survivability
1406
processing the first set of parameters and the second set of parameters to produce processed data suitable for input into the artificial neural network
1408
providing the processed data as input into the artificial neural network
1410
obtaining an output from the artificial neural network, the output providing a prediction on the survivability of the patient
1412

Figure 14

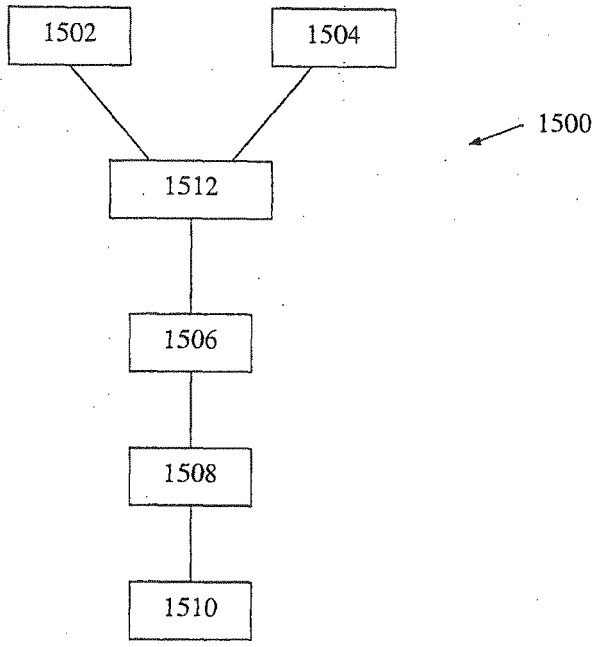


Figure 15

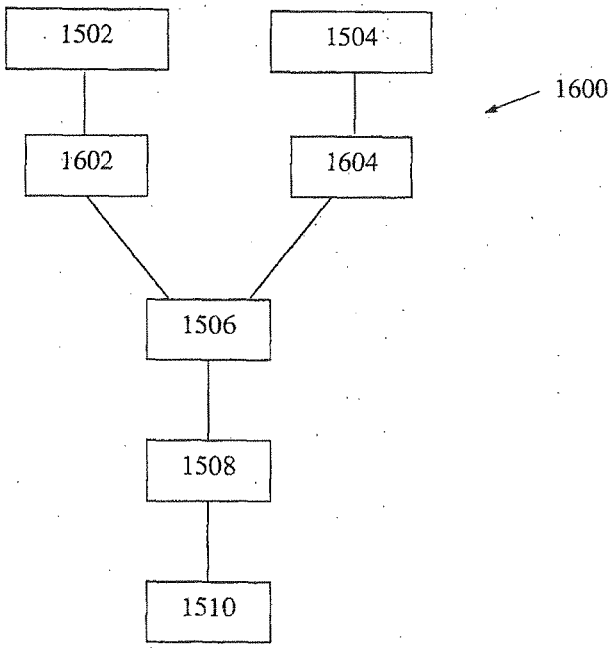


Figure 16

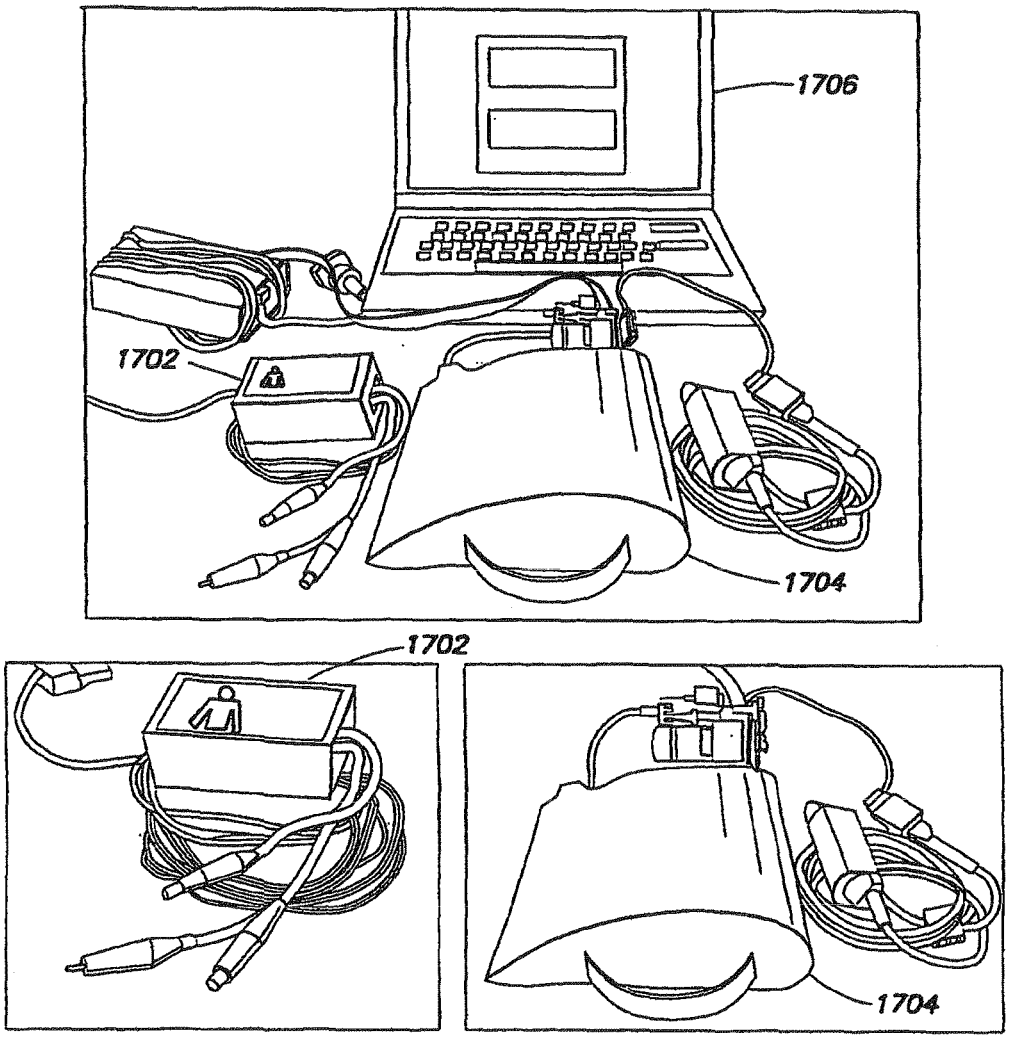


FIG. 17

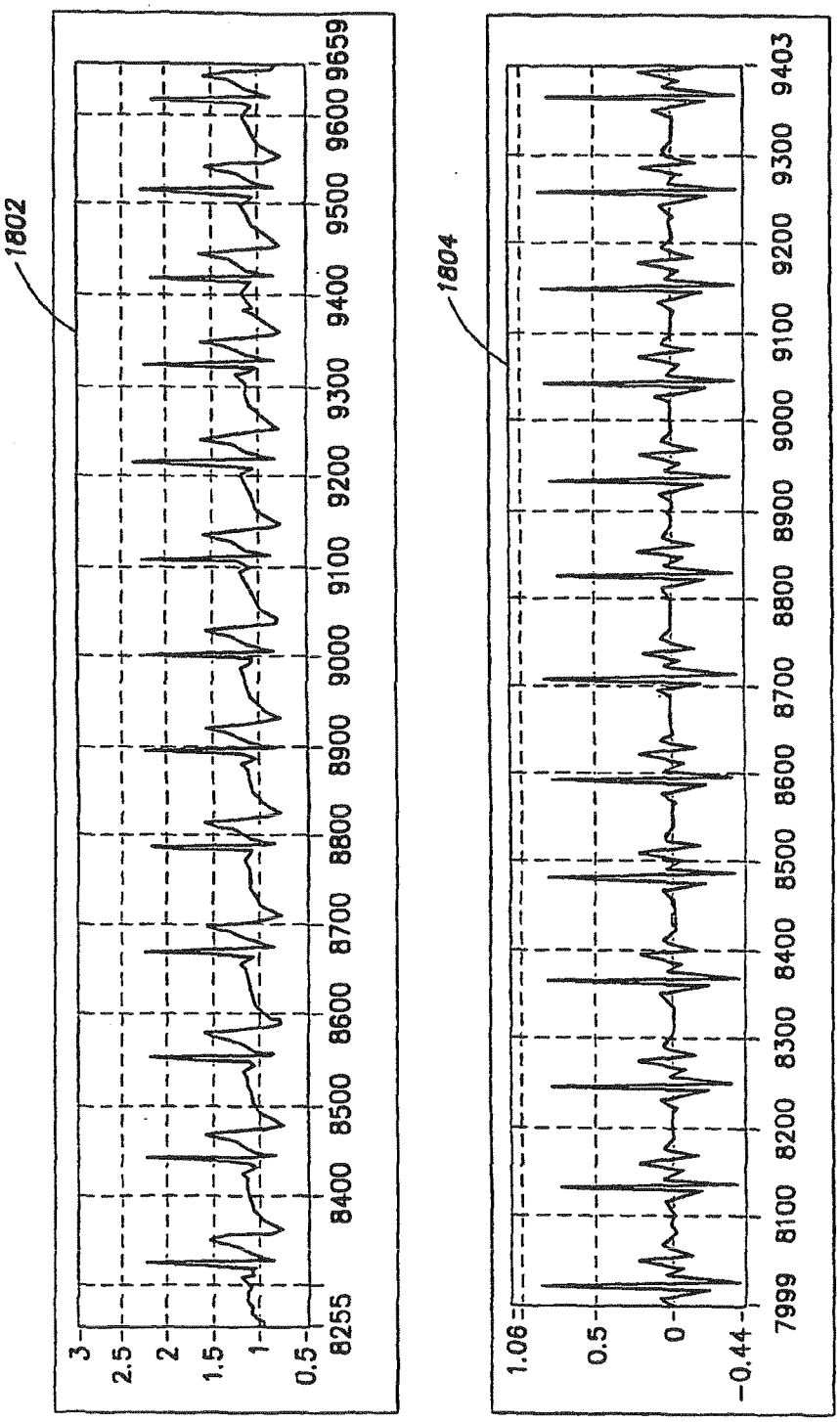

1802
3
2.5
2
1.5
1
0.5
8255
8400
8500
8600
8700
8800
8900
9000
9100
9200
9300
9400
9500
9600
9659
1804
1.06
0.5
0
−0.44
7999
8100
8200
8300
8400
8500
8600
8700
8800
8900
9000
9100
9200
9300
9403

FIG. 18

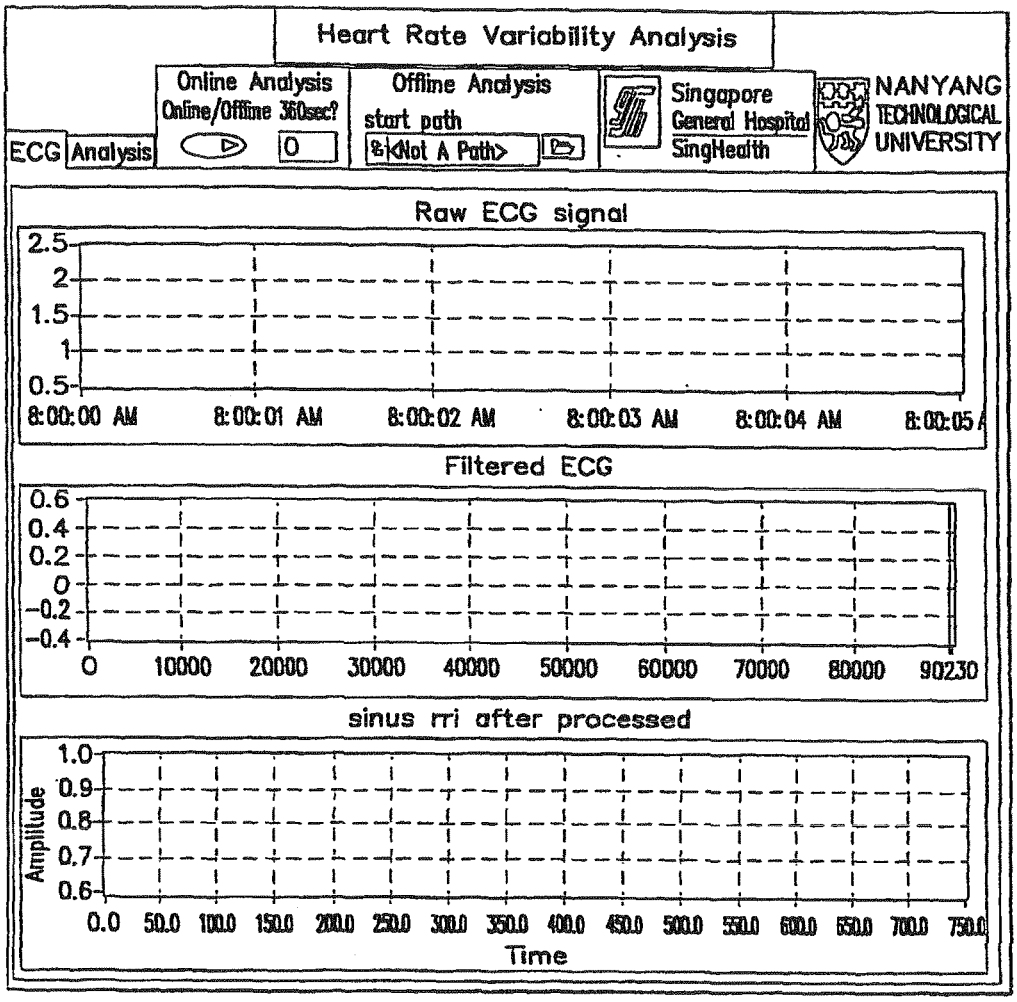

Heart Rate Variability Analysis
Online Analysis
Online/Offline 360sec?
0
Offline Analysis
start path
<Not A Path>
Singapore General Hospital SingHealth
NANYANG TECHNOLOGICAL UNIVERSITY
ECG
Analysis
Raw ECG signal
2.5
2
1.5
1
0.5
8:00:00 AM
8:00:01 AM
8:00:02 AM
8:00:03 AM
8:00:04 AM
8:00:05
Filtered ECG
0.6
0.4
0.2
0
-0.2
-0.4
0
10000
20000
30000
40000
50000
60000
70000
80000
90230
sinus rri after processed
Amplitude
1.0
0.9
0.8
0.7
0.6
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
650.0
700.0
750.0
Time

FIG. 19

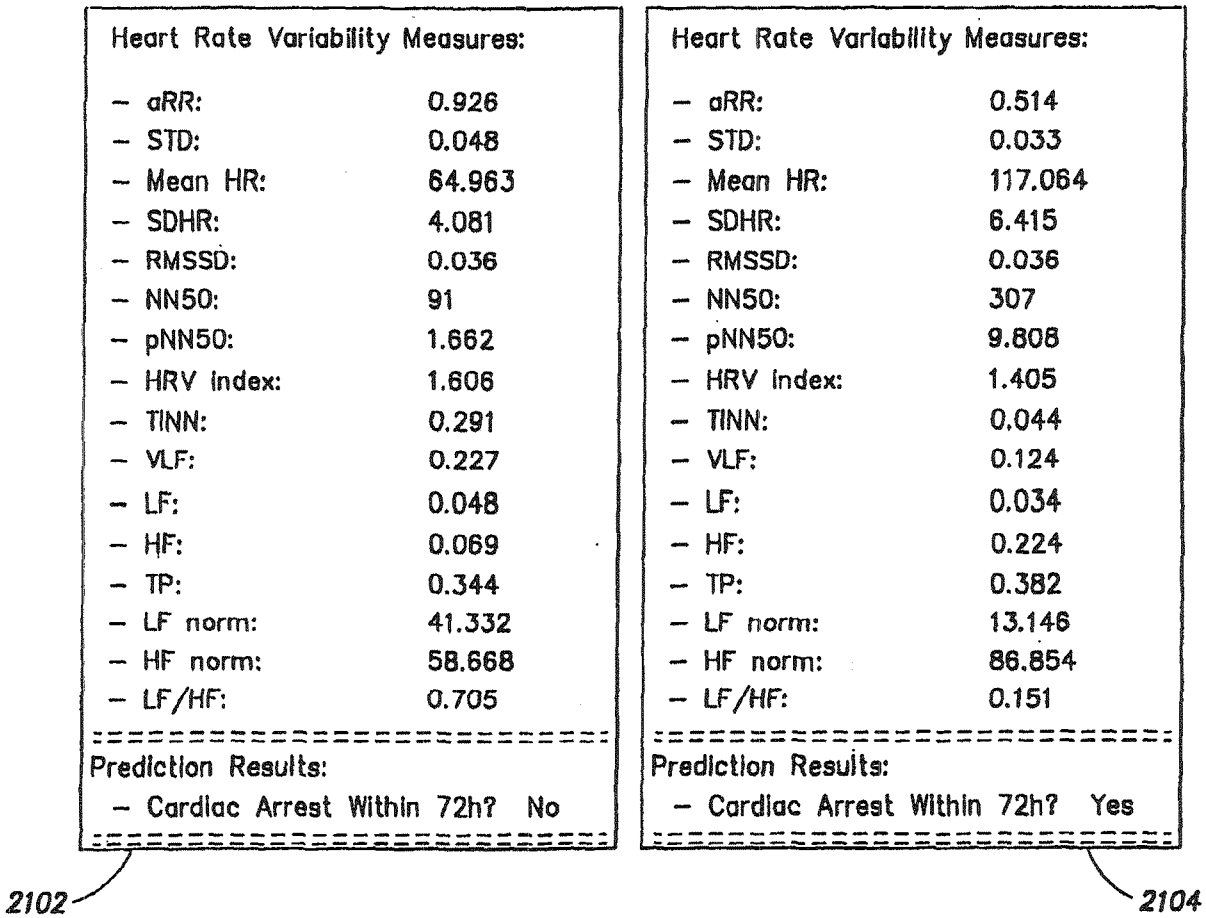

Heart Rate Variability Measures:
– aRR: 0.926
– STD: 0.048
– Mean HR: 64.963
– SDHR: 4.081
– RMSSD: 0.036
– NN50: 91
– pNN50: 1.662
– HRV Index: 1.606
– TINN: 0.291
– VLF: 0.227
– LF: 0.048
– HF: 0.069
– TP: 0.344
– LF norm: 41.332
– HF norm: 58.668
– LF/HF: 0.705
Prediction Results:
– Cardiac Arrest Within 72h? No
2102
Heart Rate Variability Measures:
– aRR: 0.514
– STD: 0.033
– Mean HR: 117.064
– SDHR: 6.415
– RMSSD: 0.036
– NN50: 307
– pNN50: 9.808
– HRV Index: 1.405
– TINN: 0.044
– VLF: 0.124
– LF: 0.034
– HF: 0.224
– TP: 0.382
– LF norm: 13.146
– HF norm: 86.854
– LF/HF: 0.151
Prediction Results:
– Cardiac Arrest Within 72h? Yes
2104

FIG. 20

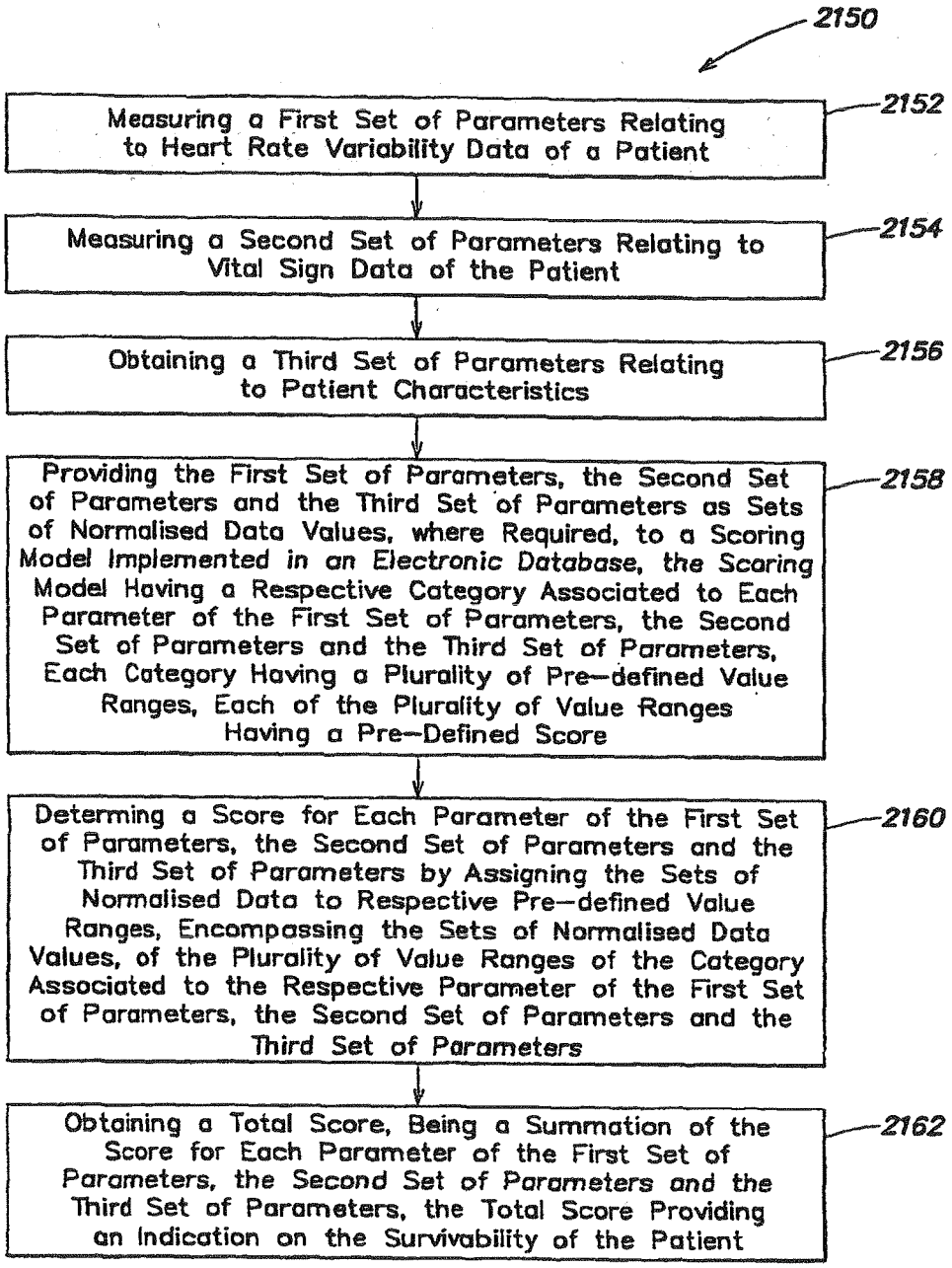

2150
Measuring a First Set of Parameters Relating to Heart Rate Variability Data of a Patient
2152
Measuring a Second Set of Parameters Relating to Vital Sign Data of the Patient
2154
Obtaining a Third Set of Parameters Relating to Patient Characteristics
2156
Providing the First Set of Parameters, the Second Set of Parameters and the Third Set of Parameters as Sets of Normalised Data Values, where Required, to a Scoring Model Implemented in an Electronic Database, the Scoring Model Having a Respective Category Associated to Each Parameter of the First Set of Parameters, the Second Set of Parameters and the Third Set of Parameters, Each Category Having a Plurality of Pre-defined Value Ranges, Each of the Plurality of Value Ranges Having a Pre-Defined Score
2158
Determing a Score for Each Parameter of the First Set of Parameters, the Second Set of Parameters and the Third Set of Parameters by Assigning the Sets of Normalised Data to Respective Pre-defined Value Ranges, Encompassing the Sets of Normalised Data Values, of the Plurality of Value Ranges of the Category Associated to the Respective Parameter of the First Set of Parameters, the Second Set of Parameters and the Third Set of Parameters
2160
Obtaining a Total Score, Being a Summation of the Score for Each Parameter of the First Set of Parameters, the Second Set of Parameters and the Third Set of Parameters, the Total Score Providing an Indication on the Survivability of the Patient
2162

FIG. 21

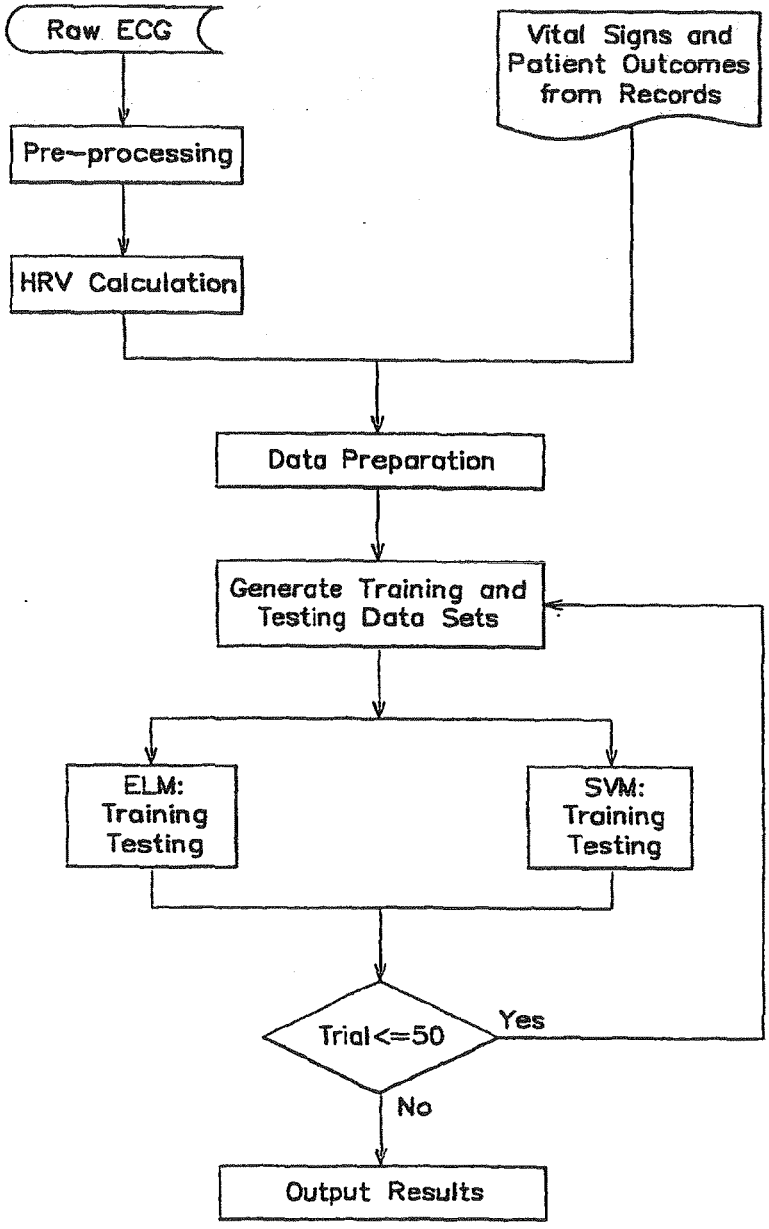

Raw ECG
Vital Signs and Patient Outcomes from Records
Pre-processing
HRV Calculation
Data Preparation
Generate Training and Testing Data Sets
ELM: Training Testing
SVM: Training Testing
Trial<=50
Yes
No
Output Results

FIG. 22

Classifier	Activation/ kernel function	Accuracy (%)	Sensitivity (%)	Specificity (%)
ELM	Hardlim	61.44	41.20	74.93
	Sigmoid	62.72	42.20	75.33
	Sine	60.72	41.80	74.84
SVM	RBF	71.60	41.20	91.87
	Linear	69.76	46.60	85.20
	Sigmoid	71.68	39.40	93.20

FIG. 23

Classifier	Activation/ kernel function	Accuracy (%)	Sensitivity (%)	Specificity (%)
ELM	Hardlim	65.76	51.27	72.13
	Sigmoid	67.60	53.23	72.53
	Sine	68.48	54.04	72.83
SVM	RBF	71.20	59.60	78.93
	Linear	71.04	58.00	79.73
	Sigmoid	66.08	48.80	77.60

FIG. 24

Classifier	Activation/ kernel function	Accuracy (%)	Sensitivity (%)	Specificity (%)
ELM	Hardlim	68.48	51.07	76.71
	Sigmoid	72.40	53.47	78.42
	Sine	68.80	52.84	78.13
SVM	RBF	73.68	56.00	85.47
	Linear	78.32	65.00	87.20
	Sigmoid	71.04	47.00	88.40

FIG. 25

Classifier	Activation/ kernel function	Number of Selected Segments M' = 1	M' = 3	M' = 5	M' = 7	M' = 9
ELM	Hardlim	65.60	68.48	69.44	67.28	67.52
	Sigmoid	68.48	72.40	73.44	71.12	69.36
	Sine	64.96	68.80	68.24	67.36	65.84
SVM	RBF	73.04	73.68	72.40	73.28	70.96
	Linear	70.00	78.32	73.84	75.04	74.24
	Sigmoid	62.54	71.04	72.00	71.28	70.24

FIG. 26

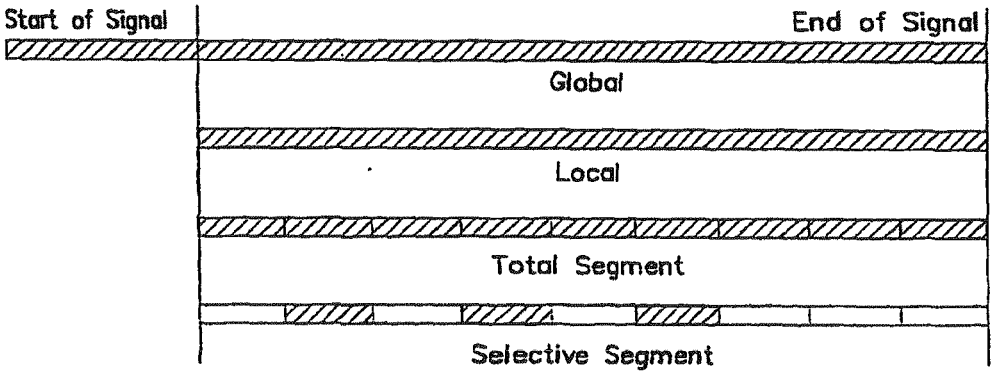


FIG. 27

Table 7 Classification accuracy with different predictive strategies using combined features.

Classifier	Activation/ kernel function	Global (%)	Local (%)	Total segment (%)	Selective segment (%)
ELM	Hardlim	60.48	60.96	67.52	68.48
	Sigmoid	64.24	65.28	69.36	72.40
	Sine	59.92	61.12	65.84	68.80
SVM	RBF	62.32	66.72	70.96	73.68
	Linear	70.00	68.64	74.24	78.32
	Sigmoid	60.64	60.72	70.24	71.04

FIG. 28

Feature type	Activation function	Accuracy (%)	Sensitivity (%)	Specificity (%)	Training time (ms)	Testing time (ms)
Vital signs	Hardlim	61.44	41.20	74.93	1.56	1.25
	Sigmoid	62.72	42.20	75.33	3.13	0.63
	Sine	60.72	41.80	74.84	2.50	0.94
HRV	Hardlim	61.60	44.44	72.40	8.13	0.63
	Sigmoid	61.36	46.27	71.40	8.13	1.25
	Sine	62.64	46.89	71.48	7.50	0.63
Combined	Hardlim	64.24	44.98	76.44	8.44	1.25
	Sigmoid	70.88	47.93	78.92	7.81	2.50
	Sine	65.92	47.82	78.09	7.50	1.25

FIG. 29

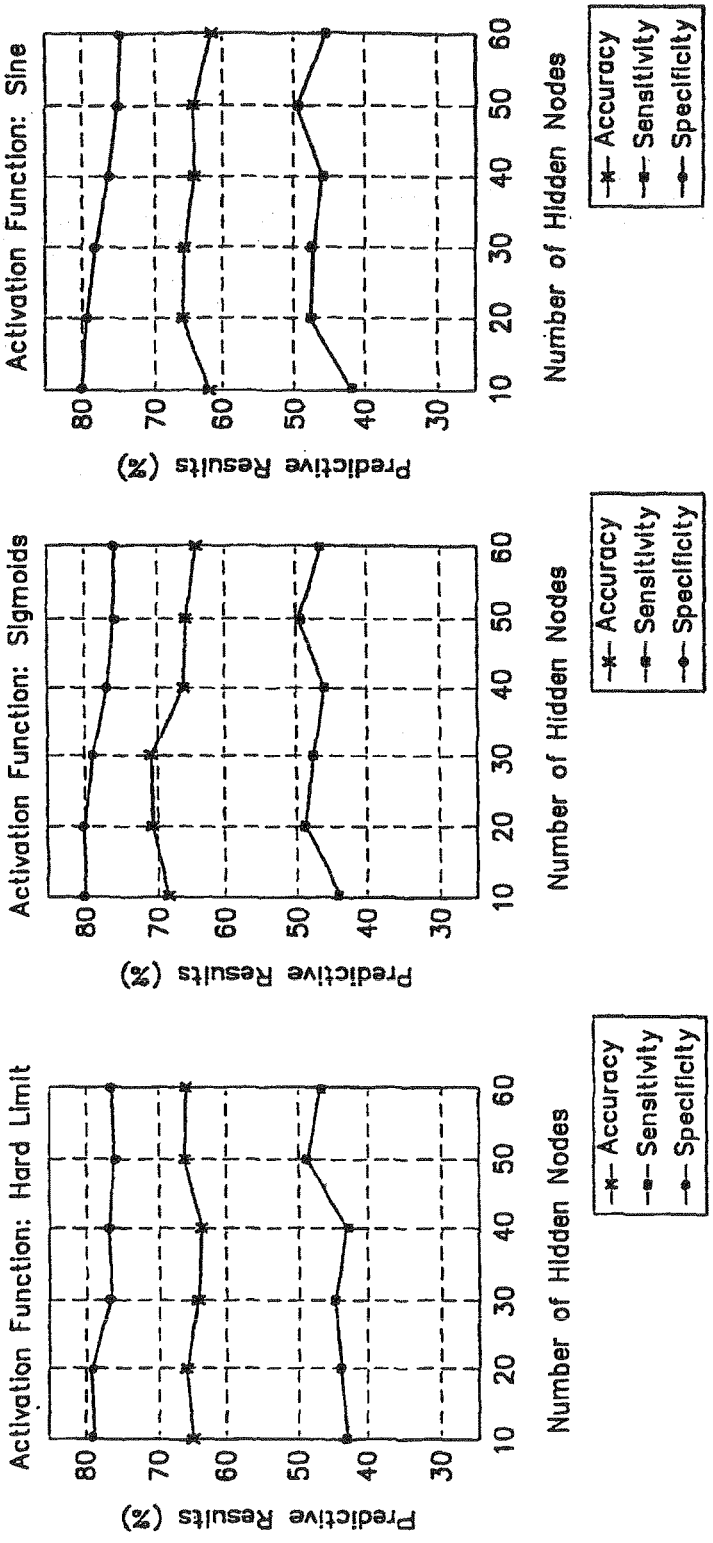


FIG. 30

FIG. 31

FIG. 32

Feature type	Activation function	Global (%)	Local (%)	Segment (%)
Combined	Hardlim	60.48	60.96	64.24
	Sigmoid	64.24	65.28	70.88
	Sine	59.92	61.12	65.92

FIG. 33

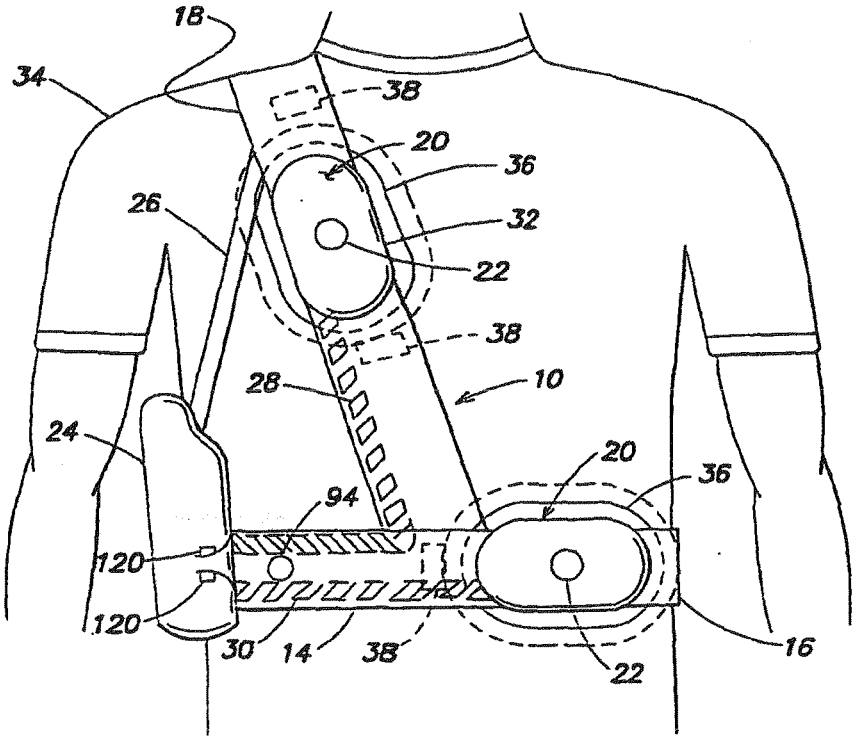


FIG. 34