US 20080146895A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2008/0146895 A1**

(43) **Pub. Date: Jun. 19, 2008**

Olson et al.

(54) **INTELLIGENT RISK MANAGEMENT SYSTEM FOR FIRST RESPONDERS**

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(21) Appl. No.: **11/611,321**

(22) Filed: **Dec. 15, 2006**

Publication Classification

(51) **Int. Cl.**
A61B 5/00 (2006.01)

(52) **U.S. Cl.** **600/301**

(57) **ABSTRACT**

A risk management system (**100**) for first responders (**102**) equips first responders with physiological and environmental sensors (**104**) in order to track the stress conditions and stress responses of the first responders. Data from the sensors is digitized and filtered and processed through a feature extraction system (**202**, **704**) that may include noise filters, (**710**) derivative filters (**706**), integrators (**708**) and derived signal generators (**712**) that use stored data on first responders, before being fed into a pattern recognition system (**402**, **900**) that assesses the risk state of the first responder. Data from multiple first responders in a team can be aggregated to obtain team risk assessments.

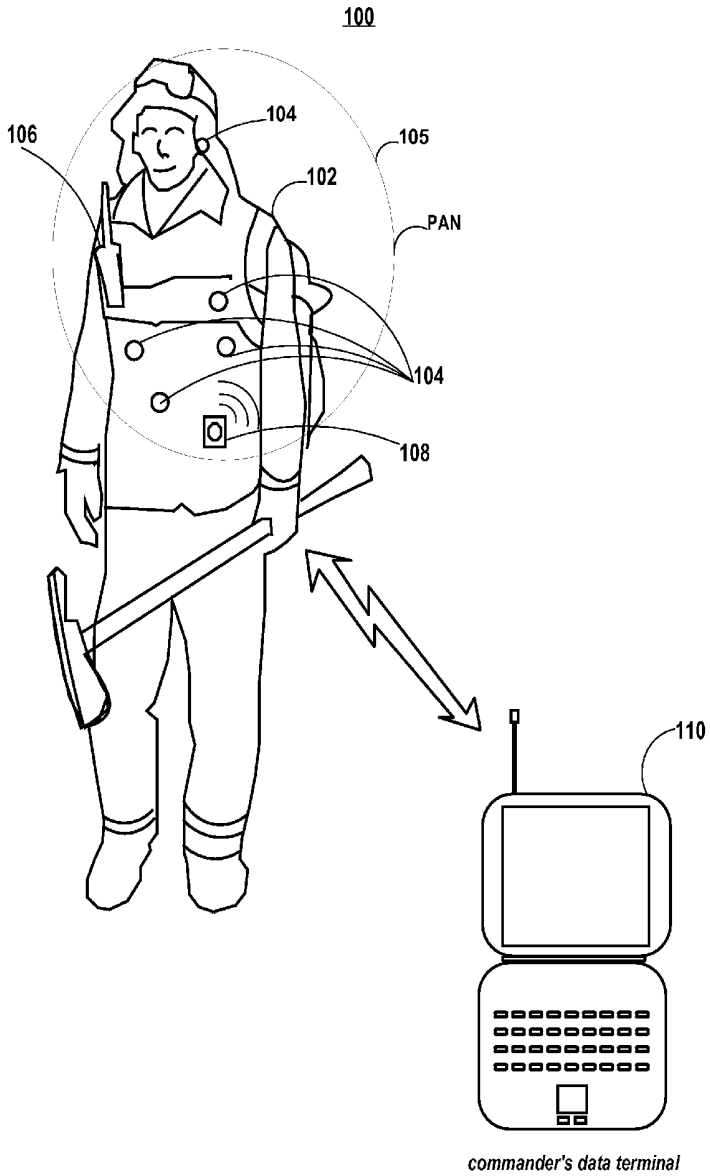


FIG. 1

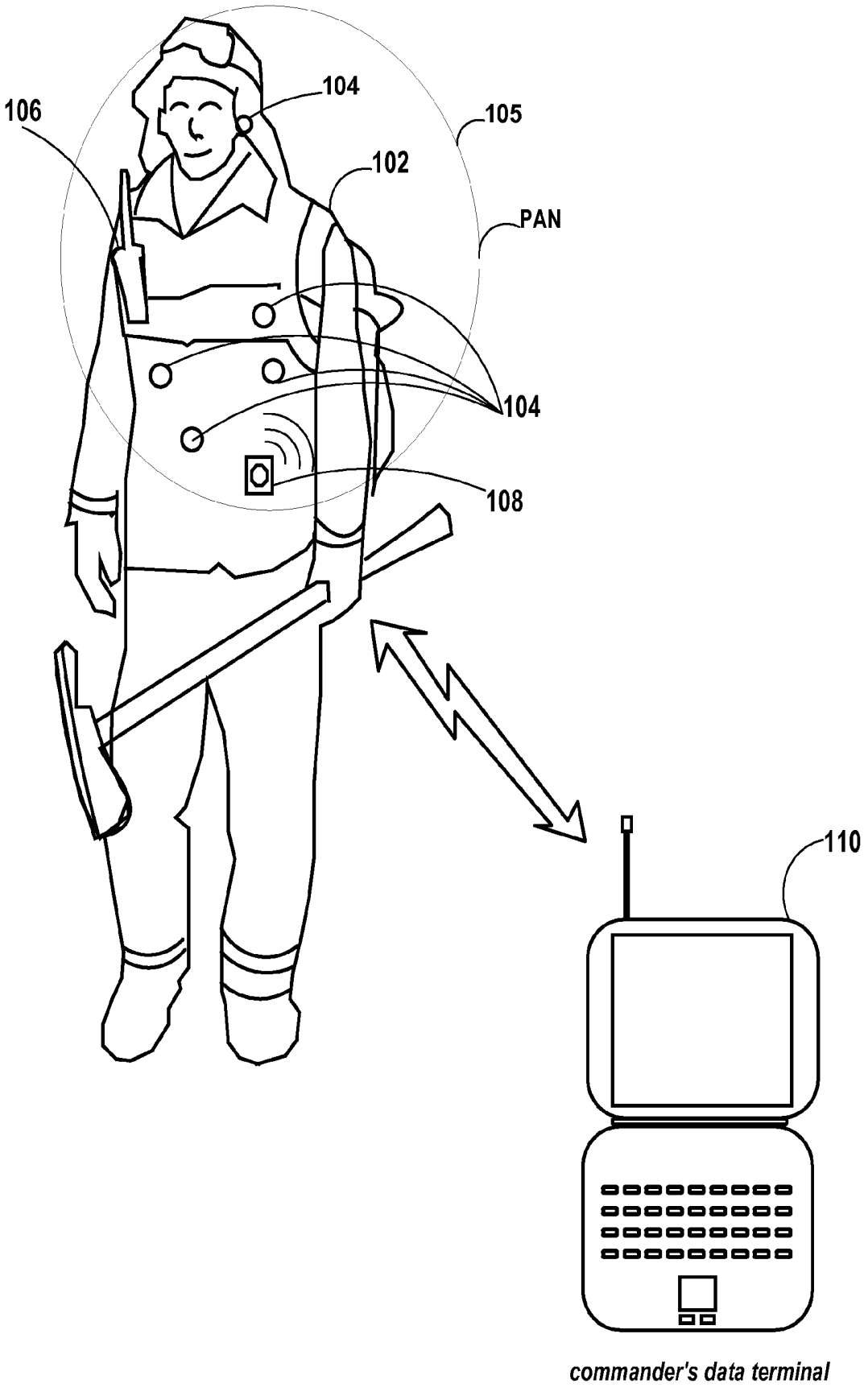


FIG. 2

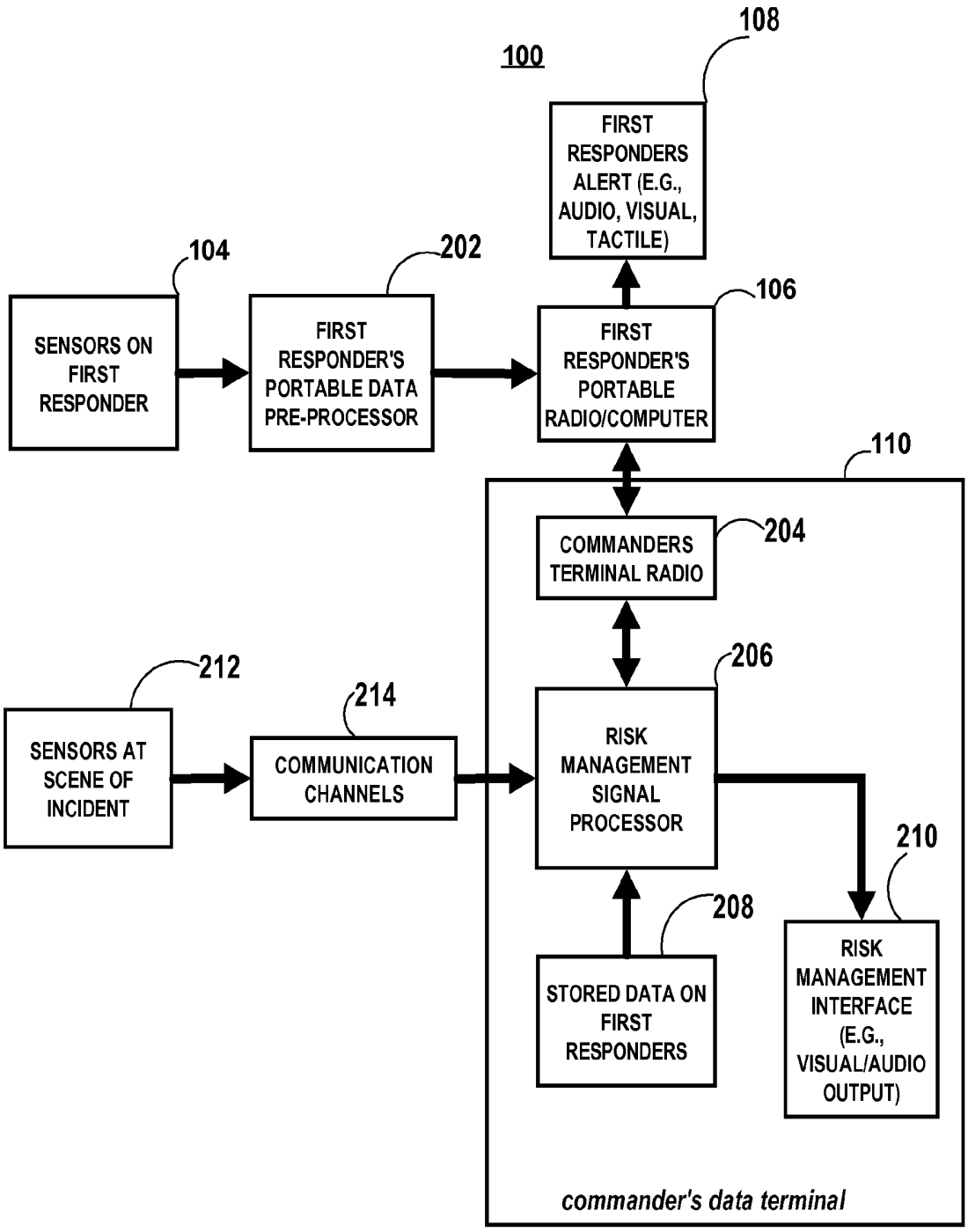

100
108
FIRST RESPONDERS ALERT (E.G., AUDIO, VISUAL, TACTILE)
104
SENSORS ON FIRST RESPONDER
202
FIRST RESPONDER'S PORTABLE DATA PRE-PROCESSOR
106
FIRST RESPONDER'S PORTABLE RADIO/COMPUTER
110
COMMANDERS TERMINAL RADIO
204
212
SENSORS AT SCENE OF INCIDENT
214
COMMUNICATION CHANNELS
206
RISK MANAGEMENT SIGNAL PROCESSOR
210
208
STORED DATA ON FIRST RESPONDERS
RISK MANAGEMENT INTERFACE (E.G., VISUAL/AUDIO OUTPUT)
commander's data terminal

FIG. 3

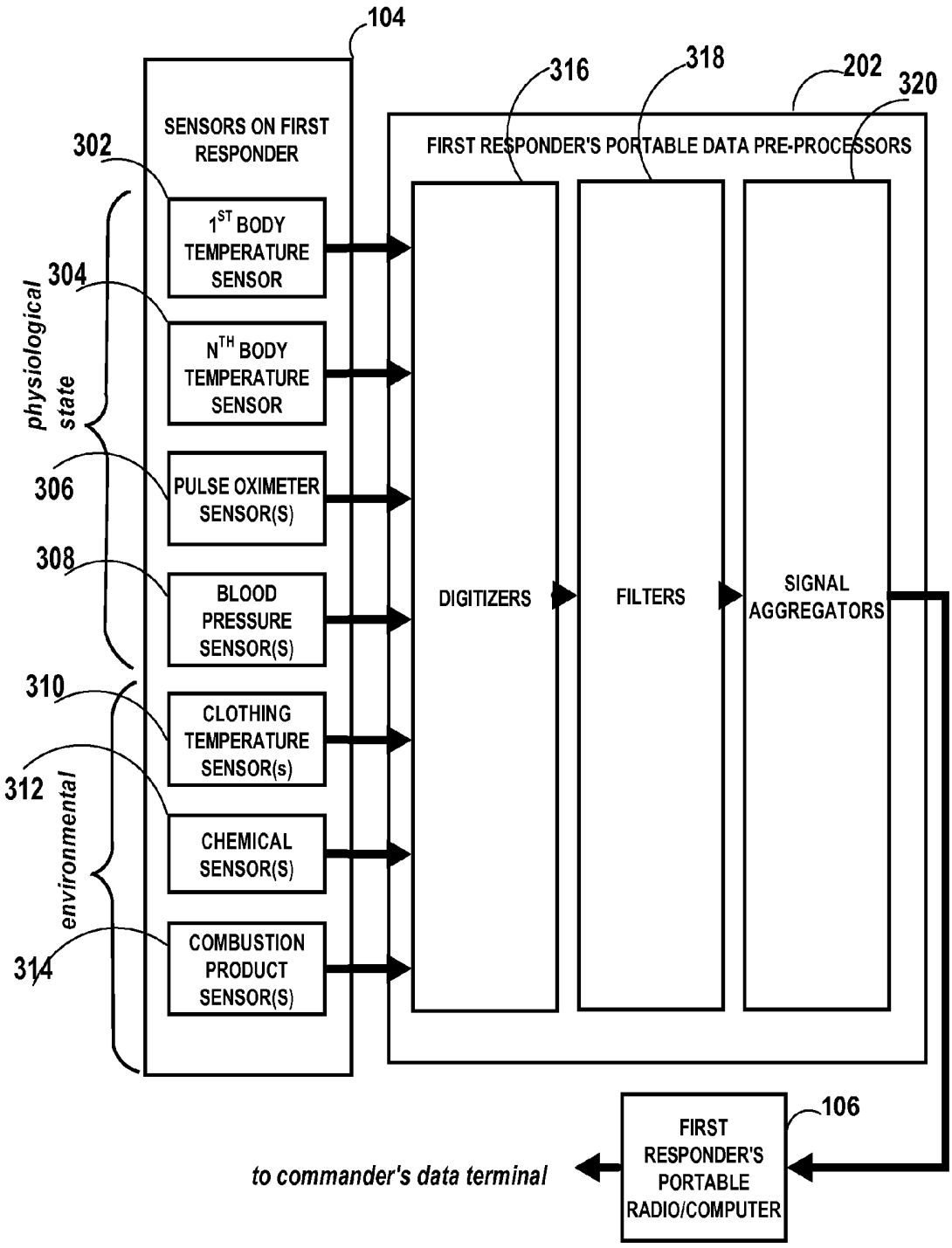

104
316
318
202
320
SENSORS ON FIRST RESPONDER
FIRST RESPONDER'S PORTABLE DATA PRE-PROCESSORS
302
1ST BODY TEMPERATURE SENSOR
304
Nth BODY TEMPERATURE SENSOR
physiological state
306
PULSE OXIMETER SENSOR(S)
308
BLOOD PRESSURE SENSOR(S)
DIGITIZERS
FILTERS
SIGNAL AGGREGATORS
310
CLOTHING TEMPERATURE SENSOR(s)
312
CHEMICAL SENSOR(S)
environmental
314
COMBUSTION PRODUCT SENSOR(S)
106
FIRST RESPONDER'S PORTABLE RADIO/COMPUTER
to commander's data terminal

FIG. 4

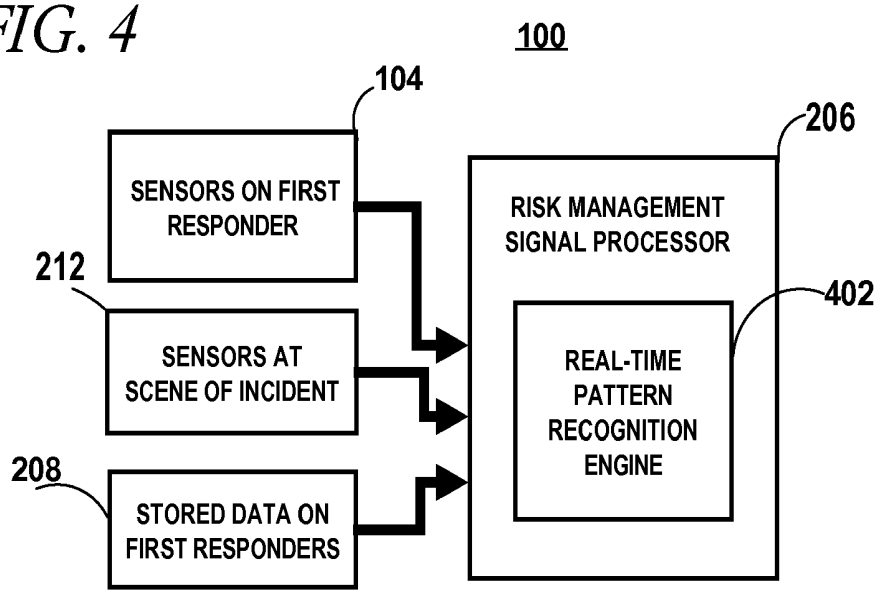


FIG. 5

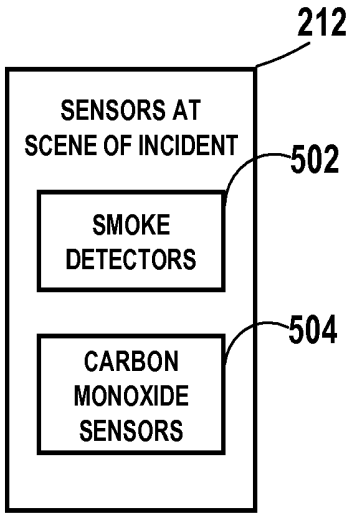


FIG. 6

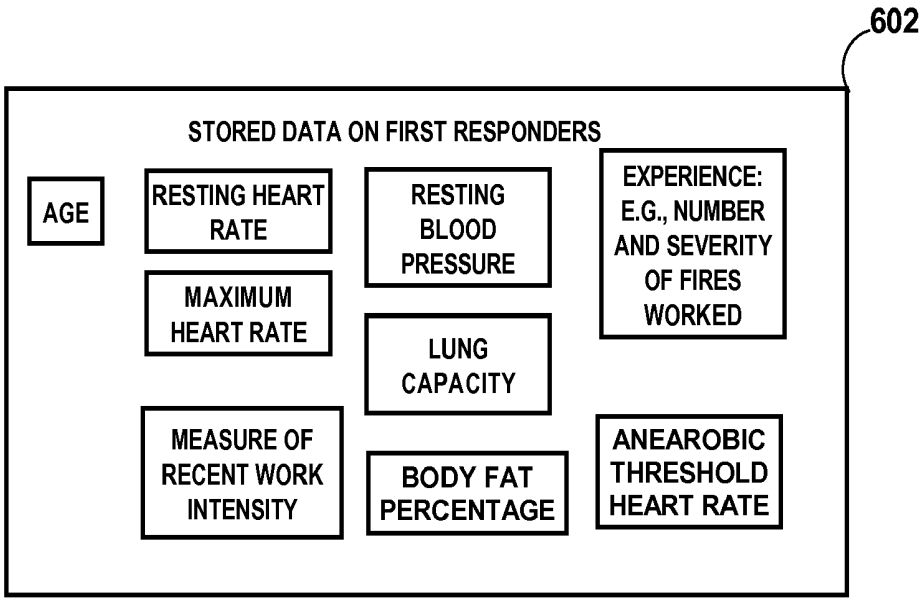


FIG. 7

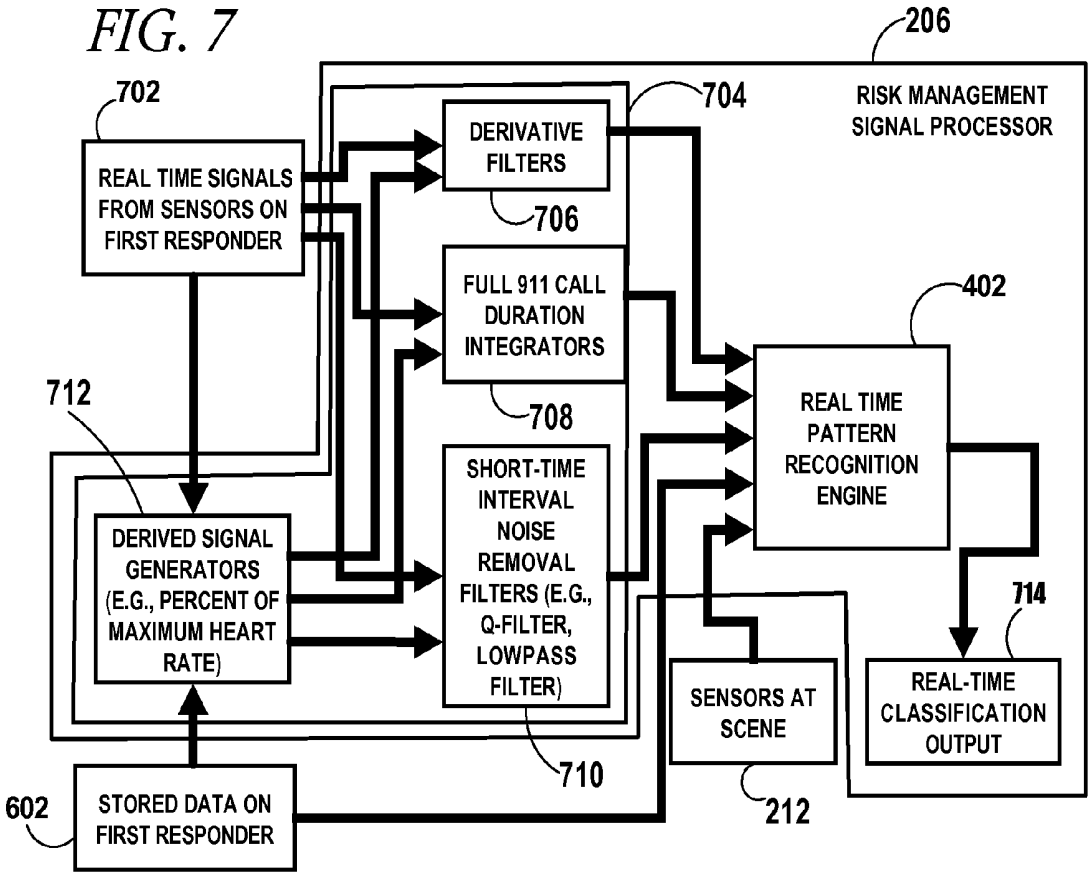
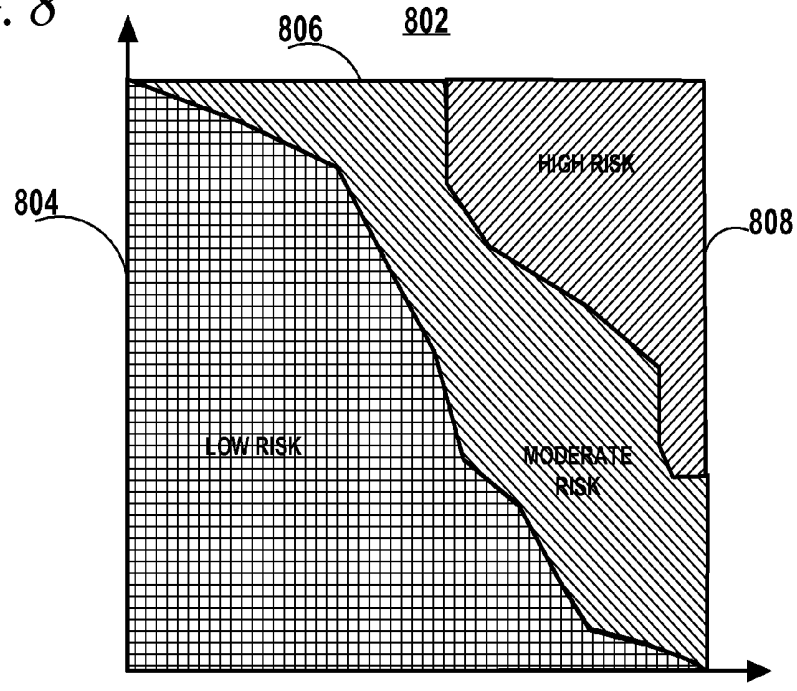


FIG. 8



2-D CROSS SECTION OF PATTERN RECOGNITION FEATURE VECTOR SPACE

FIG. 9

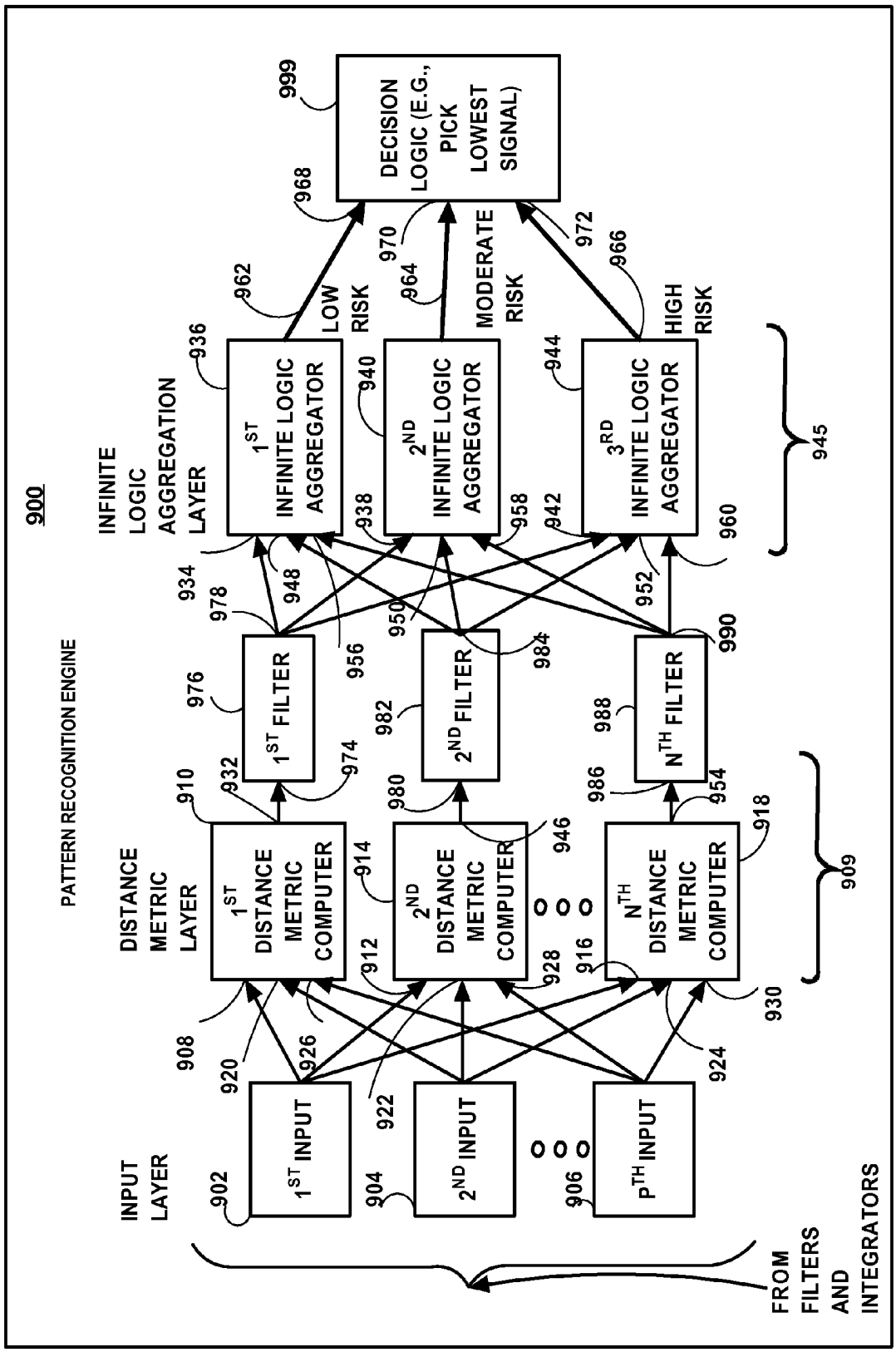

900
PATTERN RECOGNITION ENGINE
INPUT LAYER
DISTANCE METRIC LAYER
INFINITE LOGIC AGGREGATION LAYER
1ST INPUT
2ND INPUT
PTH INPUT
1ST DISTANCE METRIC COMPUTER
2ND DISTANCE METRIC COMPUTER
NTH DISTANCE METRIC COMPUTER
1ST FILTER
2ND FILTER
NTH FILTER
1ST INFINITE LOGIC AGGREGATOR
2ND INFINITE LOGIC AGGREGATOR
3RD INFINITE LOGIC AGGREGATOR
DECISION LOGIC (E.G., PICK LOWEST SIGNAL)
LOW RISK
MODERATE RISK
HIGH RISK
FROM FILTERS AND INTEGRATORS
902
904
906
908
910
912
914
916
918
920
922
924
926
928
930
932
934
936
938
940
942
944
945
946
948
950
952
954
956
958
960
962
964
966
968
970
972
974
976
978
980
982
984
986
988
990
999

FIG. 10

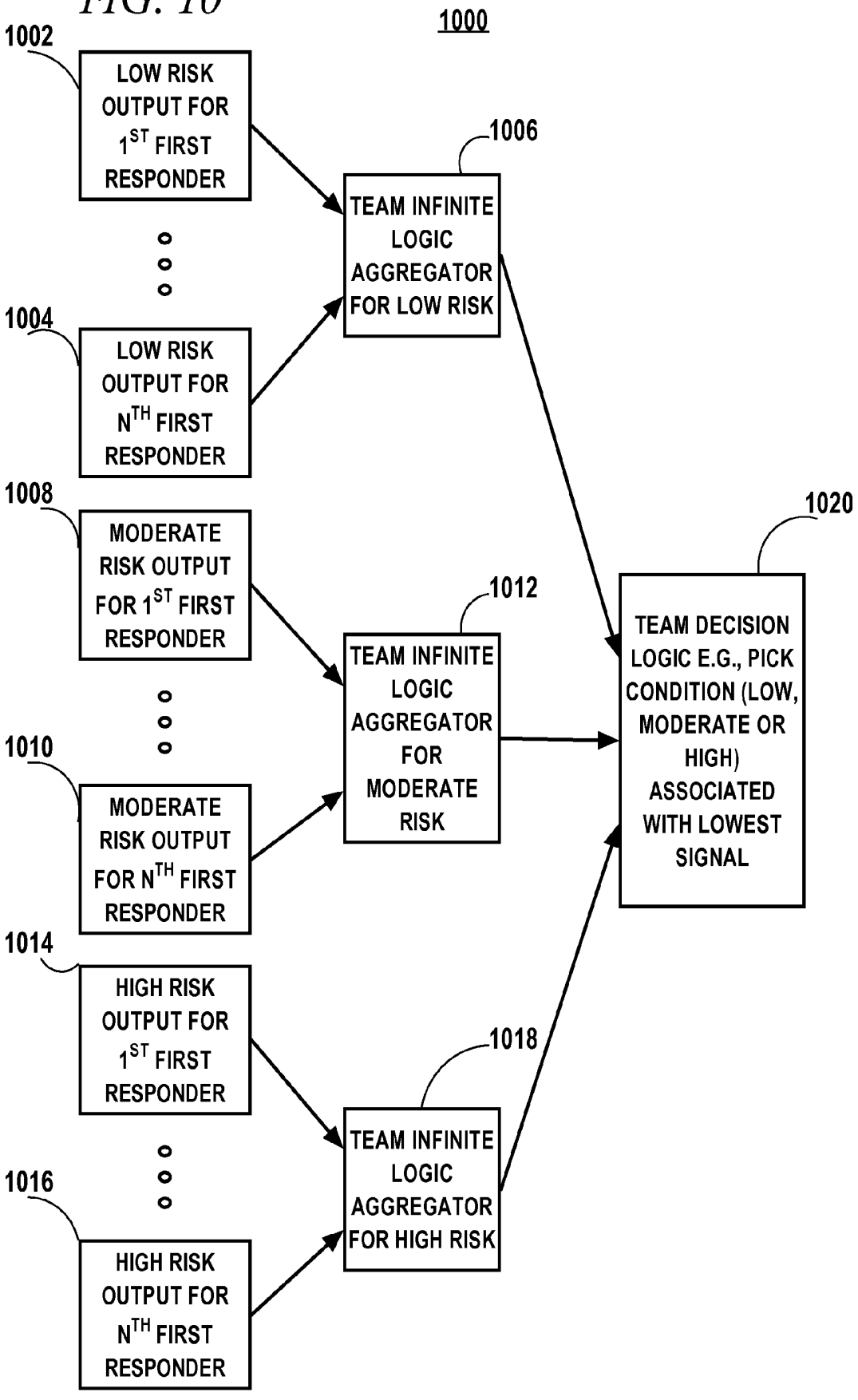
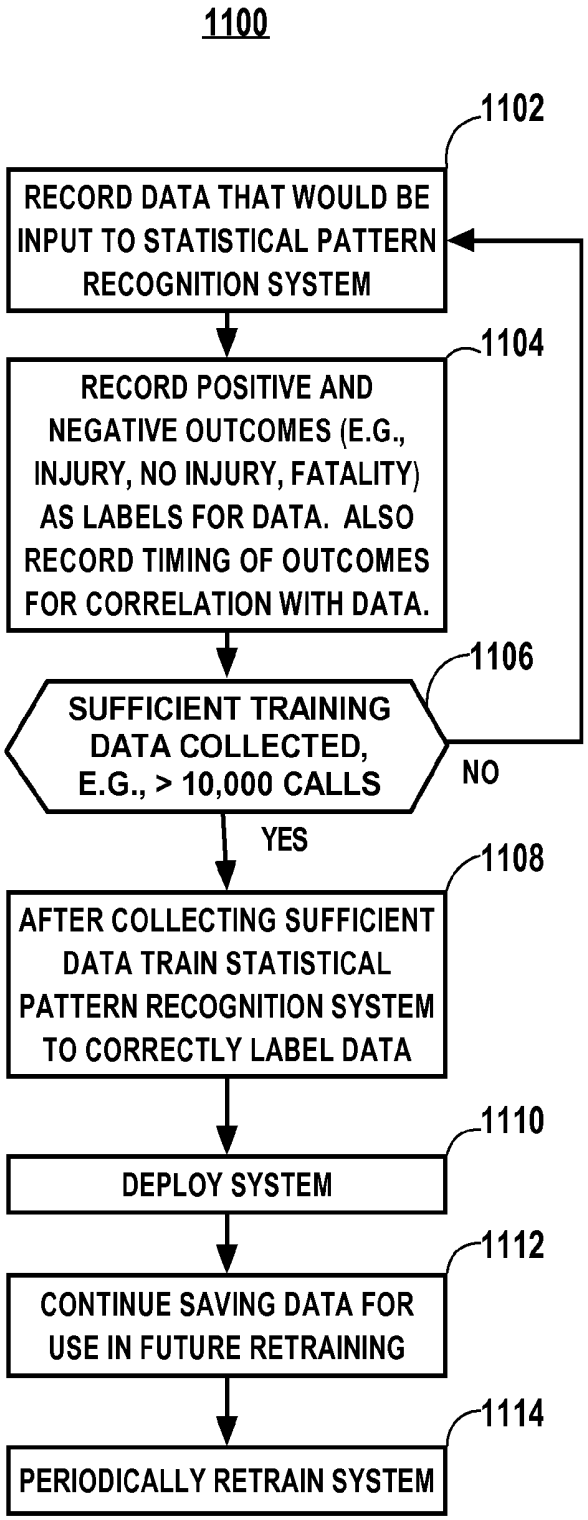

1000
1002
LOW RISK OUTPUT FOR 1ST FIRST RESPONDER
1004
LOW RISK OUTPUT FOR NTH FIRST RESPONDER
1006
TEAM INFINITE LOGIC AGGREGATOR FOR LOW RISK
1008
MODERATE RISK OUTPUT FOR 1ST FIRST RESPONDER
1010
MODERATE RISK OUTPUT FOR NTH FIRST RESPONDER
1012
TEAM INFINITE LOGIC AGGREGATOR FOR MODERATE RISK
1014
HIGH RISK OUTPUT FOR 1ST FIRST RESPONDER
1016
HIGH RISK OUTPUT FOR NTH FIRST RESPONDER
1018
TEAM INFINITE LOGIC AGGREGATOR FOR HIGH RISK
1020
TEAM DECISION LOGIC E.G., PICK CONDITION (LOW, MODERATE OR HIGH) ASSOCIATED WITH LOWEST SIGNAL

FIG. 11



TRAINING REGIMEN

FIG. 12

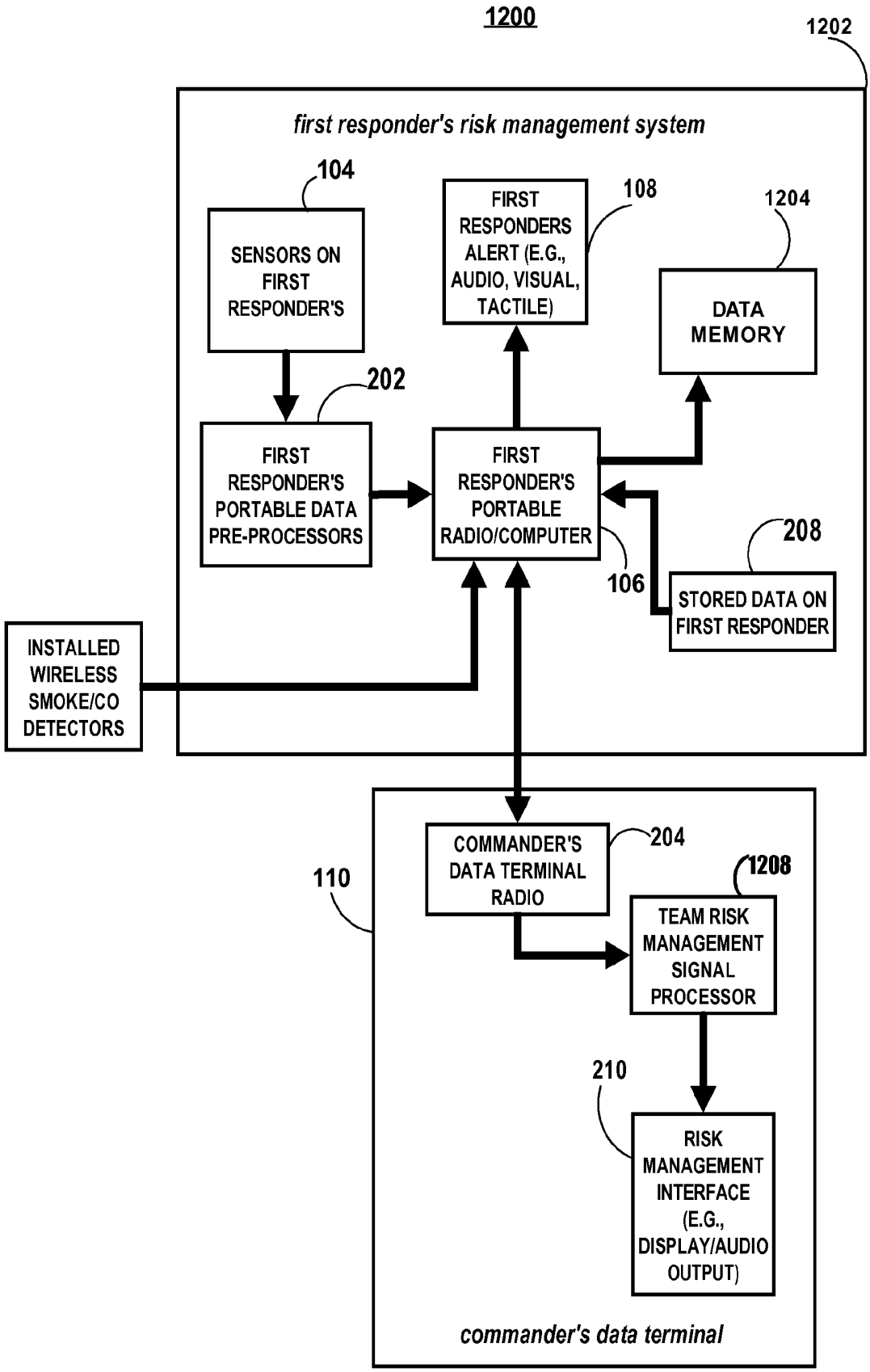

1200
1202
first responder's risk management system
104
SENSORS ON FIRST RESPONDER'S
108
FIRST RESPONDERS ALERT (E.G., AUDIO, VISUAL, TACTILE)
1204
DATA MEMORY
202
FIRST RESPONDER'S PORTABLE DATA PRE-PROCESSORS
FIRST RESPONDER'S PORTABLE RADIO/COMPUTER
208
106
STORED DATA ON FIRST RESPONDER
INSTALLED WIRELESS SMOKE/CO DETECTORS
110
COMMANDER'S DATA TERMINAL RADIO
204
1208
TEAM RISK MANAGEMENT SIGNAL PROCESSOR
210
RISK MANAGEMENT INTERFACE (E.G., DISPLAY/AUDIO OUTPUT)
commander's data terminal

FIG. 13

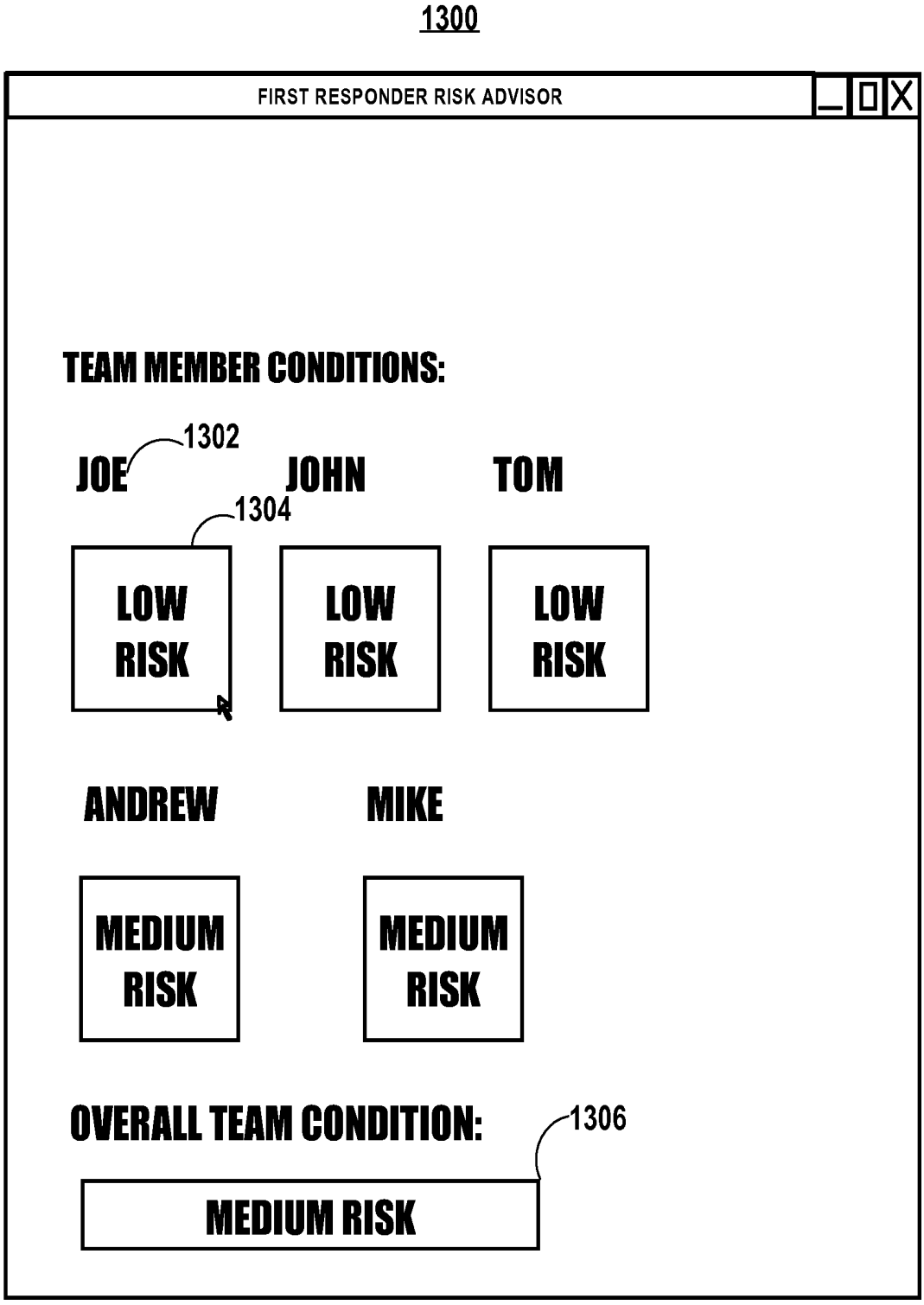

1300
FIRST RESPONDER RISK ADVISOR
TEAM MEMBER CONDITIONS:
1302
JOE
JOHN
TOM
1304
LOW RISK
LOW RISK
LOW RISK
ANDREW
MIKE
MEDIUM RISK
MEDIUM RISK
OVERALL TEAM CONDITION:
1306
MEDIUM RISK

FIG. 14

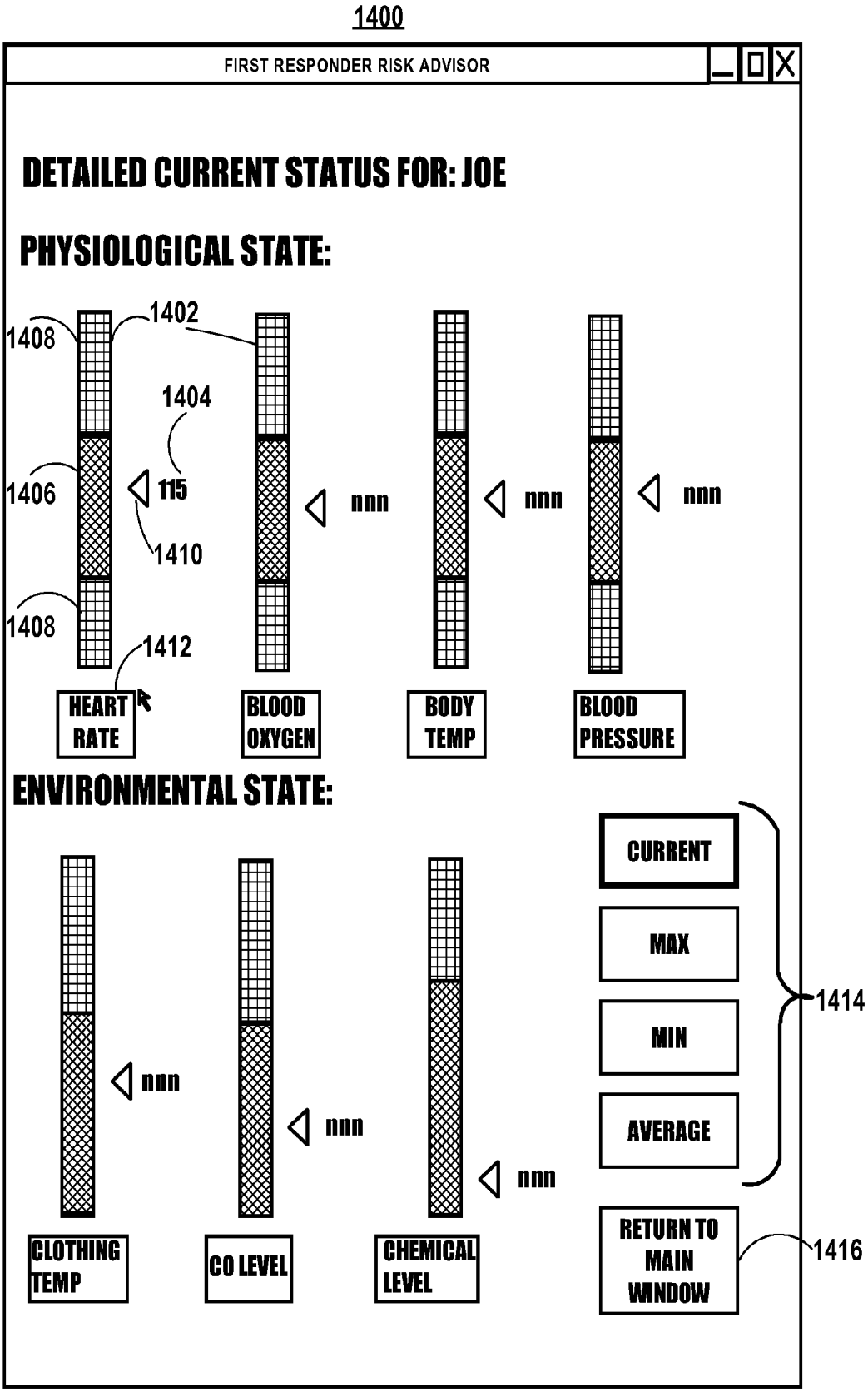

1400
FIRST RESPONDER RISK ADVISOR
DETAILED CURRENT STATUS FOR: JOE
PHYSIOLOGICAL STATE:
1408
1402
1404
1406
115
1410
1408
1412
nnn
nnn
nnn
HEART RATE
BLOOD OXYGEN
BODY TEMP
BLOOD PRESSURE
ENVIRONMENTAL STATE:
CURRENT
MAX
MIN
AVERAGE
1414
nnn
nnn
nnn
CLOTHING TEMP
CO LEVEL
CHEMICAL LEVEL
RETURN TO MAIN WINDOW
1416

FIG. 15

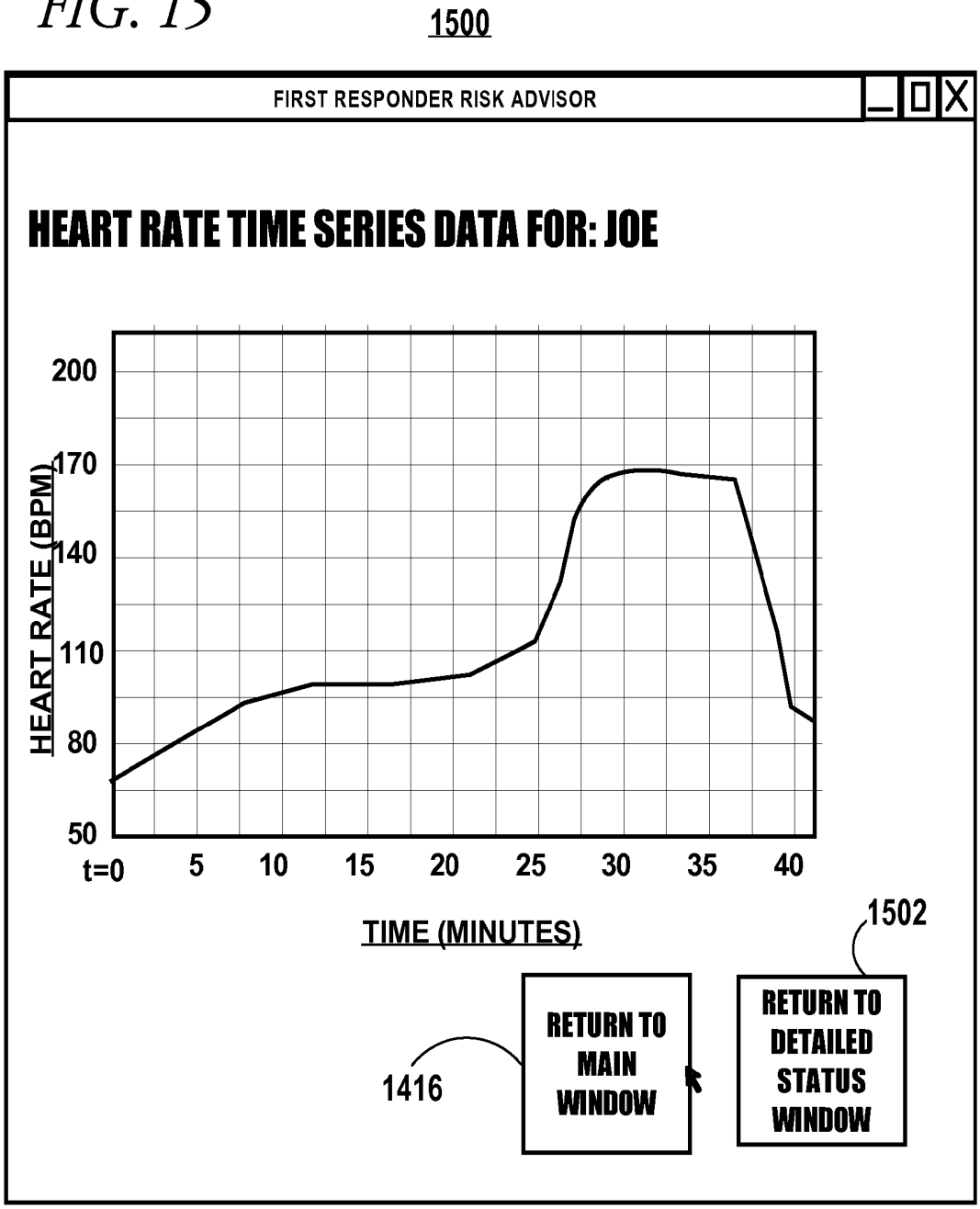

1500
FIRST RESPONDER RISK ADVISOR
HEART RATE TIME SERIES DATA FOR: JOE
200
170
140
110
80
50
HEART RATE (BPM)
t=0
5
10
15
20
25
30
35
40
TIME (MINUTES)
1502
1416
RETURN TO MAIN WINDOW
RETURN TO DETAILED STATUS WINDOW

FIG. 16

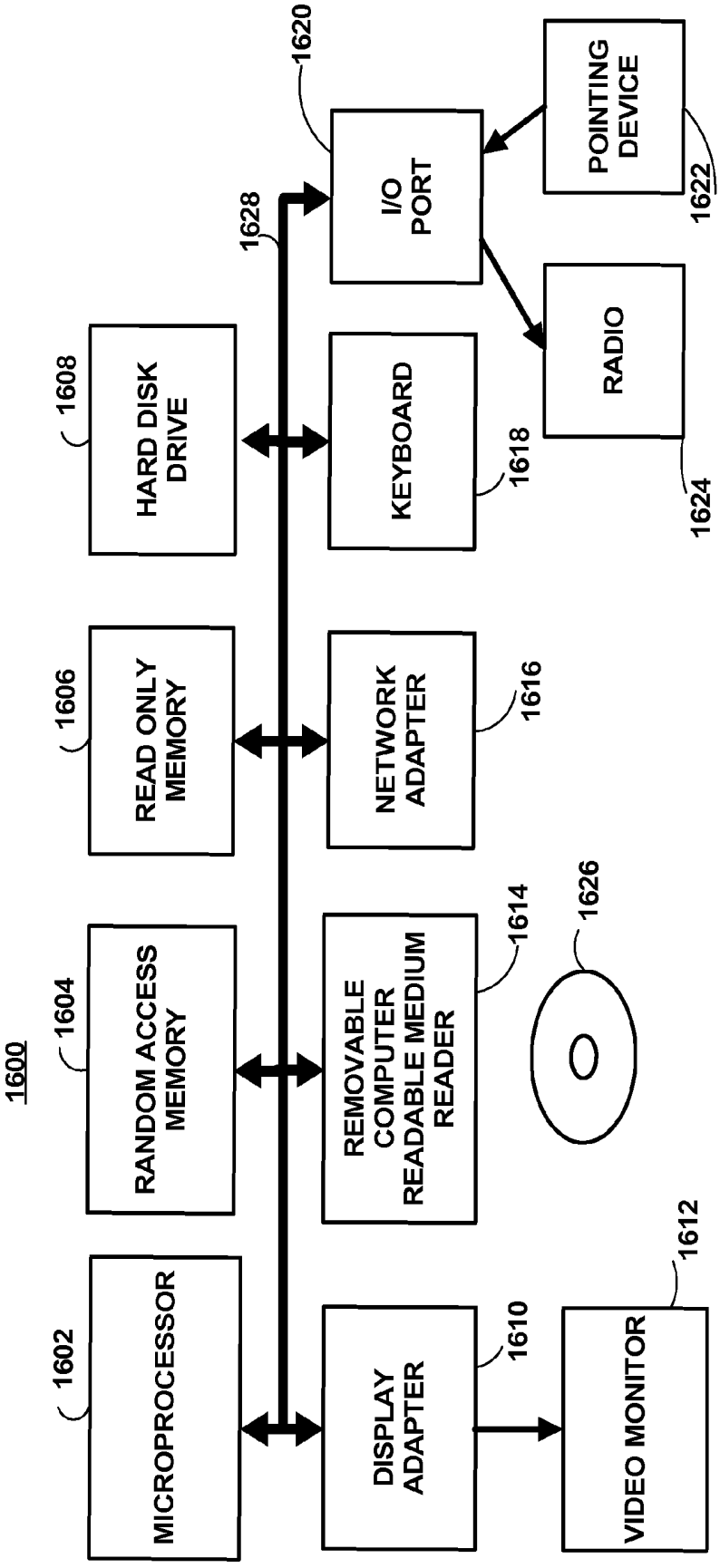

1600
MICROPROCESSOR
1602
RANDOM ACCESS MEMORY
1604
READ ONLY MEMORY
1606
HARD DISK DRIVE
1608
DISPLAY ADAPTER
1610
VIDEO MONITOR
1612
REMOVABLE COMPUTER READABLE MEDIUM READER
1614
NETWORK ADAPTER
1616
KEYBOARD
1618
I/O PORT
1620
1626
1628
POINTING DEVICE
1622
RADIO
1624

FIG. 17

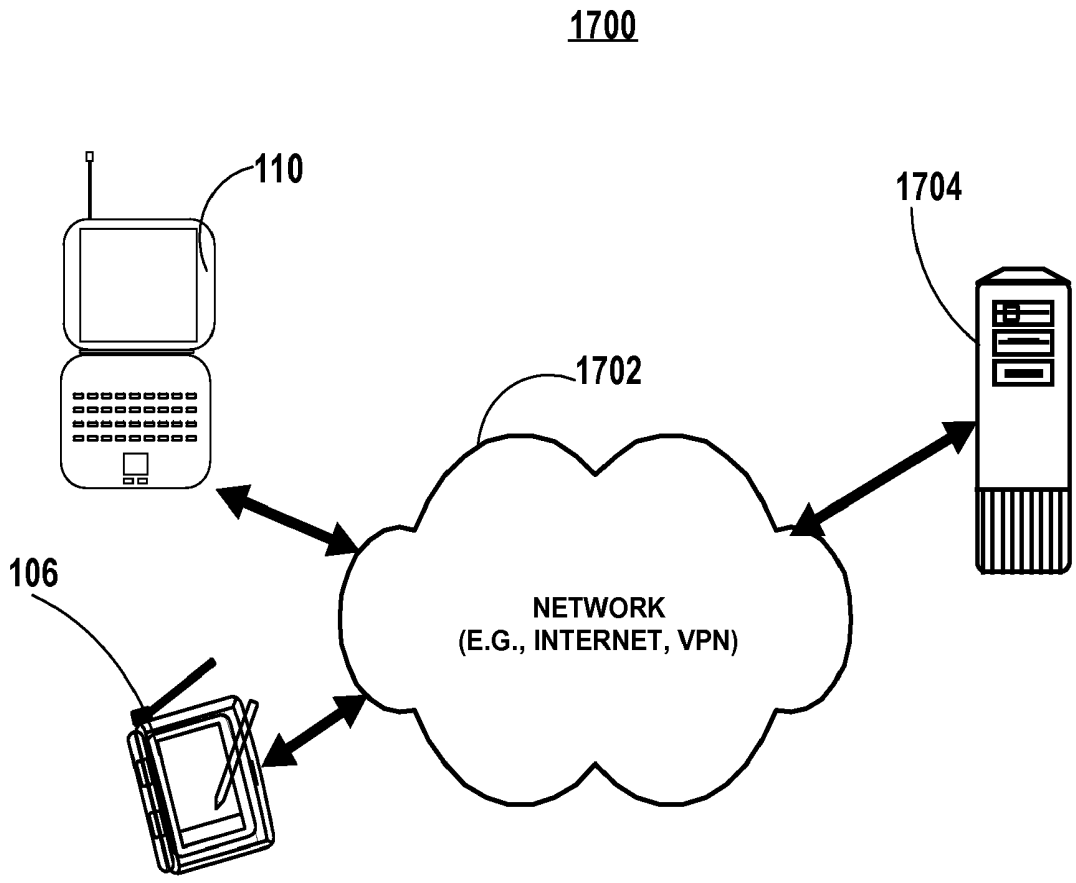
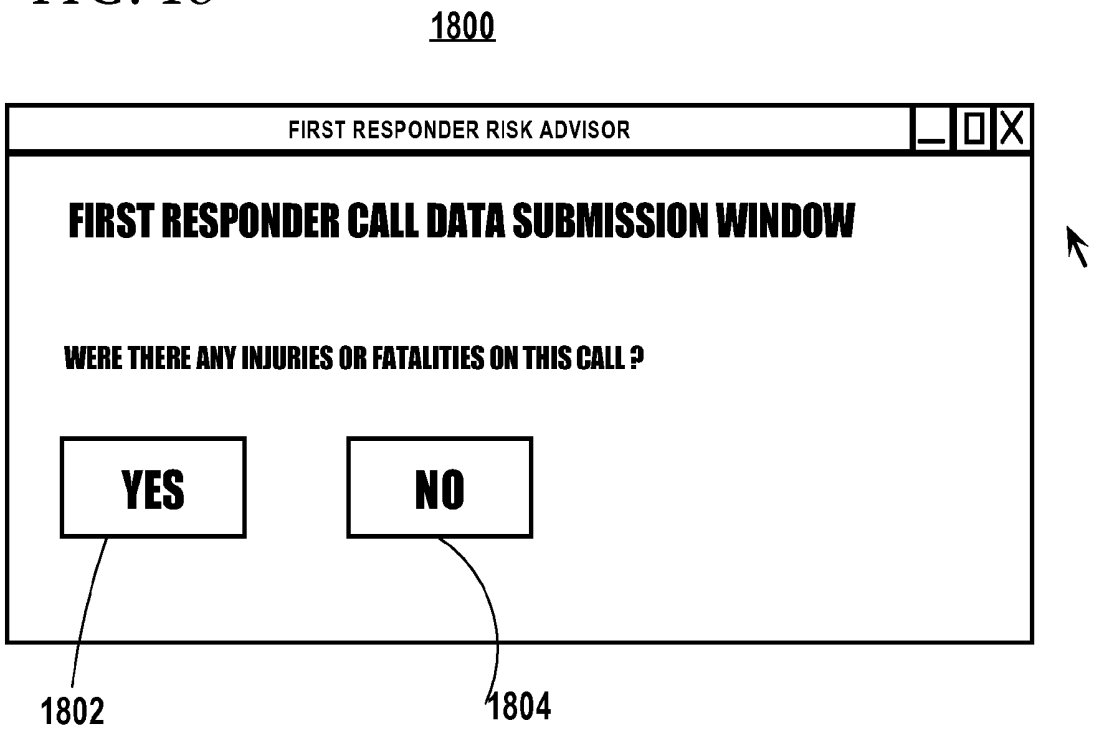
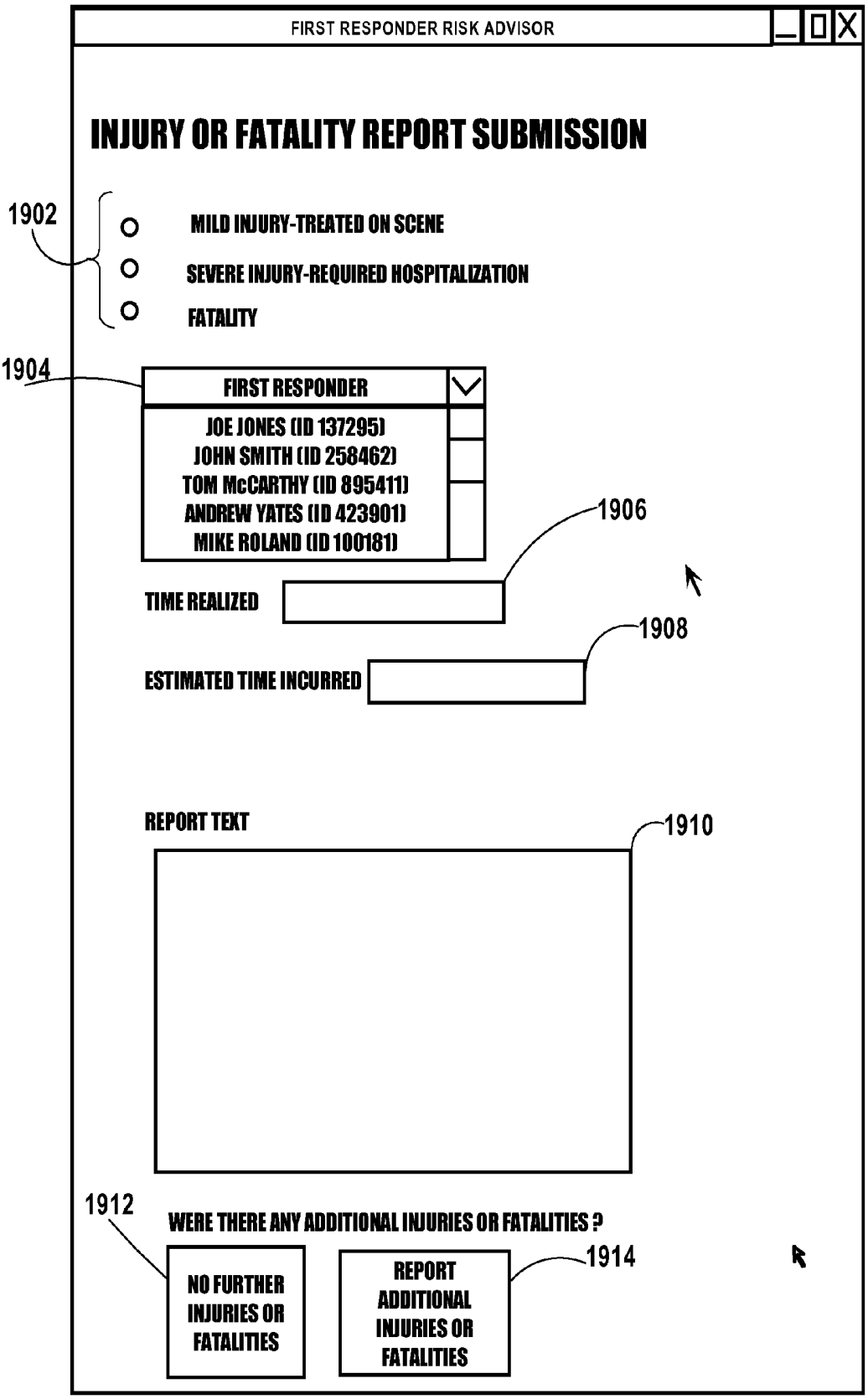


FIG. 18


1800
FIRST RESPONDER RISK ADVISOR
FIRST RESPONDER CALL DATA SUBMISSION WINDOW
WERE THERE ANY INJURIES OR FATALITIES ON THIS CALL ?
YES
NO
1802
1804

1900

FIG. 19


FIRST RESPONDER RISK ADVISOR
INJURY OR FATALITY REPORT SUBMISSION
1902
MILD INJURY-TREATED ON SCENE
SEVERE INJURY-REQUIRED HOSPITALIZATION
FATALITY
1904
FIRST RESPONDER
JOE JONES (ID 137295)
JOHN SMITH (ID 258462)
TOM McCARTHY (ID 895411)
ANDREW YATES (ID 423901)
MIKE ROLAND (ID 100181)
1906
TIME REALIZED
1908
ESTIMATED TIME INCURRED
REPORT TEXT
1910
1912
WERE THERE ANY ADDITIONAL INJURIES OR FATALITIES ?
NO FURTHER INJURIES OR FATALITIES
1914
REPORT ADDITIONAL INJURIES OR FATALITIES

INTELLIGENT RISK MANAGEMENT SYSTEM FOR FIRST RESPONDERS

FIELD OF THE INVENTION

[0001] The present invention relates generally to real-time personnel risk management.

BACKGROUND

[0002] The events of Sep. 11, 2001, brought to the fore concern for the safety of first responders such as firefighters. Firefighters and other first responders are often tasked with perilous duties. Contrary to widespread conception most firefighter fatalities do not die instantly when a building collapses or by being engulfed in flames. In fact, many firefighters succumb to heart failure brought about by the almost pathological combination of conditions of firefighting. Firefighters must work in heavy gear which although designed to protect them from the heat of fires also unfortunately serves to trap their own body heat which can lead to dehydration and accelerate physical exhaustion. In combination with the heavy gear the proximity of the fire causes further heating. At the same time, they are called on to perform strenuous tasks such as deploying heavy hoses, breaking through doors and walls and working hose lines under unpredictable emergency conditions. Moreover, in some cases they are subject to fumes and/or particulates in the air or must make due with breathing through Self Contained Breathing Apparatus (SCBA). Although firefighters are well known for their physical fitness, nonetheless the combination of conditions tends to put them at risk for cardiac arrest or injury due to mistakes made more likely due to fatigue or exhaustion. It would be desirable to provide an automated system for managing the stress levels and conditions of first responders with the aim of reducing first responder injuries and fatalities.

BRIEF DESCRIPTION OF THE FIGURES

[0003] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the present invention.

[0004] FIG. **1** is a pictorial illustration of an intelligent risk management system for first responders;

[0005] FIG. **2** is a block diagram of the intelligent risk management system for first responders shown in FIG. **1** according to an embodiment of the invention;

[0006] FIG. **3** is a block diagram of parts of the intelligent risk management system for first responders that are carried with the first responder according to an embodiment of the invention;

[0007] FIG. **4** is a block diagram of part of the intelligent risk management system for first responders shown in FIGS. **1-2** including a risk management signal processor;

[0008] FIG. **5** is a block diagram of part of the risk management system shown in FIGS. **1-2** including sensors at a scene of an incident that provide input to the risk management signal processor shown in FIG. **4** according to an embodiment of the invention;

[0009] FIG. **6** is block diagram illustrating data on first responders that is used in the risk management signal processor shown in FIG. **4** according to an embodiment of the invention;

[0010] FIG. **7** is a block diagram showing details of the risk management signal processor shown in FIG. **4** according to an embodiment of the invention;

[0011] FIG. **8** is a schematic of a 2-D cross section of a pattern recognition feature vector space that is mapped by a pattern recognition engine that is part of the risk management signal processor shown in FIG. **7**;

[0012] FIG. **9** is a pattern recognition engine that is used in the risk management signal processor shown in FIG. **7** according to an embodiment of the invention; and

[0013] FIG. **10** is a network of team aggregators that is used to aggregate risk assessments for individual first responders into a team risk assessment;

[0014] FIG. **11** is a flowchart of a training regimen for a pattern recognition engine used in the risk management signal processor, and optionally for other configurable (trainable) parts of the intelligent risk management system for first responders;

[0015] FIG. **12** is a block diagram of an intelligent risk management system for first responders according to an alternative embodiment of the invention;

[0016] FIGS. **13-15** depict three windows of a Graphical User Interface (GUI) of the intelligent risk management system for first responders shown in FIGS. **1**, **12** according to an embodiment of the invention;

[0017] FIG. **16** is a block diagram of a computer used in the intelligent risk management system for first responders shown in FIG. **1** according to an embodiment of the invention;

[0018] FIG. **17** shows a network distributed architecture used by the intelligent risk management system for first responders shown in FIG. **1** according to an embodiment of the invention

[0019] FIGS. **18-19** depict two additional GUI windows of the intelligent risk management system for first responders shown in FIGS. **1**, **12** according to an embodiment of the invention.

[0020] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

DETAILED DESCRIPTION

[0021] Before describing in detail embodiments that are in accordance with the present invention, it should be observed that the embodiments reside primarily in combinations of method steps and apparatus components related to first responder risk management. Accordingly, the apparatus components and method steps have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

[0022] In this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such

relationship or order between such entities or actions. The terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element proceeded by "comprises . . . a" does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

[0023] It will be appreciated that embodiments of the invention described herein may be comprised of one or more conventional processors and unique stored program instructions that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of first responder risk management described herein. The non-processor circuits may include, but are not limited to, a radio receiver, a radio transmitter, signal drivers, clock circuits, power source circuits, and user input devices. As such, these functions may be interpreted as steps of a method to perform first responder risk management. Alternatively, some or all functions could be implemented by a state machine that has no stored program instructions, or in one or more Application Specific Integrated Circuits (ASICs) or Field Programmable Gate Arrays (FPGAs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of these approaches could be used. Thus, methods and means for these functions have been described herein. Further, it is expected that one of ordinary skill, notwithstanding possibly significant effort and many design choices motivated by, for example, available time, current technology, and economic considerations, when guided by the concepts and principles disclosed herein will be readily capable of generating such software instructions and programs and Integrated Circuits (ICs) with minimal experimentation.

[0024] FIG. **1** is a pictorial illustration of an intelligent risk management system for first responders **100**. A first responder **102** is equipped with several sensors **104**. The sensors **104** can include environmental sensors used to sense conditions that effect the environmental stress level on the first responder (e.g., clothing temperature sensors, smoke detectors, carbon monoxide sensors) as well as physiological sensors (e.g., body temperature sensors, heart rate sensors, pulse oximeter sensors, and/or blood pressure sensors) used to sense the stress level induced by the environment and the work load of the first responder **102**. The sensors **104** can be connected by a Personal Area Network (PAN) **105** or by signal conduits (e.g., twisted pairs, fiber optics) to a portable radio/computer **106** that is equipped with signal processing circuits and is capable of data communication (e.g., Wireless Access Protocol (WAP)). A handheld data terminal such as the HDT600, made by the assignee of the instant invention Motorola of Schaumburg, Ill. can be used as the portable radio/computer **106**. The sensors **104** can be attached to the first responder's **102** clothing, shoes, or worn on the body using various straps (e.g., a chest strap) or other devices (e.g., clips).

[0025] An alert **108** which can be audible, visual (e.g., flashing light), and/or tactile (e.g., vibrator) is also part of the first responder's **102** gear. The alert **108** can be used to alert the first responder **102** that he or she is at risk for injury brought about by cardiovascular and/or environmental stress.

[0026] The portable radio/computer **106** is connected by a wireless channel to a commander's data terminal **110**. The commander's data terminal **110** can take the form of a laptop computer equipped with a radio. A model ML900 mobile laptop made by Motorola can be used as the commander's data terminal **110**.

[0027] Signal processing software and circuits that are used to determine a level of risk for the first responder **102** based on data from the sensors **104** and other information can be housed in the first responder's portable radio/computer **106** or in the commanders data terminal **110** or partly in both.

[0028] FIG. **2** is a block diagram of the intelligent risk management system for first responders **100** shown in FIG. **1** according to an embodiment of the invention. As shown in FIG. **2** the sensors **104** are coupled to a set of first responder's portable data pre-processors **202**. The data pre-processor **202** can be housed in one or more separate electronic boxes carried by the first responder, can be incorporated into the portable radio/computer **106** and/or parts of the data pre-processor **202** can be built into the sensors **104**. The sensors **104** are coupled through the data pre-processors **202** and the first responder's portable radio computer **106** to a commander's terminal radio **204**. The alert **108** is coupled to the first responder's portable radio/computer **106**, so that the alert **108** can be driven by a signal received from the commander's terminal radio **204**. The alert **108** can also be driven by a signal generated by the first responder's portable radio/computer **106** acting autonomously.

[0029] In addition to the commander's terminal radio **204** the commander's data terminal **110** includes a risk management signal processor **206**, stored data on first responders **208** and a risk management interface **210** (e.g., Graphical User Interface, GUI displayed on a display of the commander's data terminal **110**). The risk management signal processor **206** is coupled to the other parts **204**, **208**, **210** of the commander's data terminal **110**. Optionally sensors at the scene of an incident **212** (e.g., smoke detectors, carbon monoxide sensor) are coupled to the risk management signal processor **206** through other communication channels **214** (e.g., wireless communication channels). The risk management signal processor **206** can be implemented in hardware, software or a combination of the two. The risk management signal **206** processor processes information received from the first responder's sensors **104**, the stored data on the first responder **208** and optionally information received from sensors at the scene of the incident **212** in order to determine the level of risk to the first responder. An indication of the level of risk is output through the risk management interface **210**, and communicated back to the first responder's portable radio/computer **106** which then selectively activates the alert **108** based on the indication of the level of risk.

[0030] FIG. **3** is a block diagram of parts of the intelligent risk management system for first responders **100** that are carried with the first responder **102** according to an embodiment of the invention. As shown in FIG. **3** the sensors **104** that are carried with the first responder **102** (e.g., attached to the first responder's clothing, shoes, or body) include a plurality of physiological state sensors including a first body temperature sensor **302**, an N^{TH} body temperature sensor **304**, one or more pulse oximeter sensors **306** and one or more blood pressure sensors **308**. The sensors **104** that are carried with the first responder **102** also include a plurality of environmental sensors including one or more external clothing temperature sensors **310** (attached at or near the outside of the first

responders clothing, so as to register ambient temperature), one or more chemical sensors **312** and one or more combustion product (e.g., carbon monoxide) sensors **314**. The aforementioned sensors **302-314** are coupled through a set of digitizers **316**, to a set of digital domain filters **318**.

[0031] The set of digital domain filters **318** serve to reduce noise in signal received from the sensors **104**. The set of digital domain filters **318** can include Finite Impulse Response (FIR) filters, Infinite Impulse Response (IIR) filters and/or filters specialized for specific sensors. The set of digital domain filters can also include Q-filters which are covered in U.S. Pat. No. 7,117,128 to Magdi Mohamed et al. or fast Q-filters which are covered in co-pending patent application Ser. No. 11/554,689 (CML02826T) by Magdi Mohamed et al.

[0032] A Q-filter can be defined by the following sequence of equations:

$$e=r_{min}+C \quad \text{EQU. 1}$$

where,

e is a filtered signal,

r_{min} is a minimum of an ordered sequence of thresholds to which the input signal S_j is compared. The ordered sequence of thresholds is represented as: $r_0<r_1< \ldots <r_{m-1}$. Note that $r_{min}=r_0<=S_j<=r_{m-1}=r_{max}$. The input signal is bounded between minimum threshold r_{min} and maximum threshold r_{max}. If necessary, pre-amplification or attenuation is used to scale the signal appropriately. Furthermore:

$$C=\sum_{i=1}^{m-1} q_i \frac{r_{\max}-r_{\min}}{m-1}=\frac{r_{\max}-r_{\min}}{m-1}\sum_{i=1}^{m-1} q_i \quad \text{EQU. 2}$$

where

$$q_i=\begin{cases}\dfrac{\prod_{j=1}^{n}(1+\lambda_f h_{ij} f_j)-1}{F}, & \lambda_f \geq -1, \lambda_f \neq 0\\ \dfrac{\sum_{j=1}^{n} h_{ij} f_j}{F}, & \lambda_f = 0\end{cases} \quad \text{EQU. 3}$$

where

$\lambda_f>=-1$ is a filter defining parameter; and

$$F=\begin{cases}\prod_{j=1}^{n}(1+\lambda_f f_j)-1, & \lambda_f \geq -1, \lambda_f \neq 0\\ \sum_{j=1}^{n} f_j, & \lambda_f = 0\end{cases} \quad \text{EQU. 4}$$

where,

f_j are a sequence of filter defining parameters in the range [0,1], and $h_{ij}=1$ for $S_j>=r_i$ and otherwise $h_{ij}=0$.

[0033] Generally the thresholds r_i will be evenly spaced, although unevenly spaced thresholds may be used as well. Once the spacing of the thresholds has been fixed, the values of the filter nonlinearity control parameter λ and of the filter defining parameters f_j remain to be fixed in order to fully define a Q-filter. The parameters λ and f_j are suitably determined by an optimization procedure that seeks to match the output of the filter to a model desired output.

[0034] A fast Q-filter can be defined by the following set of equations:

$$e=\frac{1}{\Psi_1}\sum_{i=1}^{N} S_{index(i)}(\Psi_i-\Psi_{i-1}) \quad \text{EQU. 5}$$

where,

$$\Psi_i=F(\text{Index}(i))+\Psi_{i+1}+\lambda_f F(\text{Index}(i))\Psi_{i+1},\ i=1,\ldots,N,$$

$$\Psi_{N+1}=0.$$

[0035] N is a number of signal samples in a sample window

[0036] Index(i) is an i^{TH} element of a permutation array that describes a sorting of the N signal samples in the sample window;

[0037] $[f_1,f_2,f_3 \ldots f_j \ldots f_N]$ is a predetermined vector of filter defining parameters $f_j \epsilon [0,1]$ for all j=1, . . . , N

[0038] λ_f is a filter nonlinearity control parameter that is greater than or equal to −1.

[0039] The filter defining parameters of the Q-filter and the fast Q-filter can be determined by optimization. The optimization is performed using training data that includes input data, and associated ideal output data. During optimization, the difference between the actual output of the Q-filter and the ideal output data is monitored while the values of λ and f_j are adjusted in order to minimize the difference. A variety of optimization techniques, including but not limited to, methods that use simulated annealing, gradient information and direct-search methods can be used to optimize λ and f_j.

[0040] Alternatively, in lieu of digitizing the signals from the sensors **104** prior to filtering, some or all filtering can be performed in the analog domain. The filters **318** are coupled to a set of signal aggregators **320** to which filtered signals are supplied. Each aggregator combines filtered signals from multiple sensors. Signals from like (redundant) sensors can be aggregated, for example digitized signals from all of the body temperature sensors **302-304** can be aggregated. Optionally signals from dissimilar sensors which nonetheless relate to a common underlying state can be aggregated as well.

[0041] Alternatively, a microphone can be used to detect the first responder's heart beat. U.S. patent application Ser. No.: 11/157,640 (CM07299G) filed on June 2005, titled "Method for detecting heart rate and system thereof", by Hong et al., describes a system that uses dual Q-filters to extract a heart beat signal from a microphone signal.

[0042] Each aggregator can combine signals by averaging, generalized mean, MIN function, MAX function or fuzzy infinite logic aggregator for example. Co-pending patent application Ser. No. 11/554,674 (CML02589T) entitled "Method and Apparatus for Nonlinear Signal and Data Aggregation" by Magdi Mohamed et al., filed Oct. 30, 2006 teaches a new type of aggregator that is configurable to perform a range of infinite logic aggregation operations ranging from a fuzzy intersection operation through an averaging operation to a fuzzy union operation. The operation of this aggregator can be described by the following equation:

$$A_{\lambda_A}(a_1, \ldots, a_n) = \begin{cases} \dfrac{\prod_{i=1}^{n}(1+\lambda_A a_i) - 1}{\prod_{i=1}^{n}(1+\lambda_A) - 1} & \lambda_A \geq -1, \lambda_A \neq 0 \\ \dfrac{1}{n}\sum_{i=1}^{n} a_i & \lambda_A = 0 \end{cases} \quad \text{EQU. 6}$$

[0043] where,

[0044] $\lambda_A >= -1$ is a magnitude of a connective control parameter;

[0045] $a_k \in [0,1]$ is a value of a k^{th} input signal;

[0046] $n>1$ is an integer number of input signals; and

[0047] $A_{\lambda_A}(a_1, \ldots, a_n) \in [0,1]$ is the output signal magnitude.

The number of inputs n is varied as needed. The inputs a_k are suitably in the range from zero to one and the control parameter λ_A is suitably greater than or equal to minus one. For such ranges of the inputs a_k and control signal λ_A the output $A_{\lambda_A}(a_1, \ldots, a_n)$ is also in the range zero to one. When the control parameter λ_A is set to a high value e.g., one-hundred, the aggregator performs a fuzzy intersection-like connective (conjunctive) function. When the control parameter λ is set to minus one, the aggregator performs a fuzzy union-like connective (disjunctive) function and when the control parameter is set to zero the aggregator performs a linear averaging function. Not necessarily all of the signals from the sensors are subject to aggregation. Moreover, alternatively signal aggregation is not used in the pre-processors **202**. If aggregation is used, output of the signal aggregators is coupled to the first responder's portable radio/computer **106** which sends signals output by the aggregators to the commander's data terminal **110**.

[0048] FIG. **4** is a block diagram of part of the intelligent risk management system for first responders **100** shown in FIGS. **1-2**. As shown in FIG. **4** the risk management signal processor **206** includes a real-time pattern recognition engine **402**. Any of a variety of known and yet to be developed pattern recognition engines may be used. Examples of pattern recognition approaches that may be used include: Linear Discriminants, Quadratic Discriminants, Gaussian Mixtures, K-Nearest Neighbor, Hidden Markov Models, Support Vector Machines, Artificial Neural Networks, Tree Based Classifiers, Expert Systems, or Fuzzy Logic methods. Newly developed pattern recognition engine are taught in co-pending patent applications: Ser. No.: 11/554,724 (CML03430T) entitled "Artificial Neural Network With Adaptable Infinite-Logic Nodes", filed Oct. 31, 2006 by Weimin Xiao et al.; and Ser. No.: 11,554,643 (CML02306T) entitled "System for Pattern Recognition with Q-Metrics"; filed Oct. 30, 2006 by Magdi Mohamed et al. As shown in FIG. **4** the risk management signal processor **206** receives signals from the sensors on the first responder **104**, and sensors at the scene of the incident **212**. In general, a pattern recognition engine takes a feature vector as input an outputs an identification of a class represent by the feature vector. In the present application the feature vector is a real-time signal vector and the output of the pattern recognition engine represents a probable state of each first responder (e.g., "low risk", "moderate risk", "high risk").

[0049] FIG. **5** is a block diagram of part of the risk management system shown in FIGS. **1-2** including sensors at a scene of an incident that provide input to the risk management signal processor shown in FIG. **4** according to an embodiment of the invention. Examples of sensors at the scene of the incident include smoke detectors **502** and carbon monoxide sensors **504**. The sensors at the scene of the incident **502**, **504** can be part of built-in infrastructure or autonomous wireless devices that are thrown, dropped or propelled into the scene of the incident by the first responder **102** or another.

[0050] FIG. **6** is block diagram illustrating data **602** on first responders that is stored in memory and used by the risk management signal processor shown in FIG. **4** according to an embodiment of the invention. As shown in FIG. **6**, the data can include the age of each first responder, the resting heart rate of each first responder, the maximum heart rate or each first responder (measured or calculated), the anaerobic threshold heart rate, the percent body fat, the resting blood pressure of each first responder, data on the experience of each first responder, and a measure of recent work intensity. The resting, maximum and anaerobic threshold heart rates are useful in assessing the stress level of each first responder based on the first responder's real-time heart rate data. Similarly, the resting blood pressure is useful in combination with actual real-time blood pressure data. The resting heart rate, resting blood pressure and lung capacity are useful, independently (e.g., as separate feature vector components) as measures of the fitness of each first responder. The data on the experience of each first responder can take the form of a single metric, for example and an intensity weighted sum of all calls worked by the first responder. Calls can be assigned weights (e.g., on a scale of one to ten) based on the level of emergency. The measure of recent work intensity is used to assess a possible level of fatigue and need for recovery before further exertion. The measure of recent work intensity can be based on heart rate. For example, the measure of recent work intensity can be an integral of heart beat above a predetermined threshold (e.g., resting heartbeat, anaerobic threshold heartbeat or a learned heart beat threshold) during calls during the last predetermined number of days (e.g. 10 days). The integrand can be weighted by a persistence function that gives greater weight to exertion during more recent calls.

[0051] FIG. **7** is a block diagram showing details of the risk management signal processor shown in FIG. **4** according to an embodiment of the invention. Real-time signals from the sensors on the first responders **702** (which are received from the sensors on the first responders **104** through the first responder portable data pre-processor **202** and the first responder's portable radio/computer **106**) are input into a feature vector extraction system **704**. The feature vector extraction system **704** shown in FIG. **7** is just one example architecture, and it will be apparent to one skilled in the art that many variations on the feature vector extraction system are possible. As shown in FIG. **7** the feature vector extraction system **704** includes a set of derivative filters **706**, a set of full call integrators **708**, and a set of short time interval noise removal filters **710**. The signal aggregators **320** of the first responder's portable data pre-processor **202** can also be considered part of a broader feature vector extraction system. All or subsets of the real-time signals from the first responder **702** can be coupled into the derivative filters **706**, integrators **708** and noise removal filters **710**. The derivative filters **706** serve to detect increasing danger in the environmental conditions (e.g., increasing smoke, or temperature) and increasing stress on the first responder as indicated, for example by a rapidly increasing heart rate. The integrators **708** are used to deduce the accumulated physiological and environmentally induced

stress and during a 911 call. Alternatively, the integration period can be less that the full call (e.g. past 10 minutes). The integration period can be learned in training. Furthermore, the integrand of the integration can be weighted by a persistence function (backward decay) in order to weight more recent sensors readings more heavily. The noise removal filters **710** provide accurate estimates of instantaneous signal levels. Conventional low pass filters or Q-filters or fast Q-filters may be used as the noise removal filters. Alternatively, to what is shown in FIG. **7**, input to the derivative filters **706** and the integrators **708** can be processed through the noise removal filters **710**.

[0052] The stored data on the first responders **602** and the real-time signals from the sensors on the first responders **702** are coupled to a set of derived signal generators **712**. One example of a derived signal is obtained by dividing a real-time pulse signal from the pulse oximeter(s) **306** by a maximum heart rate for the first responder that is stored or calculated based on stored age. Another example of a derived signal is obtained by thresholding the real-time pulse rate signal at an anaerobic threshold that is stored or calculated based on age. The thresholded output signal would be active when the first responder has a heartbeat above his or her anaerobic threshold and zero otherwise. Alternatively, the first responder's heartbeat can be thresholded at the first responder's resting heart beat. Derived signal generated by the derived signal generators **712** are also, at least selectively, coupled to the derivative filters **706**, integrators **708** and noise removal filters **710**. By way of example a first responders heart beat signal thresholded at the first responders anaerobic threshold (or alternatively a learned threshold) and integrated over the duration of an emergency call should give a good indication of how close to exhaustion the first responder is.

[0053] The output of the derivative filters **706**, integrators **708** and noise removal filters **710** are coupled to feature vector inputs (signal vector inputs) of the real-time pattern recognition engine **402**. Some or all of the data from sensors at the scene **212** and stored data on the first responders **602** can also be coupled to feature vector inputs of the real-time pattern recognition engine **402**. The task of the real-time pattern recognition engine **402** is to determine a level of risk based on the input feature vector. An indication of the level of risk (e.g., "low risk", "moderate risk", "high risk") is output at a real-time classification output **714**.

[0054] FIG. **8** is a schematic of a 2-D cross section of a pattern recognition feature vector space **802** that is mapped by the pattern recognition engine **402** that is part of the risk management signal processor **206** shown in FIG. **7**. As shown in FIG. **8** the feature vector space **802** is divided into a "low risk" region **804**, a "medium risk" region **806** and a "high risk" region **808**. Depending on the type of pattern recognition engine that is used, the decision boundaries between the regions **804**, **806**, **808** may or may not be explicitly determined. In any case, the pattern recognition engine will classify the input feature vectors as corresponding to one of the conditions, e.g., "low risk", "medium risk" or "high risk". Typically pattern recognition systems are trained using labeled data. Alternatively, at least an initial configuration of the pattern recognition engine **402** can be established using hand selected values.

[0055] If based on experience with a certain feature vector extraction design, "medium risk" and "high risk" labeled feature vectors are found not to be well separated by linear or nonlinear methods, then both can be subsumed into a single category that is distinguished from "low risk".

[0056] FIG. **9** is a pattern recognition engine **900** that is used in the risk management signal processor shown in FIG. **7** according to an embodiment of the invention. As shown in FIG. **9** the pattern recognition engine **900** comprises a first pattern recognition engine input **902**, a second pattern recognition engine input **904** up to a P^{TH} pattern recognition engine input **906**. Component of the feature vector including signals output by the derivative filters **704**, full call duration integrators **708**, short time interval noise removal filters **710** and the sensors at the scene of the incident **212**; and the stored data on the first responder **602** are coupled to the pattern recognition engine inputs **902**, **904** **906**. Although only three pattern recognition engine inputs **902**, **904**, **906** are shown for purposes of illustration, it should be understood that in fact there is a separate input for each feature vector component (signal or data item). Generally, the number of pattern recognition engine inputs is equal to the dimensionality of the feature vectors.

[0057] The first pattern recognition engine input **902** is connected to a first input **908** of a first distance metric computer **910**, a first input **912** of a second distance metric computer **914** and a first input **916** of an N^{TH} distance metric computer **918**. Similarly, the second pattern recognition engine input **904** is connected to a second input **920** of the first distance metric computer **910**, a second input **922** of the second distance metric computer **914** and a second input **924** of the N^{TH} distance metric computer **918**; and the P^{TH} pattern recognition engine input **906** is connected to a P^{TH} input **926** of the first distance metric computer **910**, a P^{TH} input **928** of the second distance metric computer **914** and a P^{TH} input **930** of the N^{TH} distance metric computer **918**. The distance metric computers **910**, **914**, **918** form a hidden layer **909** of the pattern recognition engine **900**. Each distance metric computer **910**, **914**, **918** computes a distance of an input feature vector from a point (center) in the feature vector space (e.g., a cluster center). The centers in the feature vector space can, for example, typify high risk, or medium risk combinations of sensor readings. The distance function to be used may be Euclidean, weighted Euclidean, P-metric, Mahalanobis distance, or a distance computed by another distance metric. One metric that may be used is taught in co-pending patent application Ser. No. 11/554,643 (CML02306T) entitled "System for Pattern Recognition with Q-metrics", filed Oct. 30, 2006 and is given by the following equation:

$$d_{\lambda_D}(x, y) = \frac{\prod_{i=1}^{P} (1 + \lambda_D w_i |x_i - y_i|) - 1}{P\lambda_D} \qquad \text{EQU. 7}$$

where, $\lambda_D \epsilon [-1,0)$ is a metric control parameter;

$x_i \epsilon [0,1]$ is an i^{th} component of an input feature vector denoted x

$y_i \epsilon [0,1]$ is an i^{th} component of a feature vector reference point (e.g., cluster center) denoted y;

P is the dimensionality of feature vector space;

[0058] $w_i \epsilon [0,1]$ is an i^{th} dimension weight; and

$d_{\lambda_D}(x,y) \epsilon [0,1]$ is a per-unit distance between the input feature vector and the feature vector center.

[0059] Using a weighted distance metric allows input signals to be selectively emphasized or de-emphasized. An output **932** of the first distance metric computer **910** (at which a computed distance is output) is coupled to an input **974** of a first filter **976**. An output **978** of the first filter **976** is coupled to a first input **934** of a first infinite logic aggregator **936**, a first input **938** of a second infinite logic aggregator **940**, and a first input **942** of a third infinite logic aggregator **944**. Similarly an output **946** of the second distance metric computer **914** is coupled to an input **980** of a second filter **982** and an output **984** of the second filter **982** is coupled to a second input **948** of the first infinite logic aggregator **936**, a second input **950** of the second infinite logic aggregator **940** and a second input **952** of the third infinite logic aggregator **944**; and an output **954** of the N^{TH} distance metric computer **918** is coupled to an input **986** of an N^{TH} filter **988** and an output **990** of the N^{TH} filter **988** is coupled to an N^{TH} input **956** of the first infinite logic aggregator **936**, a N^{TH} input **958** of the second infinite logic aggregator **940** and a N^{TH} input **960** of the third infinite logic aggregator **944**. The filters **976**, **982**, **988** can comprise Q-filters, fast Q-filters or other filters such as FIR, IIR, for example. In any case the filters **976**, **982**, **988** provide additional noise reduction and may also effectively alter the real-time processing decision boundaries established by the pattern recognition engine **900**. Alternatively, the filters **976**, **982**, **988** are not used. The infinite logic aggregators **936**, **940**, **944** form an output layer **945** of the pattern recognition engine **900**. The first, second and third infinite logic aggregators **936**, **940**, **944** have a first output **962**, a second output **964** and a third output **966** respectively and these outputs **962**, **964**, **966** are coupled to a first input **968** a second input **970** and a third input **972**, respectively of a decision logic block **999**. Each of the aggregators **936**, **940**, **944** is associated with a particular state (e.g., low risk, medium risk, high risk) that the pattern recognition engine **900** is capable of recognizing. The decision logic **999** suitably outputs as a recognized state the state associated with the aggregator that produced the lowest output. (If the distance metric computers **910**, **914**, **918** were replaced by Gaussians functions or other monotonic decreasing functions of feature vector space distance (e.g., similarity functions), it would be appropriate to have the decision logic output the state associated with the aggregator that produced the highest output.)

[0060] The infinite logic aggregators **936**, **940** **944** can implement a variety of infinite logic rules for combining the distances computed by the distance metric computers **910**, **914**, **918** in order to judge whether a measured subject belongs to a classification. Expressed in words, such rules include, for example: "close to at least one of a select group of cluster centers", "close to all of a select group of cluster centers", "close to one cluster center but far from another cluster center" or "far from all cluster centers".

[0061] According to one embodiment the infinite logic aggregators use a composition of the aggregation function given by equation 6 on a veracity function that is a weighted sum of the identity function and an infinite logic inverter function. The veracity function allows a positive, negative, or no inference to be made based on the distance of an input feature vector from a particular feature vector center used by one of the distance metric nodes **910**, **914**, **918**. The aggregation function given by equation 6 allows the output of the veracity function for multiple distance metric nodes **910**, **914**, **918** to be combined with an infinite logic function ranging from disjunctive (fuzzy union connective) to conjunctive (fuzzy intersection connective).

[0062] One suitable form of infinite logic inverter is given by:

$$Inv_{\beta}(d)=\begin{cases}\dfrac{1-d}{1+\beta d} & d\neq 1\\ 0 & d=1\end{cases} \qquad \text{EQU. 8}$$

[0063] where, $d\in[0,1]$, is a feature vector space distance value;

[0064] $\beta\in[-1,+\text{infinity})$, is a nonlinearity control parameter; and

[0065] $Inv_{\beta}(d)\in[0,1]$ is the output of the infinite logic inverter.

[0066] One suitable form of veracity function is given by:

$$Ver(\alpha,\beta,d)=\alpha d+(1-\alpha)Inv_{\beta}(d) \qquad \text{EQU. 9}$$

[0067] where, $d\in[0,1]$, is a feature vector space distance value;

[0068] $\alpha\in[0,1]$ is a veracity control parameter;

[0069] $Ver(\alpha,\beta,d)\in[0,1]$ is the output of the veracity function.

[0070] Composing the aggregation function given by equation six on the veracity function yields:

$$A_{\lambda_A}(d_1,\ldots,d_n)= \qquad \text{EQU. 10}$$

$$\begin{cases}\dfrac{\prod_{i=1}^{n}(1+\lambda_A\cdot Ver(\alpha_i,\beta_i,d_i))-1}{\prod_{i=1}^{n}(1+\lambda_A)-1} & \lambda_A\geq -1,\ \lambda_A\neq 0\\ \dfrac{1}{n}\sum_{i=1}^{n}Ver(\alpha_i,\beta_i,d_i) & \lambda_A=0\end{cases}$$

[0071] where, d_i is the i^{th} per-unit distance values (e.g., produced by one of the distance metric computers **910**, **914**, **918**);

[0072] $\alpha_i\in[0,1]$ is the veracity control parameter for the i^{th} distance;

[0073] $\beta_i\in=[-1,+\text{infinity})$, is the nonlinearity control parameter for the i^{th} distance, and

[0074] $Ver(\alpha_i,\beta_i,d_i)\in[0,1]$ is the value of the veracity function for the i^{th} distance;

[0075] $\lambda_A>=-1$ is the connective control parameter; and

[0076] $A_{\lambda_A}(d_1,\ldots,d_n)$ is the output of one of the infinite logic aggregator **936**, **940**, **944**.

[0077] As shown in FIG. **9** each pattern recognition input **902**, **904**, **906** is connected to all of the distance metric computers **910**, **914**, **918** and each distance metric computer **910**, **914**, **918** is connected to all of the infinite logic aggregators **936**, **940**, **944**. This is termed fully connected. Alternatively, the pattern recognition engine **900** is not fully connected.

[0078] Co-pending patent application Ser. No. 11/554,734 (CML03629T) entitled "Configurable Infinite Logic Signal Processing Network and Genetic Computing Method of Designing the Same" to Magdi Mohamed et al discloses networks that include one or more adaptable infinite logic connective signal processors in combination with one or more infinite logic inverters forming an infinite logic network. As

disclosed in that application the topology of the network can be determined by a Gene Expression Programming (GEP) algorithm that uses a hybrid Genetic Algorithm (GA)/Differential Evolution (DE) subprogram to learn control parameter values. According to an alternative embodiment of the invention such infinite logic networks are used in the pattern recognition engine **900** in place of the infinite logic aggregators **936**, **940**, **944**.

[0079] Although, parameters of pattern recognition engines are typically determined by numerical optimization in the course of training with labeled feature vectors, the pattern recognition engine **900** works in an intuitively understandable manner, so that plausible values of at least some of the parameters, i.e., feature vectors space centers y, parameters α_i, λ_A and some of the β_i values can be deduced. The values that are deduced can be used as initial values that are further refined by optimization in the course of training. For example, one can select several feature vector space centers y that characterize combinations of signal levels (e.g., high body temperature, in combination with high heart rate, low blood oxygen, etc) which represent "high risk" conditions, and several that represent "medium risk" conditions. For the third infinite logic aggregator **944** that identifies the "high risk" state, the parameters α_i for distances to vector space centers that characterize "high risk" can be set/initialized to zero and λ_A set/initialized to a high value (e.g., 100) so that if an input feature vector is close to any of the feature vector space centers y associated with high risk the output of the third infinite logic aggregator **944** will be low. Furthermore, for the third infinite logic aggregator **944** that identifies the "high risk state" the α_i and β_i for distances to vector space centers that characterize "medium risk" can be set/initialized to ½ so that the output of the third infinite logic aggregator is neutral with respect to distances to the "medium risk" feature vector space centers. Analogous settings/initializations can be used for the second infinite logic aggregator **940** that identifies "medium risk" conditions. For the first infinite logic aggregator **936** that identifies the "low risk" condition, the parameters α_i corresponding to all distance to the "high risk" feature vector space centers y, and the "medium risk" feature vector space centers can be set to 0 and λ_A set/initialize to −1. With such settings, the output of the first infinite logic aggregator will only be low (strongly TRUE) if the input feature vector is far from feature vector centers y associated with "medium risk" and "high risk". With these settings the "low risk" condition is regarded as a kind of default if the combination of conditions represented in the input feature vector is not "medium risk" or "high risk". Optimization can then be applied to refine the initial settings of these parameters using training data.

[0080] Other parameters such as the remaining β_i parameters of the aggregators **936**, **940**, **944**, the λ_D parameters for the distance metric computers **910**, **914**, **918**, and the parameters $\{\lambda_f, f_i\}$ of the filters **976**, **982**, **988** can be determined by optimization in training as well.

[0081] The above description of the pattern recognition engine **900** in considerable detail should not be construed as implying that this particular pattern recognition engine is indispensable for the system **100**. Persons having ordinary skill in the art of pattern recognition will recognize that any number of known pattern recognition engines, including but not limited to: Linear Discriminants, Quadratic Discriminants, Gaussian Mixtures, Hidden Markov Models, K-Nearest Neighbor, Support Vector Machines, Artificial Neural Networks, Tree Based Classifiers, Expert Systems, or Fuzzy Logic methods, can be used, with some level of success, in the intelligent risk assess system for first responders **100** in lieu of the pattern recognition engine **900**.

[0082] FIG. **10** is a network of team aggregators **1000** that is used to aggregate risk assessments for individual first responders into a team risk assessment. If the team risk assessment indicates high risk to a team of first responders, the commander may decide to withdraw the team or send in additional first responders to help out. The network of team aggregators **1000** receive inputs from multiple pattern recognition engines, each of which processes data for a single first responder. In the case of the pattern recognition engine **900** shown in FIG. **9** the signals for the network of team aggregators **1000** are taken from the infinite logic aggregators **936**, **940**, **944** i.e., before the decision logic **999** reduces continuous output of the infinite logic aggregators **936**, **940**, **944** to a hard risk state. In particular, a low risk output **1002** (e.g., the output **962** of the first infinite logic aggregator **936**) for a first first responder through a low risk output **1004** of an N^{TH} first responder on the team of first responders are coupled to a team infinite logic aggregator for low risk **1006**. Similarly a moderate risk output **1008** (e.g., the output **964** of the second infinite logic aggregator **940**) for a first first responder through a moderate risk output **1010** for the N^{TH} first responder are coupled to a team infinite logic aggregator for moderate risk **1012**; and a high risk output **1014** (e.g., the output **966** of the third infinite logic aggregator **944**) for a first first responder through a high risk output **1016** for the N^{TH} first responder are coupled to a team infinite logic aggregator for high risk **1018**. The team infinite logic aggregators **1006**, **1012**, **1018** can implement (e.g., by programmed processor, or specialized circuits) equation six. In using equation six, if zero rather than one is taken to represent the strongest "TRUE" value, then conjunctive operations become disjunctive and vice versa. Thus, the team infinite logic aggregators **1006**, **1012**, **1018** can combine the signals from the individual team member's pattern recognition engines using disjunctive infinite logic (similar to the MAX function), conjunctive infinite logic (similar to the MIN function) or a function between these, e.g., signal averaging (or another compensative operation). To err on the side of caution, i.e., to bias the team risk state assessments to higher levels of risk, the team infinite logic aggregator for high risk **1018** can be configured to approximate the MIN function and the team infinite logic aggregator for low risk **1006** can be configured to approximate the MAX function. These choices assume that the individual pattern recognition engines **900** identify the prevailing risk condition based on the infinite logic aggregator **936**, **940**, **944** that produced the lowest output. The settings of the team infinite logic aggregators **1006**, **1012**, **1018** can also be learned using feature vector data for an entire team that is labeled based on positive, negative, and very negative outcomes of first responder calls. Outputs of the team infinite logic aggregators **1006**, **1012**, **1018** are coupled to a team decision logic **1020**. The team decision logic outputs a team risk state assessment (e.g., "low risk", "moderate risk" or "high risk"). Assuming that the decision logic **999** for the pattern recognition engines **900** for the individual first responders select the risk state assessment based on the lowest input signal, the team decision logic can select the team risk state assessment based on the team infinite logic aggregator **1006**, **1012**, **1018** that produced the lowest signal as well.

[0083] FIG. **11** is a flowchart **1100** of a training regimen for the pattern recognition engine **900**, **402** used in the risk management signal processor **206** and optionally for other configurable (trainable) parts of the intelligent risk management system **100** for first responders. Other configurable parts of the intelligent risk management system that may be trained include the filters **318** and signal aggregators **320** in the first responder's portable data pre-processors **202** and parts of the feature vector extraction system **704**. In block **1102** data that would be input into the pattern recognition engine **402**, **900** is recorded for use in training. Training data from the sensors on the first responder **104** the sensors at the scene of the incident **212** are recording during emergency response activities. In block **1104** positive outcomes (e.g., no injuries incurred) and negative outcomes, (e.g., injuries or fatalities incurred) of emergency response activities are recorded as labels for the data collected in block **1104**. Timing information for injuries and fatalities is also recorded so that the labels can be correlated with the data from the sensors **104**, **212** which is times series type data. Injuries and fatalities may sometimes occur or be discovered sometime after exposure hazardous conditions and stresses. Therefore, in some cases it may be necessary to record an earlier time for negative outcomes. The exact earlier time that is associated with a negative outcome label may be somewhat subjective, but the choice of the earlier time can be informed by reviewing the time series data from the sensors and interviewing first responder witnesses. The negative outcomes may be divided into two categories one associated with mild injuries (e.g., those only requiring treatment at scene of incident) can be labeled "moderate risk" and another associated with more acute injuries (e.g., requiring hospitalization) or fatalities can be labeled "high risk". If no negative outcomes occur during a first responder call, then feature vectors collected at regular intervals during the call (e.g., every 15 seconds) are labeled "low risk".

[0084] Decision block **1106** tests if sufficient training data has been collected. Typically more training data feature vectors are required for higher dimensionality feature vector spaces. If the outcome of block **1106** is negative then the flowchart **1100** loops back to block **1102** and continues collecting training data as previously described. If, on the other hand, sufficient training data has been collected, then in block **1108** the pattern recognition engine **900**, **402** is trained to correctly label the feature vectors in the feature vector space. Then, after training, in block **1110** the system is fully deployed, with the pattern recognition engine **900**, **402** actively assessing the risk state of first responders responding to emergency calls. In block **1112** the system continues saving data for use in future retraining which is performed periodically as indicated in block **1114**.

[0085] The pattern recognition engine **900** can, for example, be trained using differential evolution with an objective function that depends on a number of incorrect classifications and correct classifications (e.g., the ratio of the two). A higher weight may be given to incorrect classifications of feature vectors labeled "high risk" because of the criticality of avoiding misclassification of such conditions and because the relative infrequency of such "high risk" labeled data.

[0086] FIG. **12** is a block diagram of the intelligent risk management system for first responders **1200** according to an alternative embodiment of the invention. The system **1200** includes a first responder's risk managements system **1202** that is largely autonomous. The risk management signal processor **206** is implemented in software and/or hardware in the first responder's portable radio computer **106**, which can be a device such as the HDT600 handheld data terminal. The first responder's portable radio/computer **106** is coupled to a data memory **1204** that is used to log sensor data. Storing sensor data allows for later review and use of the data in future training of the pattern recognition engine **900**, **402**. The first responder's portable radio/computer **106** can also be wirelessly connected to installed wireless smoke and/or carbon monoxide sensors **1206**. According to this embodiment, even if the first responder's portable radio/computer **106** cannot establish a communication channel with the commander's data terminal **110** the first responder **102** will still have access to information from the risk management signal processor **206** because it is carried with the first responder **102**. In addition to implementing the risk management signal processor **206** locally, the first responder's portable radio/computer **106** can also transmit pre-processed sensor data and information relative to the first responder's risk state (e.g., the output of the infinite logic aggregators **936**, **940**, **944** and the decision logic **999**) to the commander's data terminal **110**. The commander's data terminal **110** includes a team risk management signal processor **1208**, which can be used to implement the network of team aggregators **1000** in software and/or hardware. If the commander's data terminal **110** has radio connections with a sufficient (pre-programmed) fraction of the first responders, the supervisory risk management signal processor can run the network of team aggregators **1000** to obtain the team risk assessment.

[0087] FIGS. **13-15** depict three windows of a Graphical User Interface (GUI) of the intelligent risk management systems for first responders **100**, **1200** shown in FIGS. **1**, **12** according to an embodiment of the invention. The GUI is part of the risk management interface **210** of the commander's data terminal **110**. A first window **1300** summarizes the status of a team of first responders under the commander's command. The name of each first responder **1302** is listed above a clickable button **1304** that indicates the current risk assessment (e.g., "low risk", "high risk", "medium risk") for the named first responder. The current risk assessment is based on the output of the decision logic **999** or the output of alternative pattern recognition engines. The overall team risk assessment is given in a separate box **1306**. The overall team risk assessment is based on the output of the team decision logic **1020**. Clicking one of the clickable buttons **1304** for the individual first responders will bring up a second window **1400** shown in FIG. **14** which gives sensor readouts for the selected first responder in bar graph form **1402** along with numerical readouts **1404**. Safe ranges **1406** and unsafe ranges **1408** are shown in different colors. A pointer **1410** indicates a level of each sensor read-out on the bar graph **1402**. The type of reading given by each sensor read-out is listed in a clickable box **1412**. Clicking one of the clickable boxes **1412** brings up a third window **1500** that shows times series data for the sensor identified by the clicked clickable box **1412**. The second window also includes a set of buttons **1414** for selecting a current reading, maximum reading (over the entire first responder call), a minimum reading or an average reading. The first window **1300** presents essential information in concise form for use by the commander during a first responder call. The third window **1500** includes information for review and analysis after the first responder call is over. Both the second window **1400** and the third window **1500** include a

button **1416** for returning to the first window **1300**. The third window also includes a button **1502** for returning to the second window **1400**.

[0088] FIG. **16** is a block diagram of a computer **1600** (e.g., **106**, **110**) used in the intelligent risk management system for first responders shown in FIG. **1** according to an embodiment of the invention. The computer **1600** comprises a microprocessor **1602**, Random Access Memory (RAM) **1604**, Read Only Memory (ROM) **1606**, hard disk drive **1608**, display adapter **1610**, e.g., a video card, a removable computer readable medium reader **1614**, a network adaptor **1616**, a keyboard **1618**, and an I/O port **1620** communicatively coupled through a digital signal bus **1628**. A display monitor **1612** is electrically coupled to the display adapter **1610** for receiving a video signal. A pointing device **1622**, e.g., a touchpad, is coupled to the I/O port **1620** for receiving signals generated by user operation of the pointing device **1622**. A radio **1624** is also coupled to the I/O port **1620**. The network adapter **1616** can be used, to communicatively couple the computer **1600** to a remote server (**1704**, FIG. **17**). The computer readable medium reader **1614** preferably comprises a Compact Disk (CD) drive. A computer readable medium **1626** that includes software embodying the programs described above is provided. The software included on the computer readable medium **1626** is loaded through the removable computer readable medium reader **1614** in order to configure the computer **1600** to carry out programs of the current invention that are described above with reference to the FIGs. The computer **1600** may for example comprise a laptop computer or handheld size data terminal. Computer readable media used to store software embodying the programs described above can take on various forms including, but not limited to, magnetic media, optical media, and semiconductor memory

[0089] FIG. **17** shows a network distributed architecture **1700** used by the intelligent risk management system for first responders **100** according to an embodiment of the invention. As shown in FIG. **17**, the commander's data terminal **110** and/or the first responder's portable radio/computer **106** are coupled by a network **1702** (e.g., the Internet, or a Virtual Private Network (VPN)) to a server **1704**. Feature vector data and optionally labels assigned by local first responder departments are transmitted via the network **1702** to the server **1704**. The server is used to perform training of the pattern recognition engine **402**, **900** and optionally other parts of the system **100**, as per block **1108** of FIG. **11**. Configuration parameters for the pattern recognition engine **402**, **900** and optionally other parts of the system **100** are from time to time transmitted back to the commander's data terminal **110** and/or the first responder's portable radio/computer **106** and used to configure the system **100**. Operation of the server **1704** may for example be run by a state or federal government bureau, government contractor or other commercial entity that offers services directly to first responder departments. The network distributed architecture allows for efficient collection of large amounts of training data which benefits training of the system **100**. Moreover, different first responder departments will benefit if the risk management system for first responders is trained based on the experiences of many different first responder departments.

[0090] FIGS. **18-19** show a fourth GUI window **1800** and a fifth GUI window **1900** that are used to submit labeled feature vectors to the server **1704**. The fourth and fifth windows **1800**, **1900** can be used by the commander after a first responder call has been concluded. The fourth window **1800** presents a question as to whether any injuries or fatalities occurred during the call along with a clickable "YES" button **1802** and a clickable "NO" button **1804**. If the "NO" button **1804** is clicked, then all of the feature vectors collected from all the first responders during the call will be labeled (or assumed to be) "low risk" and sent through the network **1702** (e.g., using the network adapter **1616**) to the server **1704**. If the "YES" button **1802** is clicked, then an instance of the fifth window **1900** will be opened. The fifth window **1900** is used to collect information on the injury or fatality that occurred. A set of radio buttons **1902** allows the commander to indicate a mild injury-treated on the scene, a severe injury-requiring hospitalization, or a fatality. According to one design a mild injury invokes "medium risk" feature vector labels and a severe injury or fatality invokes "high risk" feature vector labels. A pull down menu **1904** is used to select a name (and/or ID) of a first responder that suffered the injury or loss of life. A first text box **1906** is used to enter a time that the injury or fatality was reported and a second text box **1908** is used to enter an estimated time that the injury or fatality occurred. The time from the second box **1908** can be used to identify feature vectors that should be labeled as "medium risk" or "high risk", as the case may be. For example, feature vector data within a predetermined interval preceding the time reported in the second box **1908** can be automatically labeled "medium risk" or "high risk" depending on the selected radio button **1902**. After the data is submitted a qualified person, e.g., a doctor, may review feature vector data preceding the time entered in box **1906** or **1908** and label such data as "medium risk" or "high risk" at his or her discretion. A third text box **1910** provides space for a written report to be submitted. Such a written description may be useful deciding whether feature vector data should be relabeled and can also be used for other reporting purposes. Below the third text box **1910** a first clickable button **1912** is used to indicate that there are no further injuries or fatalities to report, and a second clickable button **1914** is used to indicate that there are additional injuries or fatalities to report. Clicking the second button **1914** results in another instance of the fourth window **1900** being opened so that information on further injuries or fatalities can be collected. Clicking the first button **1912** causes labeled feature vectors collected from all the first responders during the call being to be submitted through the network **1702** (e.g., using the network adapter **1616**) to the server **1704**. It is not necessary to transmit the names of the first responders to the server **1704**, therefore there need not be any concern that use of the systems **100**, **1200** encroach on medical privacy.

[0091] The systems **100**, **1200** can also be used to safeguard other personnel involved in high physical stress occupations, including for example, mine workers, military personnel undergoing intensive training and underwater workers. For use in underwater environments, acoustic modems can be used in lieu of radios.

[0092] In the foregoing specification, specific embodiments of the present invention have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit,

advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

We claim:

1. A first responder risk advisory system comprising:

one or more sensors selected from the group consisting of an environment sensor and a physiological state sensor carried with a first responder, wherein said one or more sensors produce one or more signals;

a risk management signal processor coupled to said one or more sensors, wherein said risk management signal processor is adapted to receive said one or more signals, process said one or more signals to deduce a level of risk to said first responder and output an indication of said level of risk.

2. The first responder risk advisory system according to claim **1** wherein said one or more sensors comprise a pulse oximeter.

3. The first responder risk advisory system according to claim **1** wherein said one or more sensors comprise a clothing temperature sensor.

4. The first responder risk advisory system according to claim **1** wherein said one or more sensors comprise a body temperature sensor.

5. The first responder risk advisory system according to claim **1** further comprising stored data on said first responder that is input to said risk management signal processor.

6. The first responder risk advisory system according to claim **5** wherein said stored data is selected from the group consisting of: a measure of recent work intensity, a measure of experience.

7. The first responder risk advisory system according to claim **5** further comprising a derived signal generator that generates a signal derived from said stored data and said one or more signals.

8. The first responder risk advisory system according to claim **5** wherein said stored data is indicative of a level of fitness of said first responder.

9. The first responder risk advisory system according to claim **8** wherein said stored data is selected from the group consisting of: resting heart rate, maximum heart rate, resting blood pressure, lung capacity, percent body fat, anaerobic threshold heart rate.

10. The first responder risk advisory system according to claim **1** wherein said one or more signals comprise a plurality of signals and first responder risk advisory system comprises an aggregator for aggregating two or more of said plurality of signals.

11. The first responder risk advisory system according to claim **10** wherein said aggregator comprises an infinite logic aggregator.

12. The first responder risk advisory system according to claim **1** wherein said one or more sensors comprise a plurality of redundant sensors.

13. The first responder risk advisory system according to claim **12** further comprising a signal aggregator for said plurality of redundant sensors.

14. The first responder risk advisory system according to claim **13** wherein said signal aggregator comprises an infinite logic aggregator.

15. The first responder risk advisory system according to claim **14** wherein said infinite logic aggregator is configurable to perform disjunctive, conjunctive and averaging functions by setting a control parameter.

16. The first responder risk advisory system according to claim **1** wherein said one or more sensors comprise a plurality of sensors and said risk management signal processor comprises a pattern recognition engine for assigning said level of risk based on output of said plurality of sensors.

17. The first responder risk advisory system according to claim **16** wherein said plurality of sensors comprise said environment sensor and said physiological state sensor.

18. The first responder risk advisory system according to claim **16** wherein said plurality of sensors comprise a plurality of environment sensors.

19. The first responder risk advisory system according to claim **16** wherein said plurality of sensors comprise a plurality of physiological state sensors.

20. The first responder risk advisory system according to claim **19** wherein said plurality of sensors comprise a plurality of environment sensors.

21. The first responder risk advisory system according to claim **16** wherein said risk management signal processor comprises a feature vector extraction system coupled to said one or more sensors and said pattern recognition engine and wherein said feature vector extraction system is adapted to produce feature vectors from said one or more signals and supply said feature vectors to said pattern recognition engine.

22. The first responder risk advisory system according to claim **21** further comprising:

a network adaptor for submitting said feature vectors to a remote server.

23. The first responder risk advisory system according to claim **1** wherein said risk management signal processor is carried with said first responder.

24. The first responder risk advisory system according to claim **23** wherein said one or more sensors comprise a plurality of sensors and said risk management signal processor comprises a pattern recognition engine for assigning said level of risk based on values of said plurality of sensors.

25. The first responder risk advisory system according to claim **1** wherein said one or more sensors are coupled through a wireless channel to said a risk management signal processor.

26. The first responder risk advisory system according to claim **1** wherein said risk management signal processor is part of a commander's data terminal.

27. The first responder risk advisory system according to claim **1** wherein said risk management signal processor comprises one or more derivative filters for processing at least one of said one or more signals.

28. The first responder risk advisory system according to claim **1** wherein said risk management signal processor comprises one or more noise removal filters for processing at least one of said one or more signals.

29. The first responder risk advisory system according to claim **28** wherein said one or more noise removal filters comprise a Q-filter.

30. The first responder risk advisory system according to claim **1** wherein said risk management signal processor comprises one or more integrators for processing at least one of said one or more signals.

31. The first responder risk advisory system according to claim **30** wherein said integrator is a full call duration integrator.

32. The first responder risk advisory system according to claim **1** further comprising a team risk management signal processor.

33. The first responder risk advisory system according to claim **32** wherein said team risk management signal processor receives signals from a plurality of said risk management signal processor for a plurality of first responders and outputs a team risk assessment.

34. The first responder risk advisory system according to claim **33** wherein said team risk management signal processor comprises one or more infinite logic signal aggregators for combining signals received from said plurality of said risk management signal processors for said plurality of team members.

35. The first responder risk advisory system according to claim **33** further comprising:

a graphical user interface including a window that shows said team risk assessment.

36. The first responder risk advisory system according to claim **1** further comprising:

a graphical user interface including a first window that shows said indication of said level of risk.

37. The first responder risk advisory system according to claim **36** wherein said graphical user interface comprises a second window that shows readouts of said one or more sensors.

38. The first responder risk advisory system according to claim **36** wherein said graphical user interface comprises a second window that shows time series data from at least one of said one or more sensors.

39. A first responder risk advisory system comprising:

one or more servers adapted to:

receive feature vectors extracted from one or more signals from one or more sensors, wherein said one or more sensors are selected from the group consisting of an environment sensor and a physiological state sensor carried with a first responder;

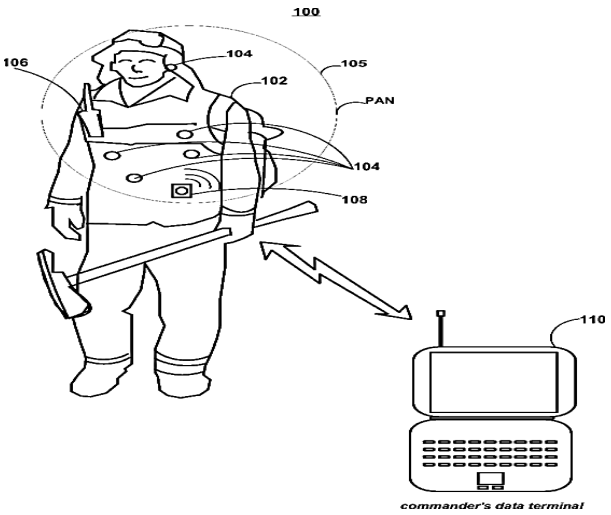
receive information indicative of outcomes of first responder calls; and

process said feature vectors and said information to determine configuration settings for a first responder risk management signal processor; and

send said configuration settings to said first responder risk management signal processor.

* * * * *

专利名称(译)	第一响应者的智能风险管理系统		
公开(公告)号	US20080146895A1	公开(公告)日	2008-06-19
申请号	US11/611321	申请日	2006-12-15
[标]申请(专利权)人(译)	摩托罗拉公司		
申请(专利权)人(译)	MOTOROLA，INC.		
当前申请(专利权)人(译)	MOTOROLA SOLUTIONS，INC.		
[标]发明人	OLSON WILLIAM L MOHAMED MAGDI A		
发明人	OLSON, WILLIAM L. MOHAMED, MAGDI A.		
IPC分类号	A61B5/00		
CPC分类号	G06F19/3431 G08B21/0453 G08B31/00 A61B5/02055 A61B5/7275 G06F19/3418 G06F19/3425 A61B5/7267 A61B5/7242 A61B2560/0242 G16H50/30 G16H80/00		
其他公开文献	US7880607		
外部链接	Espacenet USPTO		

摘要(译)

用于第一响应者（102）的风险管理系统（100）为第一响应者配备生理和环境传感器（104），以便跟踪第一响应者的压力状况和压力响应。来自传感器的数据被数字化并过滤并通过特征提取系统（202,704）处理，该系统可包括使用存储数据的噪声滤波器，（710）导数滤波器（706），积分器（708）和导出信号发生器（712）。在第一响应者之前，在被馈送到评估第一响应者的风险状态的模式识别系统（402,900）之前。可以聚合来自团队中多个第一响应者的数据以获得团队风险评估。