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(54) ENVIRONMENTAL HEAT STRESS MONITOR

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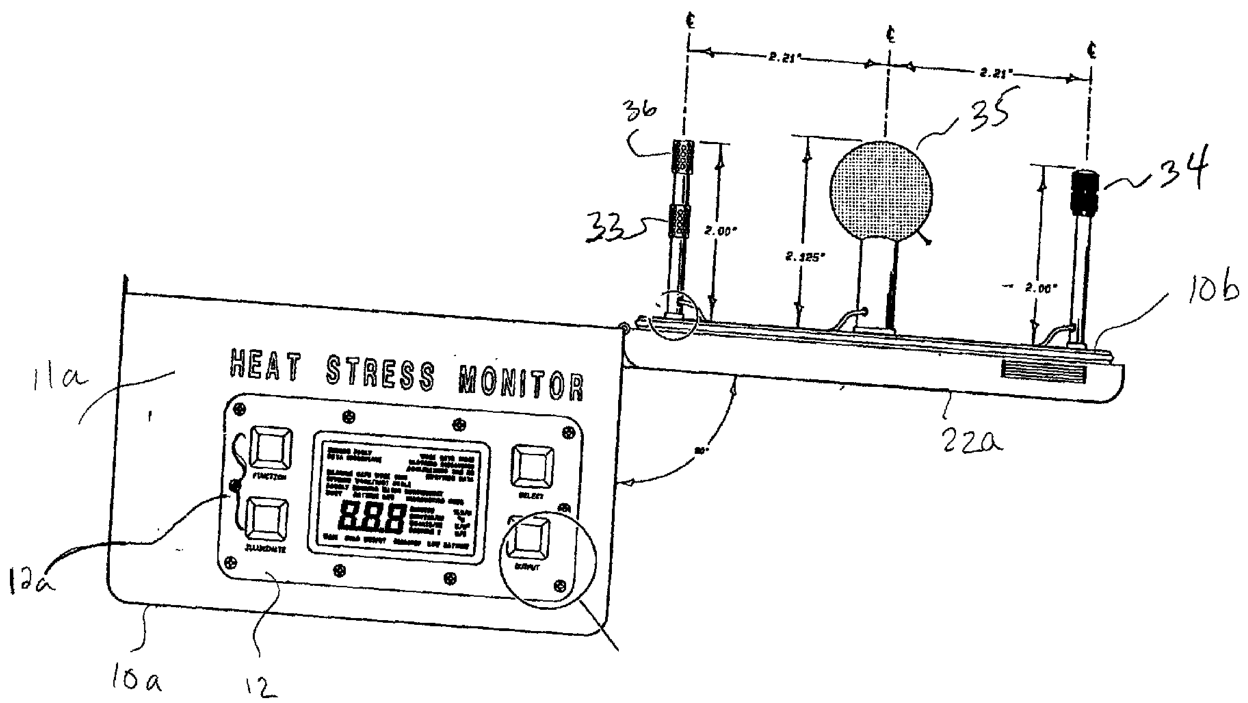
(57) **ABSTRACT**

A portable stress monitor is provided for monitoring conditions under which physiological activity is occurring. The conditions monitored may be environmental, such as ambient temperature and humidity, or physiological, such as heart rate or body temperature. The monitor includes a main body portion and a hinged cover. The hinged cover includes a removable sensor module. One or more sensors are attached to the sensor module, each sensor may be pivotally mounted on a mast, such that the sensors extend outwardly from the hinged cover when the sensor module is in the deployed position and may be pivoted to sit substantially flush with the hinged cover when the sensor module is in the storage position. A central processing unit is contained within the main body, and is operable to process data acquired by the sensors according to a heat strain algorithm. A display is attached to the outer surface of the main body for providing read out information, and an input device is provided for user input.



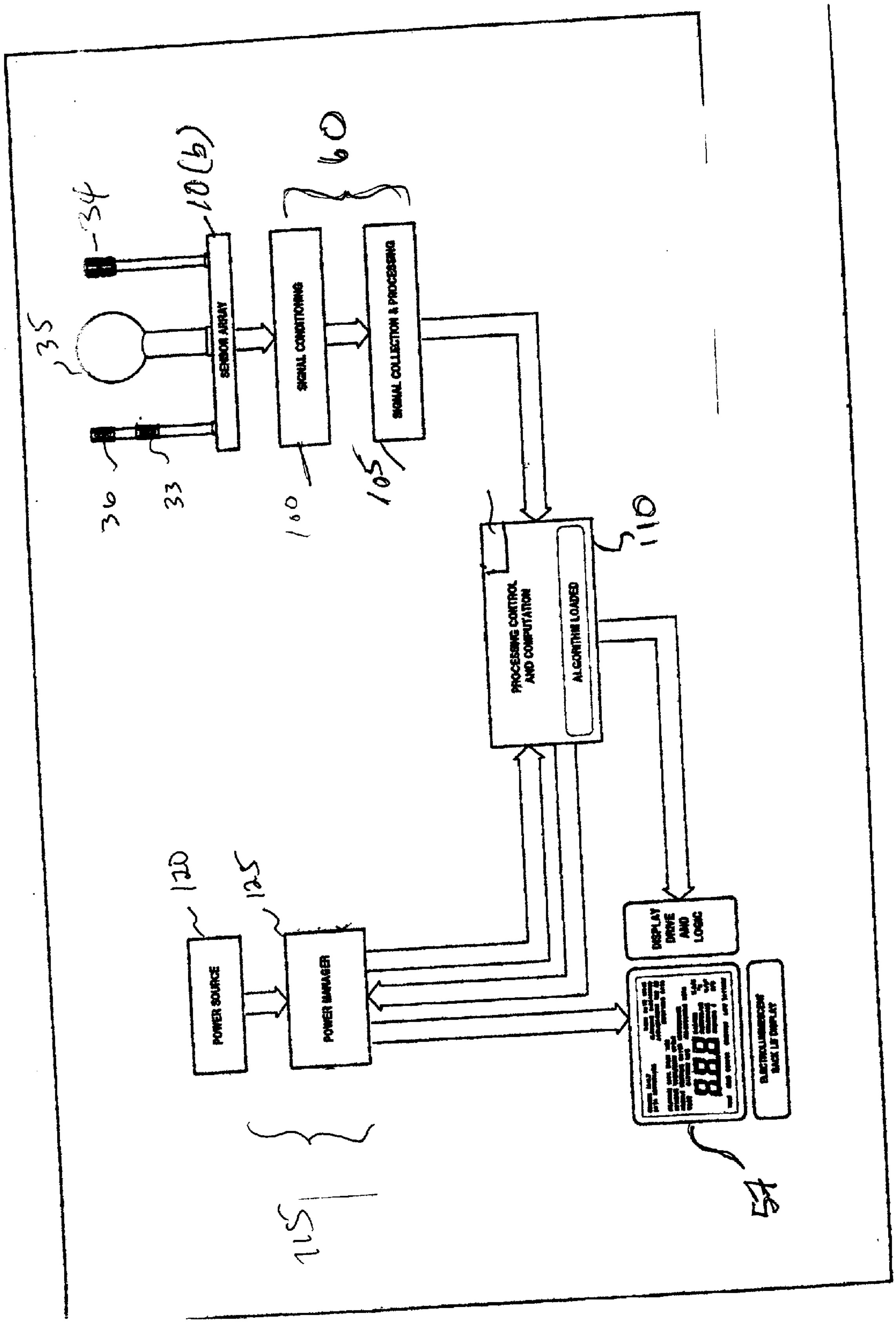

SENSOR ARRAY
SIGNAL CONDITIONING
SIGNAL COLLECTION & PROCESSING
PROCESSING CONTROL AND COMPUTATION
ALGORITHM LOADED
POWER SOURCE
POWER MANAGER
DISPLAY DRIVE AND LOGIC
ELECTROLUMINESCENT BACK LIT DISPLAY
888
10(b)
34
35
36
33
60
100
105
110
120
125
115
57

Figure 1

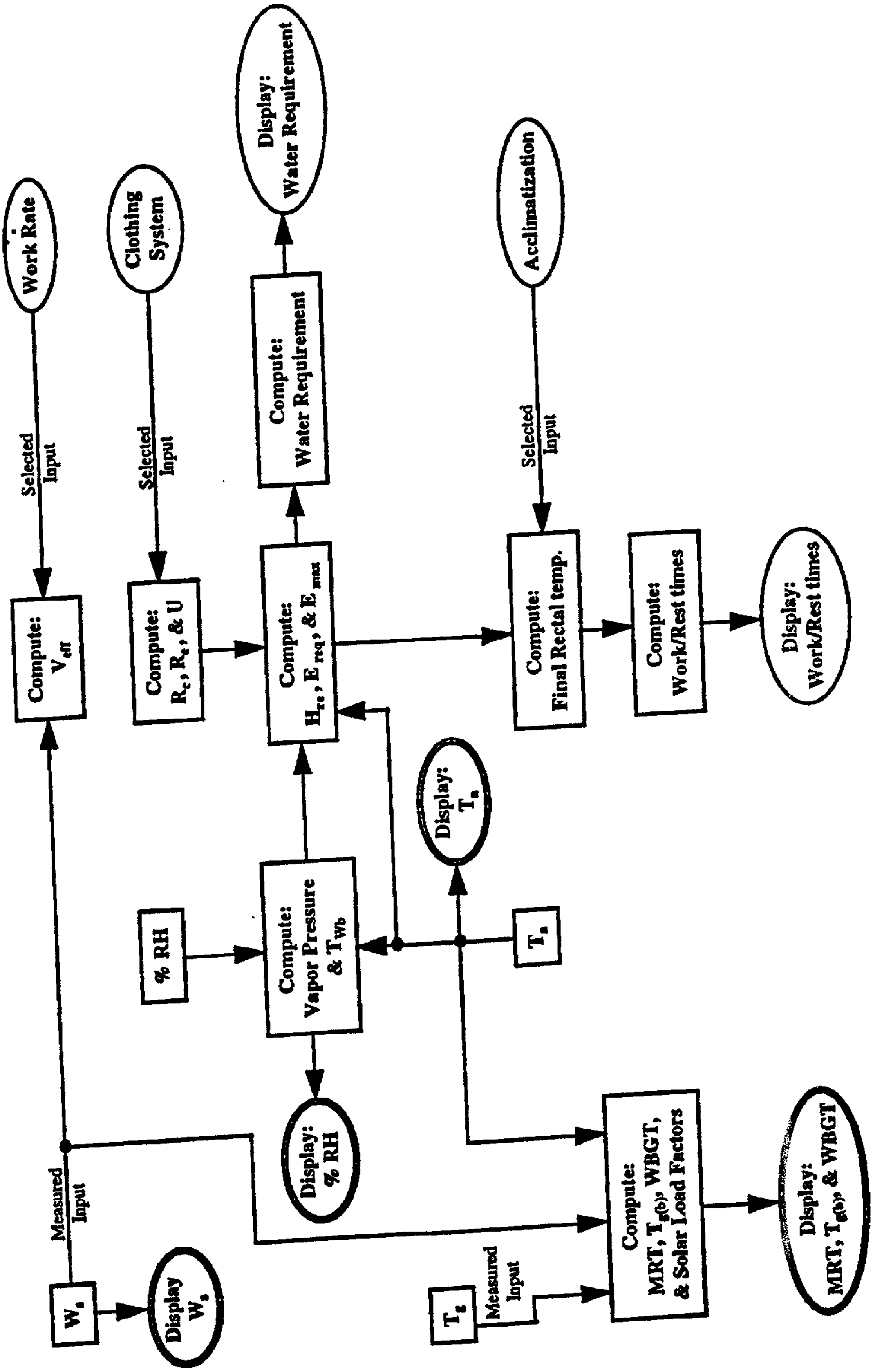

Work Rate
Selected Input
Compute: V_{eff}
Clothing System
Selected Input
Compute: R_t, R_e, & U
Display: Water Requirement
Compute: Water Requirement
Compute: H_{re}, E_{req}, & E_{max}
Acclimatization
Selected Input
Compute: Final Rectal temp.
Compute: Work/Rest times
Display: Work/Rest times
Display: T_a
% RH
Compute: Vapor Pressure & T_{Wb}
T_a
Display: % RH
Measured Input
W_s
Display W_s
Compute: MRT, $T_{g(b)}$, WBGT, & Solar Load Factors
Display: MRT, $T_{g(b)}$, & WBGT
Measured Input
T_g

Figure 2

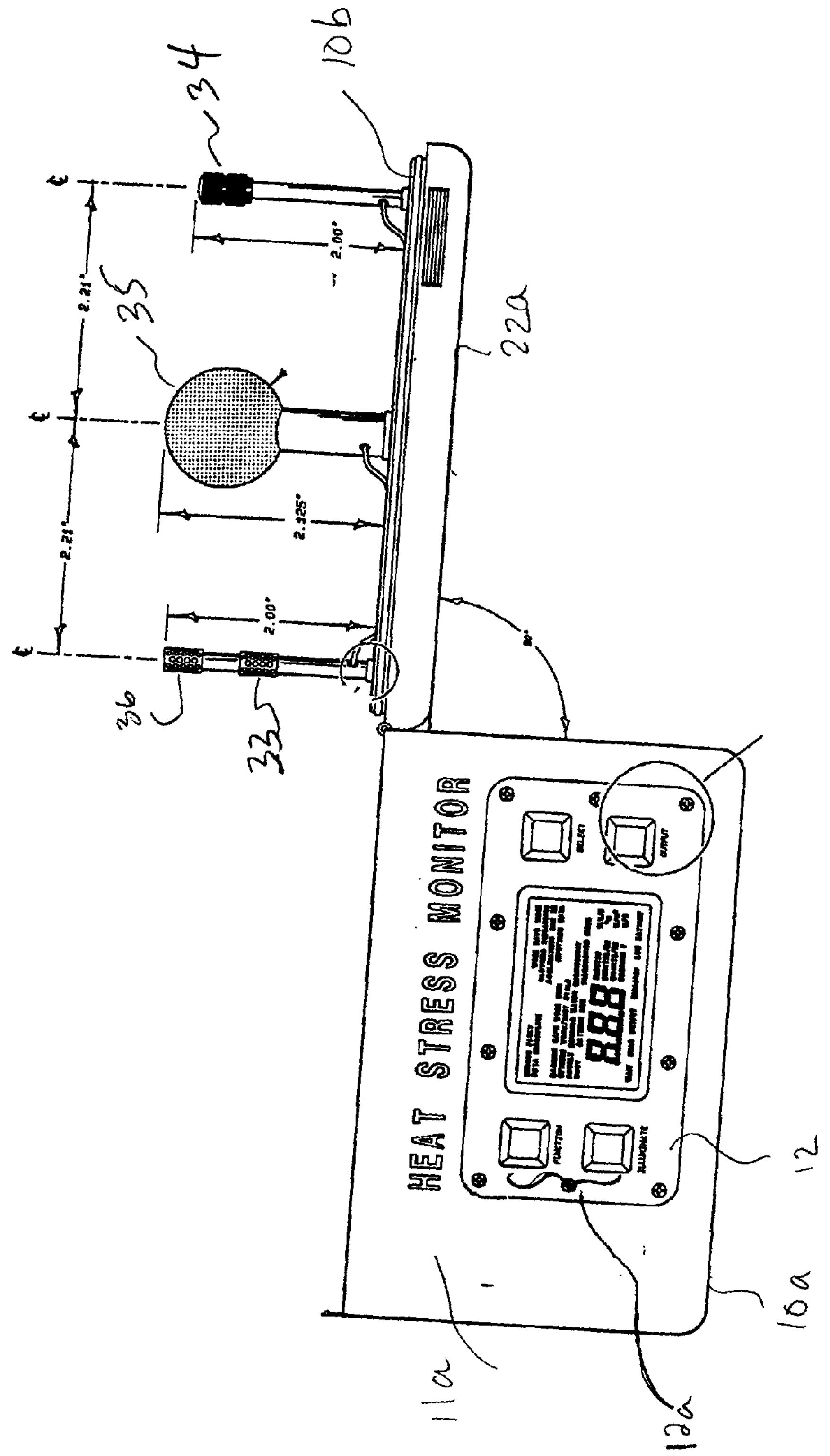

HEAT STRESS MONITOR
34
10b
35
22a
36
33
12
10a
11a
12a
2.21"
2.21"
2.00"
2.325"
2.00"

Figure 3

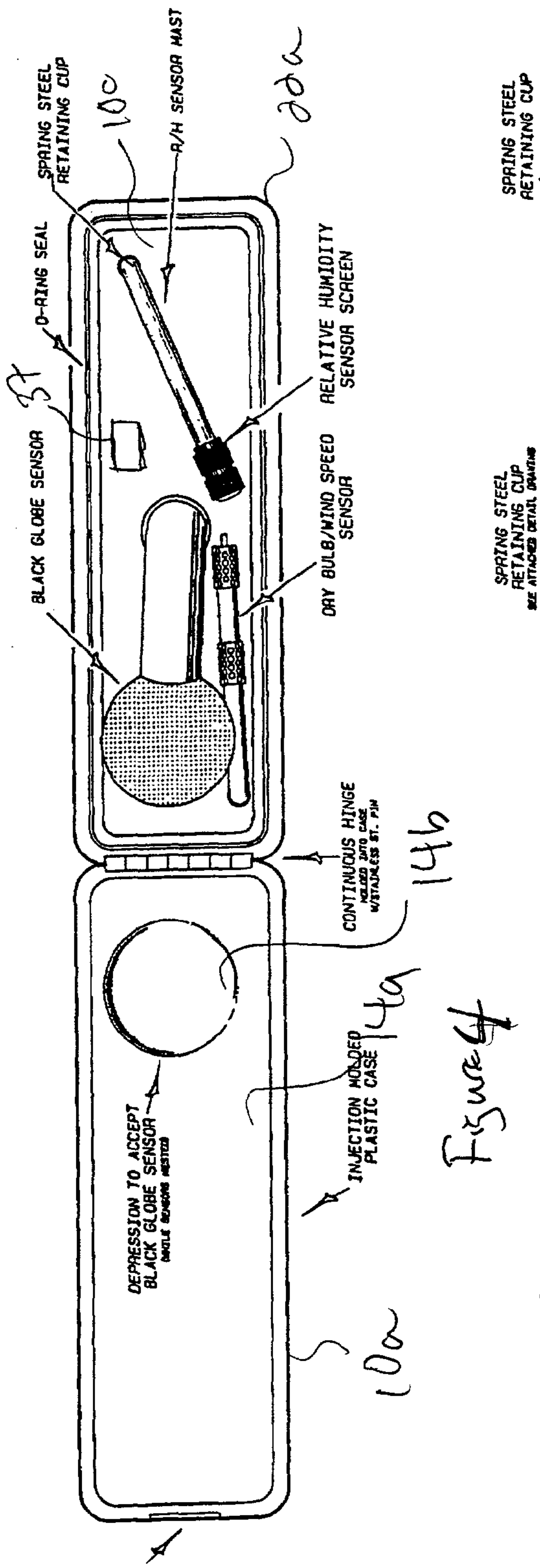


Figure 4

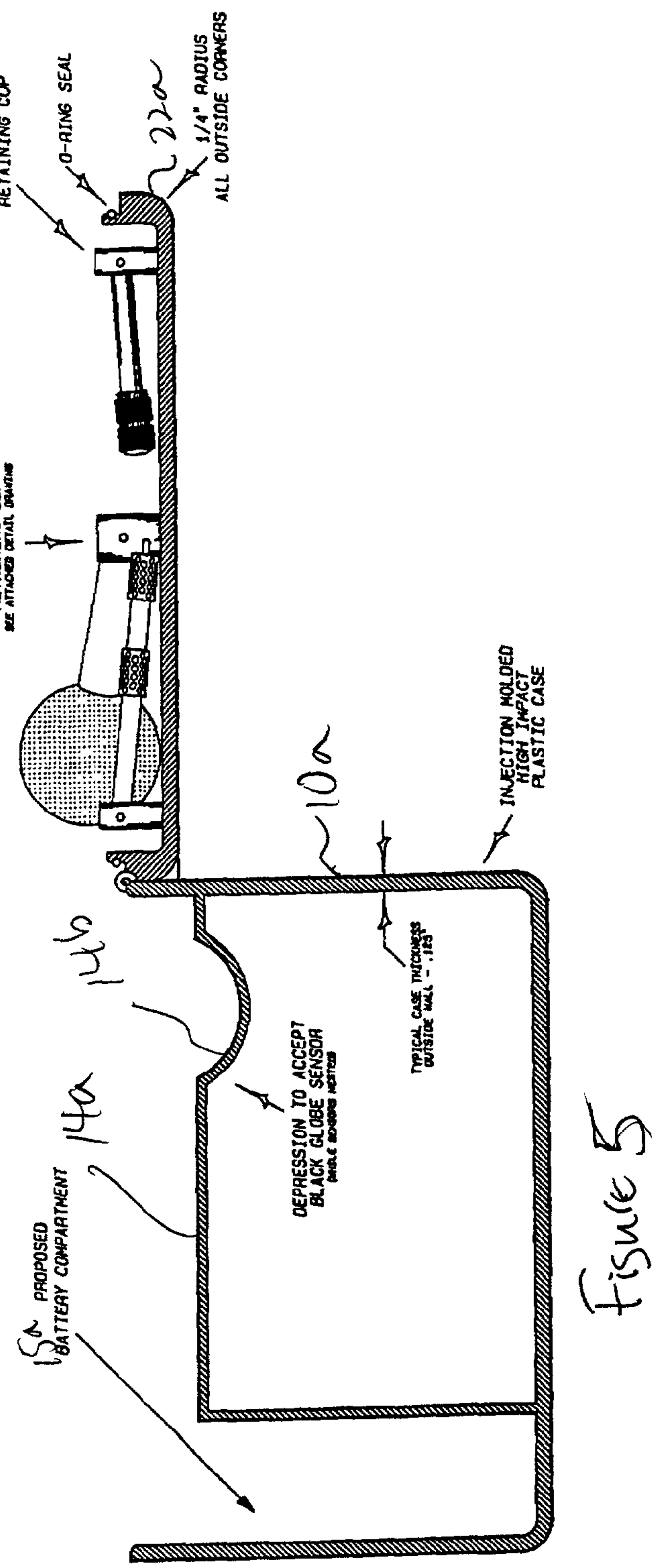


Figure 5

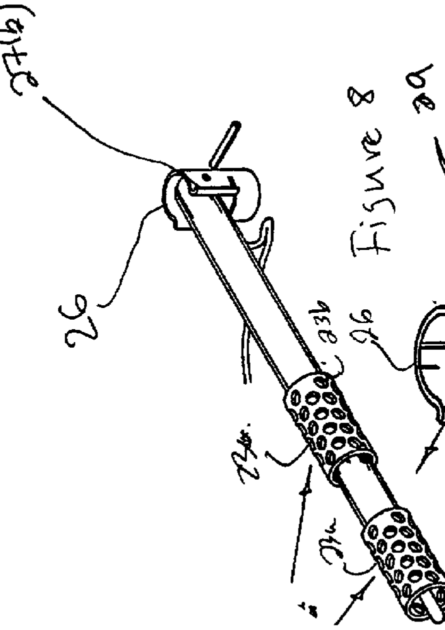


Figure 8

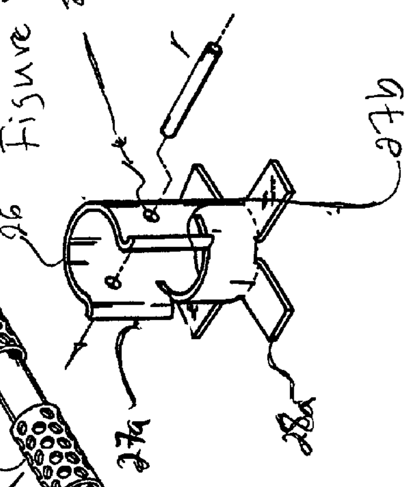


Figure 7

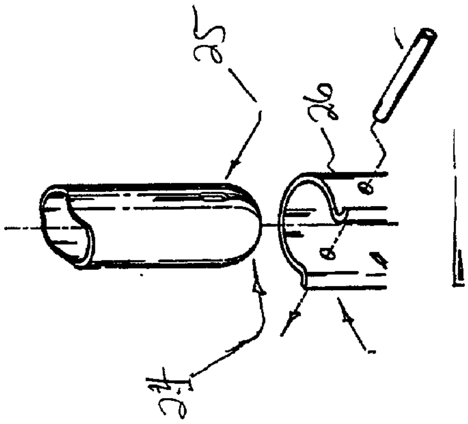


Figure 6

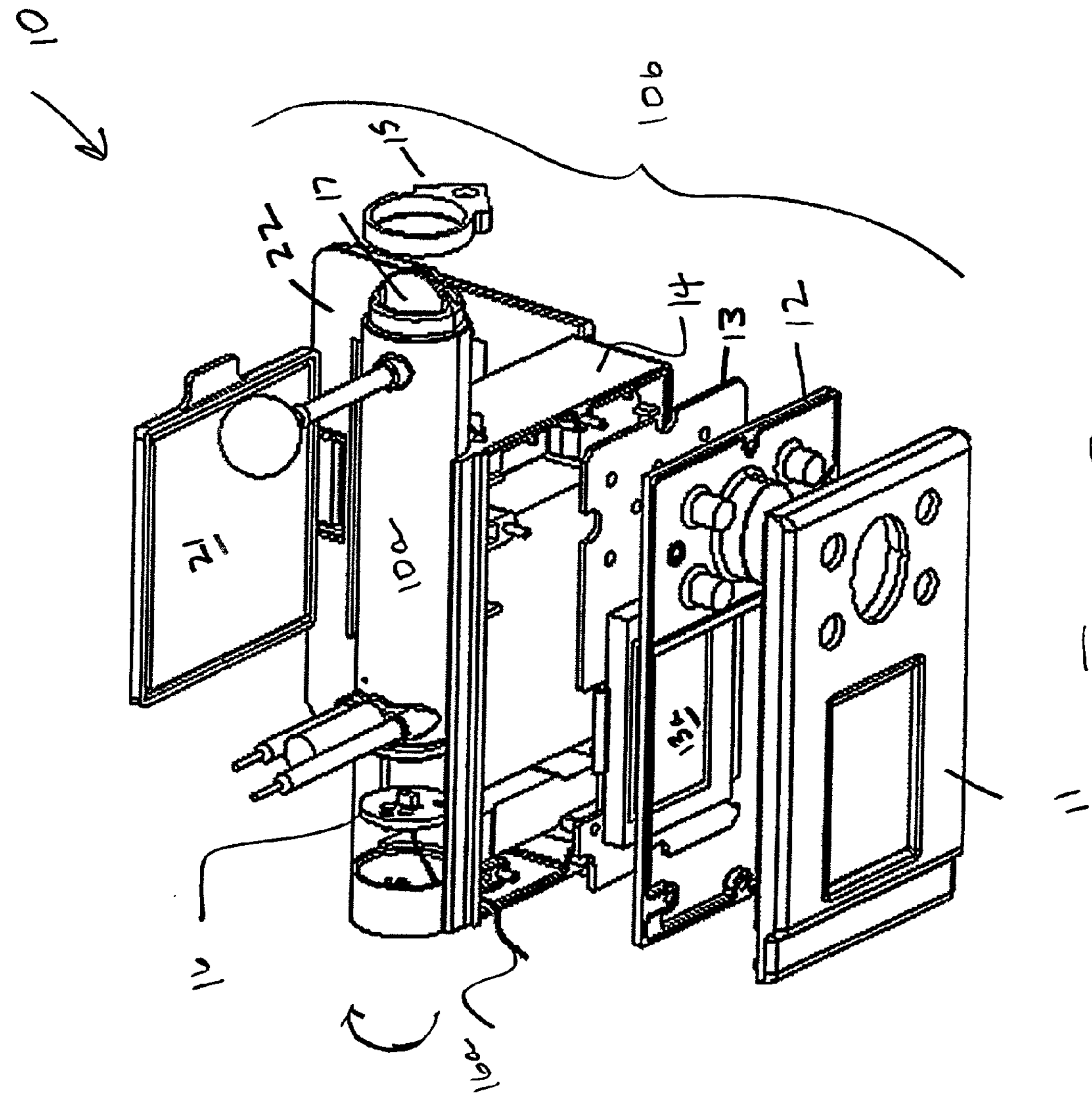


Figure 9

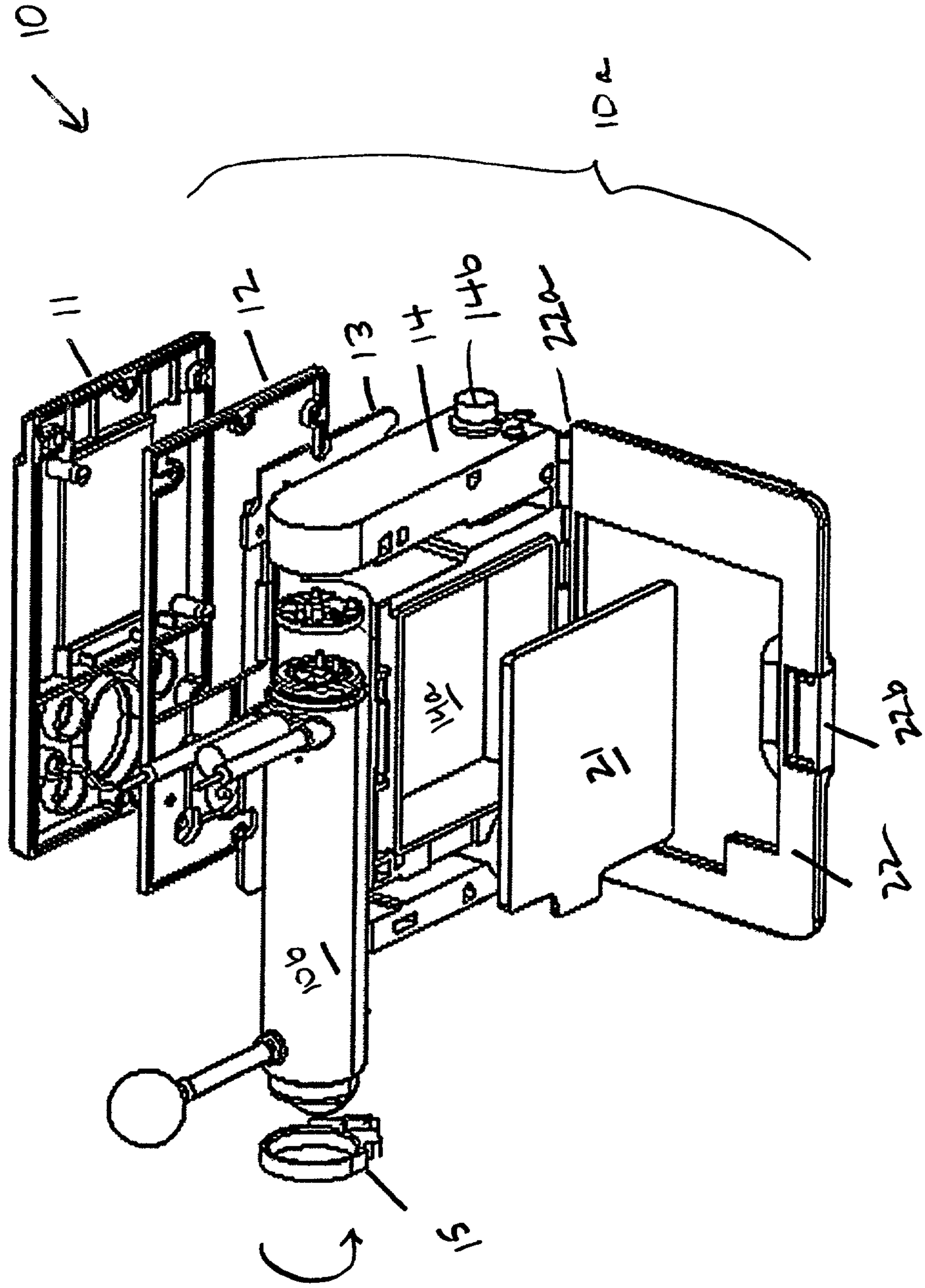


Figure 10

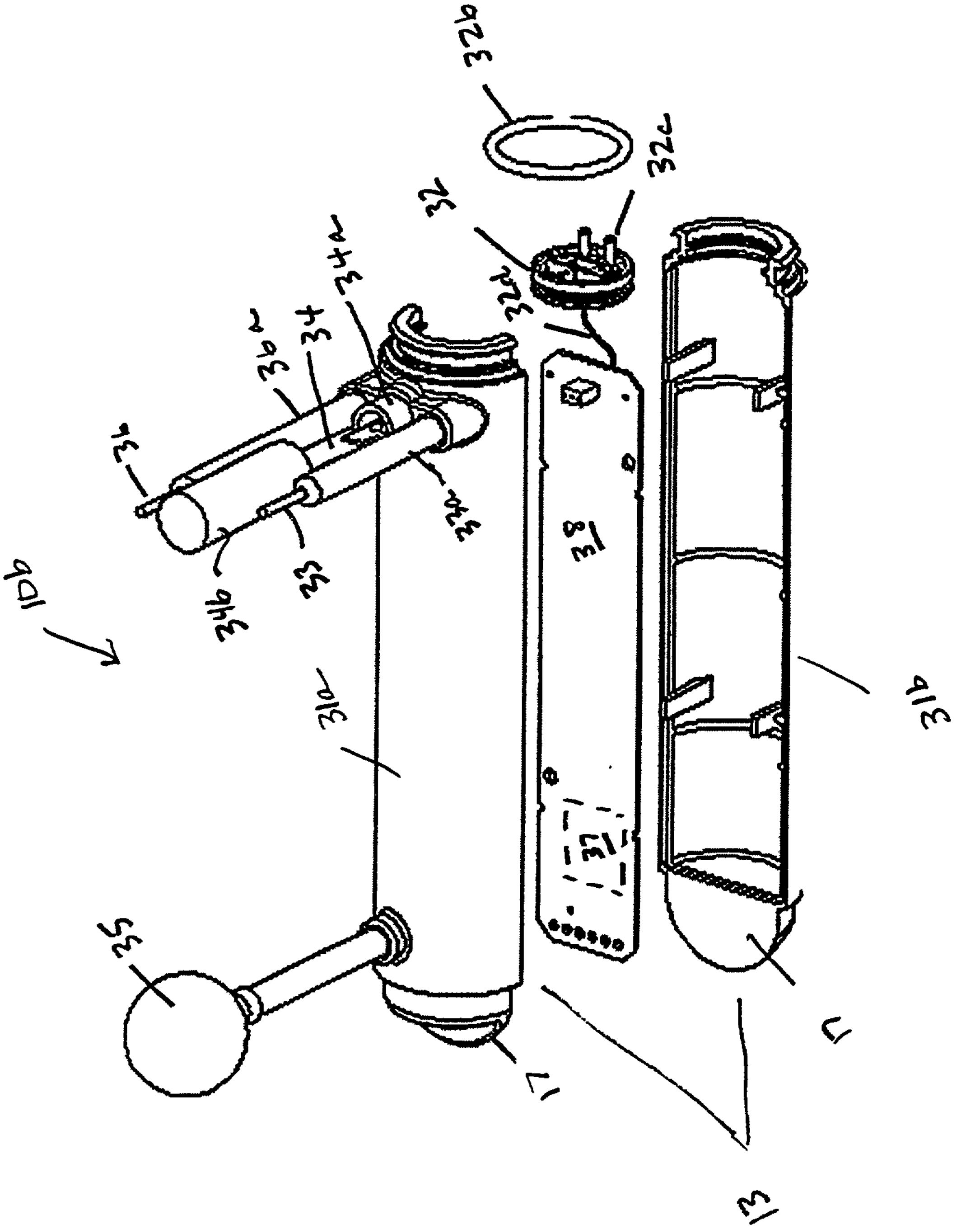


Figure 11

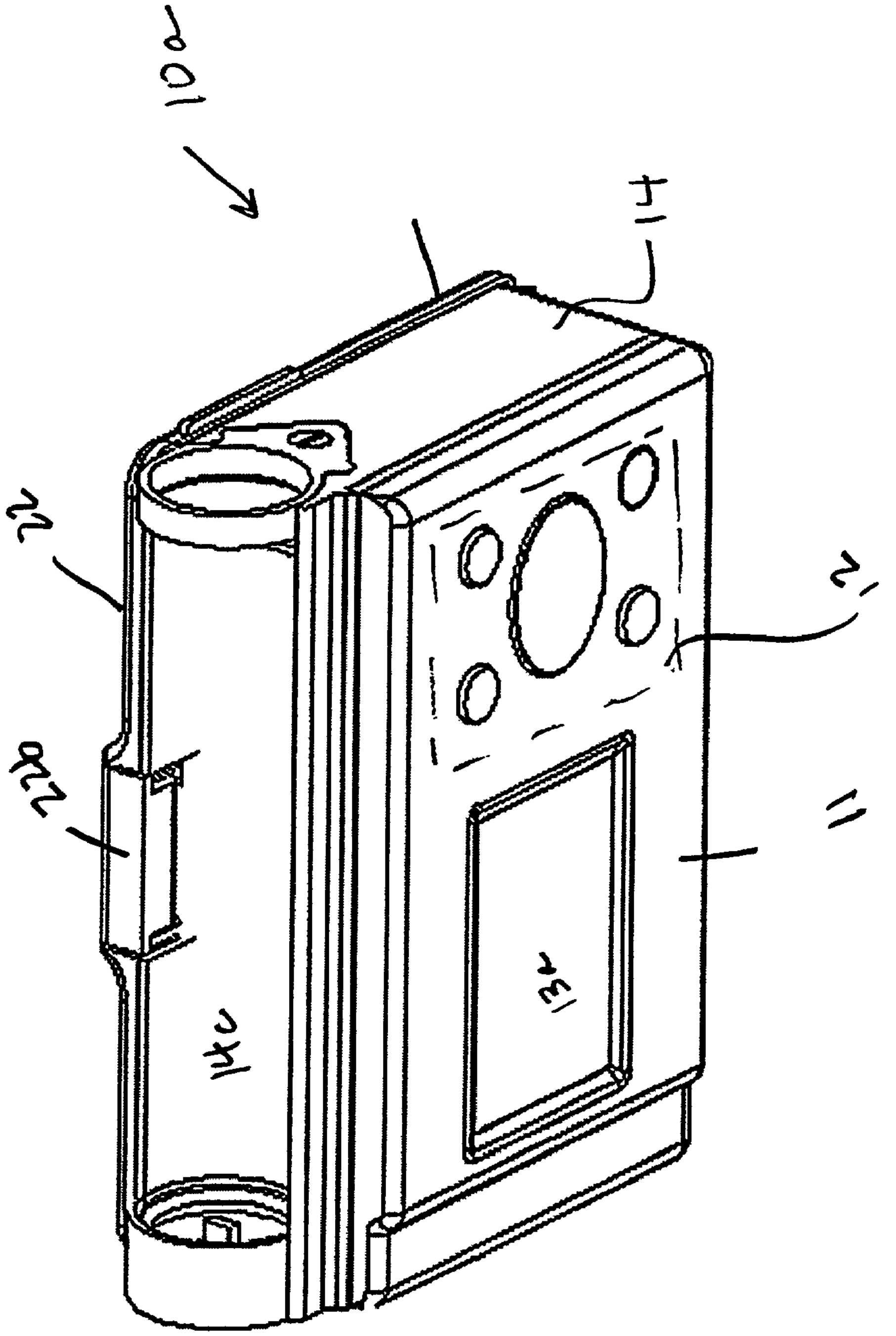


Figure 12

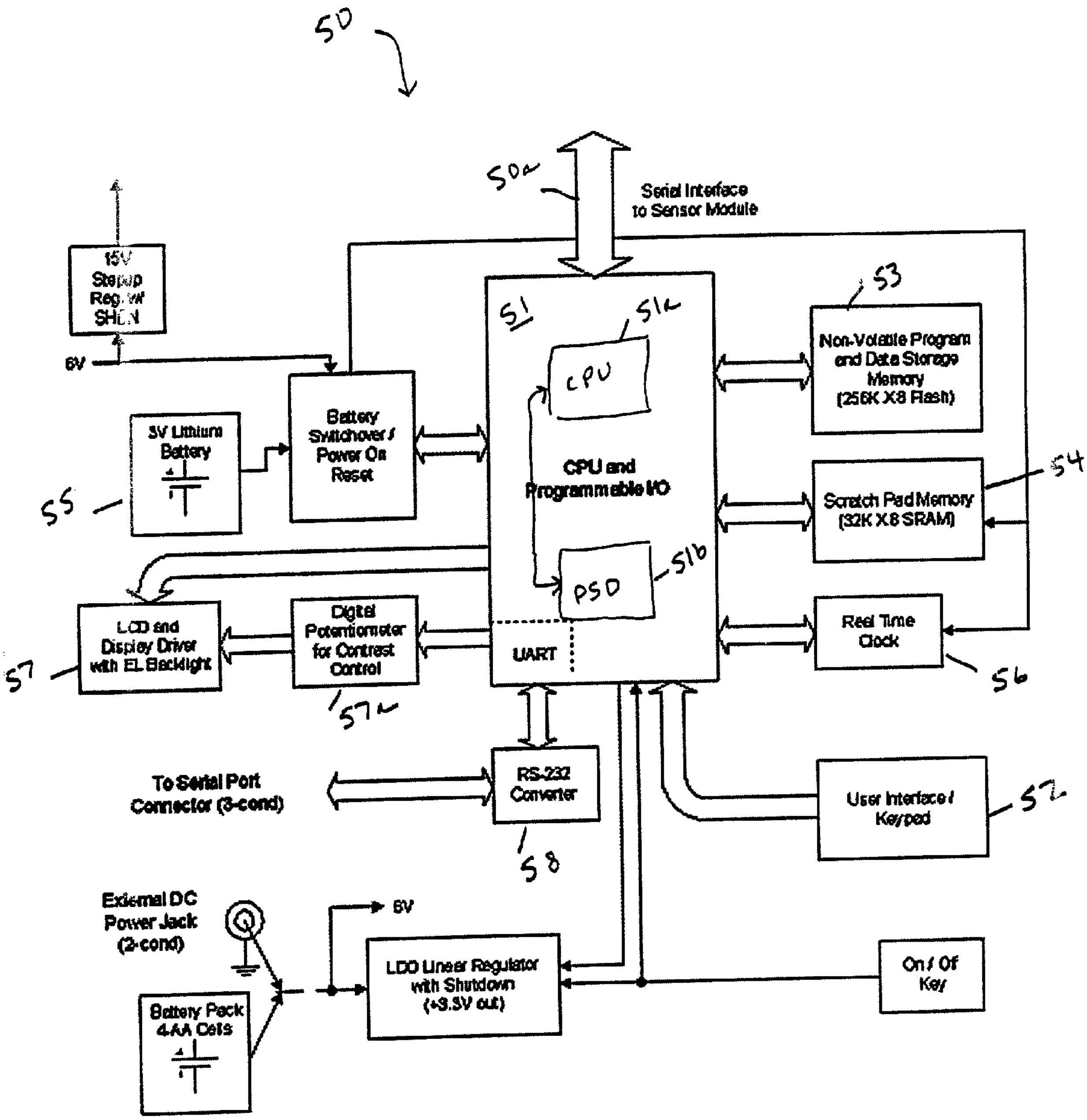

50
50a
Serial Interface
to Sensor Module
15V
Stepup
Reg. w/
SHDN
6V
51
51a
CPU
53
Non-Volatile Program
and Data Storage
Memory
(256K X8 Flash)
3V Lithium
Battery
Battery
Switchover /
Power On
Reset
CPU and
Programmable I/O
54
Scratch Pad Memory
(32K X8 SRAM)
55
PSD
51b
LCD and
Display Driver
with EL Backlight
Digital
Potentiometer
for Contrast
Control
UART
Real Time
Clock
57
57a
56
To Serial Port
Connector (3-cond)
RS-232
Converter
User Interface /
Keypad
52
58
External DC
Power Jack
(2-cond)
6V
LDO Linear Regulator
with Shutdown
(+3.3V out)
On / Off
Key
Battery Pack
4AA Cells

Figure B

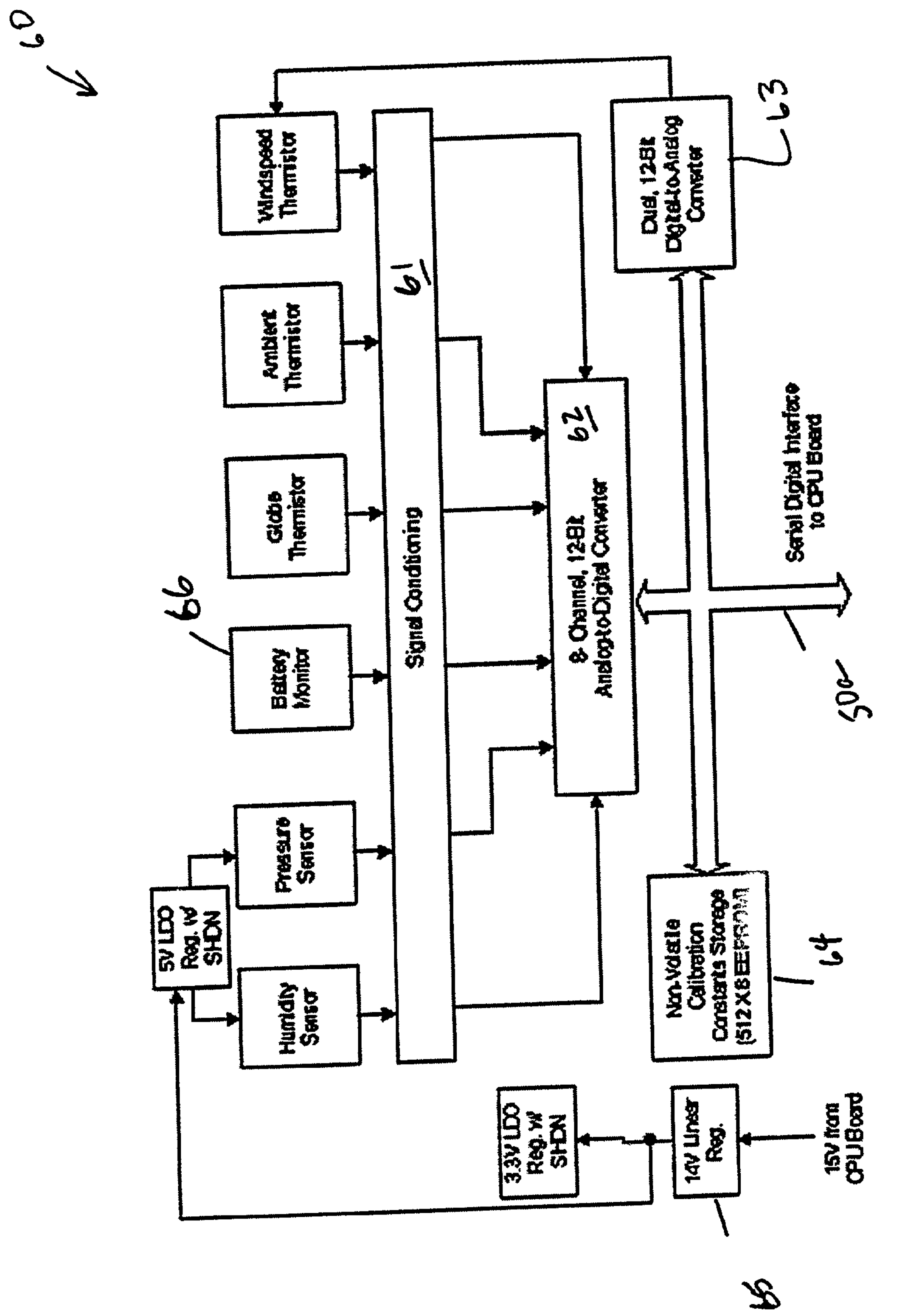

60
Windspeed Thermistor
Ambient Thermistor
Globe Thermistor
Battery Monitor
66
Pressure Sensor
Humidity Sensor
5V LDO Reg. w/ SHDN
Signal Conditioning
61
8-Channel, 12-Bit Analog-to-Digital Converter
62
Dual, 12-Bit Digital-to-Analog Converter
63
Serial Digital Interface to CPU Board
500
Non-Volatile Calibration Constants Storage (512 X 8 EEPROM)
64
3.3V LDO Reg. w/ SHDN
14V Linear Reg.
15V from CPU Board
65

Figure 14

ENVIRONMENTAL HEAT STRESS MONITOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from provisional application Ser. No. 60/182,051 filed Feb. 11, 2000.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not Applicable.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] The invention relates generally to the filed of environmental data acquisition systems, and particularly to portable environmental heat stress monitors that can be used to monitor the effects of exposure to extreme environmental conditions.

[0005] 2. Description of Related Art

[0006] Military leaders, industrial managers and athletic trainers are all confronted with the problem of achieving high productivity or performance and safeguarding health under conditions of high heat or heat stress. Heat stress is the aggregate of all environmental and physical work factors that impose a heat load on the body. The environmental factors of heat stress include the air temperature, radiant heat, air movement, relative humidity and barometric pressure. Physical work contributes to the aggregate by producing metabolic heat in the body in direct proportion to the intensity of activity. The amount and type of clothing also can affect the heat load.

[0007] Several methods have been developed to index the conditions that lead to heat stress. Of these, the Web Bulb Globe Temperature (WBGT) is a popular measure in use in military, government and industrial arenas. The WBGT index is relatively simple to compute. It is defined by:

$$WBGT=0.7(WB)+0.2(GT)+0.1(DB)$$

[0008] where:

[0009] WB=natural wet-bulb temperature

[0010] GT=6-inch diameter black Vernon-globe temperature (indicating radiant heat)

[0011] DB=shaded dry-bulb temperature

[0012] For indoor use involving radiant heat sources other than direct solar radiation, the equation modifies to:

$$WBGT_{\text{indoors}}=0.7(WB)+0.3(GT)$$

[0013] Guidelines for determining work/rest schedules or protective measures for persons exposed to heat stress conditions, based on the WBGT index have been used in government and industry. However, the major use of WBGT measurements is in evaluation and quantification of the environment in industries such as aluminum production, steel production, foundry work, and the chemical and refinery fields where workers are routinely exposed to high radiant and convective heat. With accurate index to heat-stress levels, worker comfort and health can be assured while maintaining peak productivity and efficiency.

[0014] While the WBGT has proved to be a workable index, there are several factors that contribute to heat stress that are not accounted for by the WBGT index. Therefore, there is a need for a more comprehensive measure for heat stress.

[0015] Heat stress often affects workers in isolated locations, e.g., the battlefield, oil rigs, in mine shafts, in quarries etc. Accordingly, it is desirable to have a portable measurement device so that measurements can easily be taken in locations that are not readily accessible. Previous monitoring devices have sensors that are mounted to a tripod and attached to a separate display units by cables. This can limit their use to areas that can physically accommodate such equipment. Other devices use individual sensors that directly attach to the display unit, and are removed and placed in a protective case for storage. There is a need for a portable, self contained device that may be carried and operated by a worker without additional accessories.

SUMMARY OF THE INVENTION

[0016] One embodiment of the invention may be realized by a portable stress monitor for monitoring conditions under which physiological activity is occurring. The conditions monitored may be environmental, such as ambient temperature and humidity, or physiological, such as heart rate or body temperature. The monitor includes a main body portion and a hinged cover. The hinged cover includes a removable sensor module. One or more sensors are attached to the sensor module, each sensor may be pivotally mounted on a mast, such that the sensors extend outwardly from the hinged cover when the sensor module is in the deployed position and may be pivoted to sit substantially flush with the hinged cover when the sensor module is in the storage position. A central processing unit is contained within the main body, and is operable to process data acquired by the sensors according to a heat strain algorithm. A sensor electronics circuit is contained within the sensor module, and is operable to perform sensor-related functions, such as signal conditioning and A/D conversion. A display is attached to the outer surface of the main body for providing read out information, and a keypad is provided for user input.

[0017] An advantage of the heat/stress monitor according to the present invention is that tailored heat stress management guidance is provided based on clothing worn, acclimatization status and work level.

[0018] Another advantage of the heat stress monitor according to the present invention is that the sensor suite and the central processor permit flexible implementation of additional physiological models or supplemental environmental stress parameters. More particularly, this invention permits facile adjustment of the heat strain algorithm.

[0019] Still a further advantage of the invention is the removable sensor module allows rapid replacement of the sensors as a single unit for repair and calibration.

BRIEF DESCRIPTION OF THE FIGURES.

[0020] **FIG. 1** is a block diagram of the heat stress monitor in accordance with the present invention.

[0021] **FIG. 2** is a computational diagram of a preferred heat strain algorithm in accordance with the present invention.

[0022] **FIG. 3** is a side view of an embodiment of the heat stress monitor of the invention illustrating the sensors in a deployed position.

[0023] **FIG. 4** is a top view of the embodiment shown in **FIG. 3** depicting the sensors in a storage position.

[0024] **FIG. 5** is a side cut away view of the embodiment shown in **FIG. 3** illustrating the sensors in a storage position and illustrating the system for coupling the sensors to the body.

[0025] **FIG. 6** is an exploded view of a sensor coupling system in accordance with the invention showing the mast and the cuff.

[0026] **FIG. 7** is an exploded view of the sensor coupling system of **FIG. 6** illustrating only the cuff.

[0027] **FIG. 8** depicts the wind speed sensor and the dry bulb sensor in a storage position.

[0028] **FIG. 9** is a perspective front view of the stress monitor, with the sensor module in the "deployed" position.

[0029] **FIG. 10** is a perspective rear view of the stress monitor of **FIG. 9**.

[0030] **FIG. 11** is a perspective view of the sensor module of **FIGS. 9 and 10**.

[0031] **FIG. 12** is a perspective front view of the assembled main body of **FIGS. 9 and 10**.

[0032] **FIG. 13** is a block diagram of the main electronics contained within the main body.

[0033] **FIG. 14** is a block diagram of the sensor electronics contained within the sensor module.

DETAILED DESCRIPTION OF THE INVENTION

[0034] The apparatus, systems and methods of the present invention may be used for monitoring environmental conditions. A better understanding of the several embodiments of the invention and their use for monitoring environmental conditions will be achieved by reading the following description in conjunction with the above-incorporated references.

[0035] The present invention encompasses a compact, self-contained monitor that measures environmental conditions and calculates related safety factors and environmental stress parameters. The monitor preferably includes a main body and a sensor module. The sensor module preferably includes a number of environmental sensors including an atmospheric pressure sensor, a humidity sensor, an air temperature sensor, a wind speed sensor, and a solar radiation sensor. The sensor module is preferably releasably engaged with the main body such that the sensor module may be movable between a deployed position and a storage position and such that the sensor module may be readily replaced according to the intended use of the environmental monitor.

[0036] The sensor module may be provided with circuitry required to operate the various sensors. For example, the sensor module may be provided with A/D and D/A converters for processing current and voltage generated and/or required by the sensors and a memory device that stores calibration information for the sensors.

[0037] The main body may include a main processor for operating the monitor, a display for exhibiting input parameters, a central processing unit for computing safety factors and environmental stress parameters using manually input as well as measured environmental parameters. In some embodiments, the main body may include a communication port for facilitating communication with a local or remote server.

[0038] In other embodiments the central processing unit may be separate and distinct from the maim body and, for example, disposed in a server that communicates with the main body.

[0039] In accordance with preferred aspect of the invention, the central processing unit may be programmed according to a heat strain prediction model to calculate selected environmental safety factors e.g., work/rest cycle limits, hourly drinking water requirements and maximum safe work times. These selected environmental safety factors may be calculated based upon inputs from the environmental sensors as well as manual inputs from a user and/or remote inputs from a server, e.g., type of clothing worn by subject, work rate, and acclimatization status.

[0040] **FIG. 1** illustrates an environmental data monitor in accordance with a preferred embodiment of the invention. A sensor module **10***b* is provided with a plurality of sensors including a dry bulb sensor **33**, a relative humidity sensor **34**, a globe sensor **35** and a wind speed sensor **36**. In addition, sensor module **10***b* also includes an atmospheric pressure sensor **37** not illustrated in **FIG. 1**. Sensors **33-37** each collect data to be transmitted to a central processing unit **110**. Each of the sensors **33-37** and central processing unit **110** are described in greater detail below in connection with specific embodiments of the invention. Sensor module **10***b* further includes sensor electronics **60** which may comprise signal conditioning circuitry **100** and collection and processing circuitry **105**. Signal conditioning circuitry **100** preferably converts signals transmitted and received by the sensors to a form usable by other system circuitry. Collection and processing circuitry **105** includes a suitable memory device that stores information unique to sensors **33-37**. For example, collection and processing circuitry **105** may store calibration information related to sensors **33-37** and facilitate recalibration. While it is preferable that sensor electronics **60** be included in sensor module **10***b*, in other embodiments, sensor electronics may be disposed in main body **10***a*.

[0041] In some embodiments, a graphical display **57** may be disposed in main body **10***a*. Display **57** is preferably provided with a menu that allows a user to select parameters to be input to central processing unit **110**. In accordance with the invention, the menu allows the user to select parameters related to environmental stress for input to central processing unit **110**. Display **57** is preferably a backlit LCD display of the type generally known to those of skill in the art.

[0042] In other embodiments, no display is provided with main body **10***a*. In these embodiments, a user may input environmental stress parameters at a remote location and those parameters may be transmitted to environmental monitor **10** by any method of signal transmission. For example, the signals may be transferred wirelessly, via the Internet, through a direct modem connection, via satellite, via spread spectrum techniques, or via optical communication links.

[0043] In keeping with an aspect of the invention, environmental monitor **10** may be provided power management circuitry **115** to facilitate efficient energy consumption. Power management circuitry **115** preferably includes a power source **120** and a power manager **125** for controlling power output from power source **115**. Power manager **125** communicates with display **57** and controls powerup and shutdown of monitor **57**. For example, in accordance with the user's wishes, display **57** may be driven into low power consumption mode after a period of inactivity or it may be shut down all together. In addition, display **57** may be automatically powered up upon deployment of one or more of sensors **33-37** or upon some other event.

[0044] Turning to a particularly preferred aspect of the invention, central processing unit **110** is preferably programmed to carry out a physiological heat strain model to determine at least the following safety factors for workers and others exposed to extreme heat: 1) optimal work/rest cycle limits, 2) hourly water consumption needs and 3) maximum safe work time. In addition, CPU **110** may compute the following environmental parameters WBGT (computed from, mean radiant temperature, dew point and air-cooling power). A preferred physiological heat strain model uses both measured parameters and user input parameters to calculate the above safety factors. More particularly, the preferred heat strain model employs the following measured inputs: air temperature, humidity, solar radiation, wind speed and barometric pressure. In addition, the preferred heat strain model uses the following user supplied inputs: clothing type, work rate and acclimation status. A particularly preferred heat strain model is that described in *Computer Biological Medicine,* by Pandolf et al., Vol. 16 No. 5, pp. 319-329, 1986, which is herein incorporated by reference.

[0045] The heat strain model may be realized as software to provide real-time safety factors and environmental parameters upon demand for assessing the effects of heat stress on human beings. A diagram representing the steps to be performed by the software in the preferred embodiment is shown in **FIG. 2**. The software may be implemented as a computer program or other electronic device control program or an operating system. The software may be resident in the environmental monitor **10** in CPU **110**, if desired. Alternatively, CPU **110** including the software may be resident in a stand-alone device in communication with environmental monitor **10** either continuously or intermittently. The standalone device may be a standard personal computer (PC), a PAL device, a personal digital assistant (PDA), an e-book or other handheld or wearable computing devices (incorporating Palm OS, Windows CE, EPOC, or future generations like code-named Razor from 3Com or Bluetooth from consortium including IBM and Intel), or a specific purpose device receiving signals from environmental monitor **10**. Depending on the location of the software, the software may be stored, for example, in random access memory (RAM); in read only memory (ROM); on a storage device like a hard drive, disk, compact disc, punch card, tape or in other computer readable material; in virtual memory on a network such as an intranet or the Internet, computer or otherwise; on an optical storage device; on a magnetic storage device; and/or on an EPROM. The software may be modified or updated as desired.

[0046] In operation, the user preferably deploys sensors **33-37** and activates monitor **10**. Monitor **10** may be activated automatically when sensors are deployed or may be manually activated by the user. Upon activation, display **57** preferably shows various parameters and indicia including date, time and power status. The user may then activate a selection menu on LCD **57** and select the appropriate input parameters, i.e., the type of clothing, the work rate and the acclimation status. The input parameters are then transferred to CPU **110**. The selection menu preferably provides the user with a variety of options for each parameter from which the user may select. Further, upon activation of the monitor **10**, sensors **33-37** collect data and transmit the collected to CPU **110**. The user may then request computation of any one or more of the safety factors and environmental parameters described above. In accordance with a preferred aspect of the invention, over a two-minute span, sensor measurements may be made at one-second intervals, averaged and input to CPU **110**. The safety factors may be calculated and output by CPU **110** either to display **57** or to a remote server in as little as three seconds. A preferred algorithm for calculation of safety factors and environmental parameters is depicted in **FIG. 2**. Accordingly, environmental monitor **10** provides real time computation of safety factors.

[0047] In accordance with another feature of the invention, the environmental monitor **10** may be operated in automatic mode. That is, environmental monitor **10** may be set to log data from sensors **33-37**. The user may input start time, duration and interval for sensors to take readings. All data logged is saved and, when logging is complete, data may be viewed on display **57** and/or downloaded to a server for viewing and computation of safety factors via communication port **135**.

[0048] Upon calculation of the safety factors, the safety factors may be displayed in graphical or alphanumerical fashion. For example, a cyclic work guidance display screen may show optimal minutes of work/rest per hour to keep predicted body core temperature within safe limits as well as amount of water to drink per hour to replace predicted sweat losses. A continuous work guidance display screen may show predicted maximum safe work time in minutes for a one-time bout of continuous work and the amount of drinking water needed to replace predicted sweat loss. An environmental data screen may show measured environmental parameters such as air temperature, relative humidity, wind speed, black globe temperature and barometric pressure. In addition, the environmental data screen may show calculated environmental parameters such as wet bulb temperature, mean radiant temperature, and the wet bulb-globe temperature (WBGT) index.

[0049] The above-described display screens may be provided on display **57**, However, CPU **110** may also transmit the display information directly to a server simultaneously, serially or to the exclusion of display **57** for display on a server monitor. Of course, in embodiments of environmental monitor **10** that do not include display **57**, CPU **110** transmits the display information directly to the server and information is displayed on the server monitor.

[0050] **FIG. 3** illustrates a specific embodiment of the environmental monitor **10** in accordance with the invention. Environmental monitor **10** is adapted for use in monitoring environmental conditions associated with heat stress, and has sensors and programming appropriate for that application. However, monitor **10** could be easily adapted for monitoring other environmental conditions, such as cold, air quality, and noise. Appropriate sensors could be added or substituted for those described herein.

[0051] Structurally, environmental monitor **10** is comprised of a case including a main body **10***a* and a sensor module **10***b*. In **FIG. 3**, sensor module **10***b* is shown in the "deployed" position, positioned for operation of its sensors. A hinged cover **22***a* of main body **10***a* is open to facilitate deployment of the sensors.

[0052] The main body **10***a* of monitor **10** has a front face **11***a*, and a keypad **12** with individual keys **12***a*. A CPU **110** for computation of safety factors and environmental stress parameters such as that described above may be disposed within main body **10***a*.

[0053] As illustrated in **FIGS. 4 and 5**, main body **10***a* includes a shelf **14***d* including a substantially spherical depression **14***e* dimensioned to accept the black globe sensor described in greater detail below when the sensors are in the rest or nestled position. More particularly, spherical depression **14***e* may have a diameter equal to or less than about 1.125". Main body **10***a* may also be provided with a compartment **15***a* for storing a power source, e.g., a battery (not shown).

[0054] Sensor module **10***b* is preferably releasably disposed in hinged cover **22***a*. Sensor module **10***b* may be snap fit, friction fit or otherwise matingly engaged with hinged cover **22***a*. A feature of the invention is that monitor **10** easily permits sensor modules **10***b* to be interchanged and used with the main body **10***a*. All signal processing and calibration information is stored in the sensor module **10***b*, with a digital control interface to the main body **10***a*.

[0055] Sensor module **10***b* is comprised of a substantially planar base **10***c* which supports a dry bulb sensor **33**, relative humidity sensor **34**, black globe sensor **35**, and wind speed sensor **36**. Sensors **33-36** are illustrated in **FIG. 3** in their deployed position. That is, sensors **33-36** are position erect, substantially perpendicular to planar base **10***c*. Sensors **33-36** may be placed in their storage position by folding down each sensor as described in detail below and closing hinged cover **22***a*. In the storage position, sensors **33**, **34** and **36** will be substantially flush with planar base **10***c* and the globe of sensor **35** will be nestled in depression **14***e*. Accordingly, cover **22***a* may be closed and mated with main body **10***a*. **FIGS. 4 and 5** illustrate sensors **33-36** in their storage position, substantially parallel to planar base **10***c* prior to closing cover **22***a*.

[0056] Each of sensors **33-36** is attached to or coupled with a mast **23** and the mast is secured to planar base **10***c*. Mast **23** is preferably comprised of a thin walled stainless steel tube member as depicted in FIGS. **6-8**. As best shown in **FIG. 6**, each mast has a substantially hemispherical closed end **24** and a clearance slot **25** disposed along a side of mast **23** proximate to closed end **24**. Closed end **24** is configured for hinged engagement with spring retainer cup **26** to permit rotation of sensors **33-36** through an angle of approximately **90°** from rest position to deployed position. Spring retainer cup **26**, depicted in greater detail in **FIG. 7**, defines a collar having first and second wings **27***a* and **27***b*. Spring retainer **26** is preferably formed form stainless steel or beryllium copper. Lodging mast **23** into spring retainer **26** and threading roll pin **28** through eyelets **29** and clearance slot **25** may establish a secure hinged connection. Wings **27***a* and **27***b* are inwardly biased to secure mast **23** in position as shown in **FIG. 8**. Spring retainer **26** is further provided with extension ears **28***a* that may be potted into planar base **10***c*.

[0057] Although a preferred coupling system for sensors **33-36** is described above, the invention is not limited to such a system. Sensors **33-36** may be coupled to planar base **10***c* using any mechanism that allows sensors **33-36** to be moved to and from and locked into their deployed and storage positions.

[0058] As discussed above, each of sensors **33-36** are disposed on a mast **23** as shown. Dry bulb sensor **33** and wind speed sensor **36** are preferably disposed on the same mast **23**. **FIG. 8**. However, wind speed sensor **36** is preferably disposed above dry bulb sensor **33** near the top end of mast **23**. To prevent damage to wind speed sensor **36** and dry bulb sensor **33**, a protective covering **23***a* may be disposed about the respective sensors. An exemplary protective covering is illustrated in **FIG. 8** is a stainless steel collar having a plurality of perforations **23***b* to facilitate airflow. Wind speed sensor **36** and dry bulb sensor **33** may be of a type known to those of skill in the art. For example, both wind speed sensor **36** and dry bulb sensor **33** may be realized by thermistors.

[0059] Likewise, black globe sensor **35** and relative humidity sensor **34** are of the type generally known to those of skill in the art. In accordance with a feature of the invention, the wet bulb globe temperature (WBGT) may be obtained by measuring relative humidity with sensor **34** and the dry bulb temperature with sensor **33** and using a mathematical formula to determine wet bulb temperature. Alternatively, a dedicated wet bulb sensor could be used in sensor module **10***b*.

[0060] An atmospheric pressure sensor **37** is preferably located inside sensor module **10***b*. In the embodiment of **FIG. 4**, pressure sensor **37** may be mounted on planar base **10***c*. In addition, sensor electronics **60** may be disposed on the underside of planar base **10***c*. In preferred embodiments, sensor electronics **60** may be implemented on a printed circuit board (not shown), which may be readily attached to planar base **10***c*.

[0061] In keeping with the invention, the user may control operation of environmental sensor **10** using keypad **12***a*. Specifically, using keypad **12***a*, the user may perform one or more of the following: a) input environmental stress parameters, b) control illumination of display **57** and c) direct CPU **110** to compute environmental stress parameters and environmental safety factors.

[0062] FIGS. **9-15** illustrate still another embodiment of the invention. **FIGS. 9 and 10** are exploded front and rear views of an environmental data monitor **10** in accordance with the invention, respectively. In the example of this description, monitor **10** is adapted for use in monitoring environmental conditions associated with heat stress, and has sensors and programming appropriate for that application. However, monitor **10** could be easily adapted for monitoring other environmental conditions, such as cold, air quality, and noise. Appropriate sensors could be added or substituted for those described herein.

[0063] Structurally, monitor **10** is comprised of a main body **10***a* and a sensor module **10***b*. In **FIGS. 9 and 10**, sensor module **10***b* is in the "deployed" position, positioned for operation of its sensors. A hinged rear cover **22** of main body **10***a* is open, but could be closed to protect the sensors of sensor module **10***b* during use.

[0064] The main body **10***a* of monitor **10** has a front piece **11**, a keypad **12**, a CPU board **13**, with a midpiece **14**, a battery cover **21**, a rear cover **22** with latch **22***a*, an endpiece **15**, and a sensor module connector **16**.

[0065] CPU board **13** is located between front piece **11** and midpiece **14**. On its front side, CPU board **13** contains the graphics display and traces for keypad **12**. Other electronic components are on the rear side. The electrical circuitry of CPU board **13** is explained below in connection with **FIG. 13**.

[0066] Midpiece **14** has a curved sensor bed **14***c* at its top end. As explained below, sensor bed **14***c*, such that sensor module **10***b* may rotate at least **180** degrees. **FIG. 10** illustrates this rotation.

[0067] Sensor module connector **16** attaches to midpiece **14**, such as by screws. The attachment is after its wiring harness **16***a* is threaded to CPU board **13**. Sensor module connector **16** has alignment holes **16***b*, which prevent a rotating connector **32** on sensor module **10***b* from making contact with sensor module connector **16** until it is properly aligned.

[0068] A battery compartment **14***a* in midpiece **14** contains four AA-size batteries wired in series to provide a nominal six-volt DC power source. A battery cover **21** is a friction fit rubber cover, which seals the battery compartment **14***a* when rear cover **22** is closed.

[0069] The '+' and '−' terminals of the batteries protrude through the battery compartment **14***a* and a wiring harness connects them to CPU board **13**. An external connector **14***b* also attaches to CPU board **13** with a wiring harness. All wiring harnesses are of sufficient length to allow CPU board **13** to be removed from the midpiece **14** and manipulated for repair.

[0070] Once all wiring harnesses are attached to the CPU board **13**, keypad **12** is placed into the front piece **11**. Keypad **12** is made from conductive rubber and forms a weatherproof seal where it comes in contact with the midpiece **14**. The front piece **11** attaches to the midpiece **14** by screws that enter through the rear of the midpiece **14**.

[0071] Rear cover **22** and midpiece **14** have a hinge-type attachment **22***a* along their bottom edges. A sliding latch **22***b* is attached to the rear cover **22** by compression springs, which hold latch **22***b* in its latched position. Operating the latch **22***b* opens the rear cover **22**. A compressible gasket may be attached to the perimeter of the rear cover **22** to serve as a seal and to allow the rear cover **22** to spring out from the midpiece **14** when unlatched.

[0072] Sensor module **10***b* is cylindrical in shape, with a rotating connector **32** at one end and a rotation knob **17** at the other. Connector **32** permits sensor module **10***b* to rotate within the sensor bed **14***c* of midpiece **14**.

[0073] When monitor **10** is in the "storage" position (not shown), sensor module **10***b* is rotated approximately 180 degrees from the "deployed" position illustrated in **FIGS. 9 and 10**. This permits its sensors to be placed under rear cover **22**, when cover **22** is hinged shut.

[0074] For assembly, sensor module **10***b* is slid into position on the main body **10***a* with the sensors in their deployed position and the rear cover **22** unlatched. Once the sensor module **10***b* is seated properly, endpiece **15** is positioned over the knob **17** and attached to the midpiece **14** with screws. For the storage position of monitor **10**, the sensors can be rotated into the sensor cavities in the midpiece **14**, and the rear cover **22** can be closed.

[0075] **FIG. 11** illustrates sensor module **10***b* in further detail. A feature of the invention is that monitor **10** easily permits sensor modules **10***b* to be interchanged and used with the main body **10***a*. All signal processing and calibration information is stored in the sensor module **10***b*, with a digital control interface to the main body **10***a*.

[0076] Sensor module **10***b* is comprised of a cylindrical housing **31**, having an upper half **31***a* and a lower half **31***b*. The two parts of housing **31** are screwed together, ultrasonically welded, glued, or otherwise attached.

[0077] The upper half **31***a* provides a platform for various sensors. In the embodiment of **FIG. 11**, sensor module **10***b* has a dry bulb sensor **33**, relative humidity sensor **34**, black globe sensor **35**, and wind speed sensor **36**. Thus, monitor **10** has three thermistors: dry bulb, black globe, and wind speed. Wet bulb globe temperature (WBGT) is obtained by measuring relative humidity with sensor **34** and the dry bulb temperature with sensor **33** and using a mathematical formula to determine wet bulb temperature. Alternatively, a dedicated wet bulb sensor could be used.

[0078] The dry bulb sensor **33**, globe sensor **35**, and wind speed sensor **36** are each located on a mast **33***a*, **35***a*, and **36***a*. These masts protrude perpendicular to the face of the cylindrical housing **31**. A removable light-shadowing housing **34***b* covers the humidity sensor **34**.

[0079] Sensor PCB (printed circuit board) **38** is contained within sensor housing **31**, between upper half **31***a* and the lower half **31***b*. Sensor PCB **38** contains the sensor electronics **50**, described below in connection with **FIG. 14**.

[0080] An atmospheric pressure sensor **37** is located inside sensor module **10***b*. In the embodiment of **FIG. 11** pressure sensor **37** is mounted on the underside of sensor PCB **38**.

[0081] At one end of sensor module **10***b* is a rotating connector **32**, which has a groove on its edge to allow it to rotate within cylindrical housing **31**. The upper half **31***a* and lower half **31***b* of housing **31** have mating ridges. An O-ring **32***b* is slipped onto the cylindrical housing **31**.

[0082] When rotating connector **32** is plugged into fixed connector **16**, there is a seated rotating connection between sensor module **10***b* and main body **10***a*. As a result of the rotating connector **32** and O-ring **32***b*, sensor module **10***b* is sealed from the effects of the environment. Alignment pins **32***c* provide strain relief for the connector pins and sockets when sensor module **10***b* is rotated.

[0083] Referring again to **FIGS. 9 and 10**, main body **10***a* has cavities into which the various sensors fit when sensor module **10***b* is rotated approximately 180 degrees into a "storage" position. The arrow is **FIG. 10** illustrates the direction of rotation. The hinged rear cover **22** is closed to protect the sensors when they are stored. Cover **22** can also be re-closed after it is opened and the sensors are deployed into their "operate" position.

[0084] As stated above in connection with **FIGS. 9 and 10** and as also illustrated in **FIG. 12**, main body **10***a* has an endpiece **15**. The endpiece **15** fits over a rotation knob **17** on sensor module **10***b*. It attaches to main body **10***a* and holds sensor module **10***b* in place. Endpiece **15** may be removed to permit sensor module **10***b* to be removed, such as for replacement or repair.

[0085] Discrete wires **32***d* from the rotating connector **32** are attached to the sensor PCB **38**. When the assembled sensor module **10***b* is attached to the main body **10***a*, rotating connector **32** is held in a fixed position with respect to the main body **10***a* by a mated connection. When the knob **17** is used to rotate the sensor module **10***b*, the upper half **31***a*, lower half **31***b*, and sensor PCB **38** rotates around the rotating connector **32**.

[0086] **FIGS. 13 and 14** are functional block diagrams of the electronics of the present invention. **FIG. 13** illustrates the main electronics **50** contained within main body **10***a*. **FIG. 14** illustrates the sensor electronics **60** contained within sensor module **10***b*. A serial digital interface **50***a* provides the electrical connection between main electronics **50** and sensor electronics **60**.

[0087] Main electronics **50** has a central processing unit (CPU) **51***a* with a peripheral system device (PSD) **51***b*. The PSD **51***b* provides address decode logic, additional static RAM and digital I/O ports, and a bootloader routine for the flash memory **53**. A static RAM **54** provides both scratchpad memory and nonvolatile storage for data logging applications. RAM **54** is backed up by a lithium battery **55**. The lithium battery **55** also maintains a real time clock **56**, which can be used for timestamping logged data. The graphics display **57** is addressed by the CPU **51***a* and uses a digital potentiometer **57***a* for contrast adjustment. The backlight control for the graphics display **57** is controlled by the PSD **51***b*. The keypad **52** is interfaced to digital I/O ports on the PSD **51***b*.

[0088] The system is powered by a DC power source, which may be either user-replaceable batteries placed in compartment **14***a* or an external power source.

[0089] An RS-232 converter **58** converts the TTL-level signals on the CPU board **10** to RS-232 signals for the external serial connector. The main body **10***a* of monitor **10** functions as an intelligent user interface containing the graphics display, keypad, power supply CPU and associated digital electronics. The main body also contains an external port that can be used to supply external power and communicate with a personal computer through an RS-232 interface. Software can also be loaded into the device through this port and stored in flash memory.

[0090] The connection between main body **10***a* and sensor module **10***b* provides battery power, supply voltage, and a digital control interface. All sensing electronics and storage for calibration and sensor identification information is located on the sensor module **10***b*. This allows sensor module **10***b* to be calibrated independently of the main body **10***a* and to produce the same results when attached to any main body **10***a*.

[0091] The design of monitor **10** permits different types of sensor modules to be used with the main body, whereby the sensor module **10***b* can be queried by the main body **10***a* to determine the type of each sensor and its calibration information. The application software in the main body **10***a* can then configure itself to acquire and display the sensor data. Alternatively, a dedicated application for a given type of sensor module **10***b* can be loaded into the flash memory **53** through an external port.

[0092] Referring to **FIG. 14**, the sensor electronics **60** contains signal conditioning circuitry for the dry bulb sensor **33**, the black globe sensor **35**, the relative humidity sensor **34**, the wind speed sensor **36**, and the pressure sensor **37**.

[0093] The analog voltages produced by the various sensors are digitized by the A/D converter **62**. A D/A converter **63** is used to provide current to the wind speed sensor **36** and to heat it to a constant temperature above the dry bulb temperature. The amount of power required to heat the wind speed sensor **36** is related to the wind speed.

[0094] An EEPROM **64** stores all calibration information related to the sensors **33-37**. The calibration information may include various calibration constants, unique to each sensor. In general, all circuitry and programming unique to any sensor is placed on sensor module **10***b* rather than in main body **10***a* so that sensor modules having the same, or different, sensors may be easily interchanged.

[0095] A/D converter **62**, D/A converter **63**, and EEPROM **64** all share the same serial control lines on the interface **50***a*, with the exception of their chip select signals. This minimizes the number of connections that need to be made between the CPU electronics **50** and the sensor electronics **60**.

[0096] Voltage regulator **65** produces a stepped-up voltage for the sensor electronics **60**. The battery voltage is delivered to the sensor electronics **60**, where it is input to a battery monitor **66**, whose output signal is converted to digital form by A/D converter **62**, and delivered back to the CPU electronics **60**. The location of battery monitor **66** in sensor electronics **60** is merely for convenience of using A/D converter **62**, and in other embodiments, battery monitor **66** could be part of CPU electronics **50**.

[0097] CPU **51***a* can be programmed to execute various environmental data processing algorithms. For example, when monitor **10** is used to heat stress monitoring, known heat strain models can be used. For example, a model based on the WBGT index may be used.

[0098] A feature of the invention is the incorporation of wind speed into heat strain models. As a result, the effect of evaporative cooling is considered in determining weather effects.

[0099] Measured parameter data acquired from sensor module **10***b* can be combined with user input parameter data acquired via keypad **12** or other means. Such parameters might include, clothing type, work type, or work rate.

[0100] As stated above, monitor **10** can be easily adapted for use with other or additional sensors. For example, one sensor might be an air quality sensor, such as one that measures oxygen content or one or more pollutants. Or, a sensor might measure noise. Other sensors might measure the user's physiological conditions, such as heart rate, blood pressure, or body temperature (skin or core). For physiological monitoring, sensors such as used by athletes could be used—for example, a heart rate monitor that attaches to the user's finger and provides input to the A/D converter **62** of sensor module **10***b* or directly to the processor **51** of the main body **10***a*.

[**0101**] Although the invention has been described with reference to specific embodiments, this description is not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternative embodiments, will be apparent to persons skilled in the art. It is, therefore, contemplated that the appended claims will cover all modifications that fall within the true scope of the invention.

What is claimed is:

1. A portable environmental heat stress monitor, comprising:

a main housing having a front piece and a rear cover;

a sensor module operable to move from a sensor deployed position to a sensor storage position;

a plurality of sensors attached to the sensor module, each sensor mounted on a mast, such that the sensors extend outwardly from the main housing when the sensor module is in the deployed position and rest in the main housing when the sensor module is in the storage position, the sensors including at least a humidity sensor and a wind speed sensor;

a main electronics circuit contained within the main housing, operable to process data acquired by the sensors and to provide heat stress data output that incorporates wind speed as a parameter;

a sensor electronics circuit contained within the sensor module;

a display viewable at the outer surface of the main housing for providing read out information; and

a keypad for receiving input from a user.

2. A portable environmental heat stress monitor comprising:

a main housing;

a cover hingedly connected to said main housing;

a sensor module disposed in said cover, said sensor module including a planar base;

a plurality of sensors, each sensor mounted on a mast, the mast being pivotally attached to the planar base such that each sensor extends substantially orthogonally from the planar base in deployed position and such that each sensor is disposed substantially parallel to the planar base in a storage position, the sensors including at least a humidity sensor and a wind speed sensor;

a central processing unit in communication with said plurality of sensors to receive input signals from at least one of said plurality of sensors; and

an input device that transmits environmental stress parameter inputs to said central processing unit whereby said central processing unit computes work/rest cycles responsive to the sensor input signals and the environmental stress parameters.

3. The monitor of claim 2, wherein the sensors include an ambient temperature sensor and a humidity sensor.

4. The monitor of claim 2, wherein the sensors include a black globe sensor.

5. The monitor of claim 2, wherein the sensors include a wind speed sensor.

6. The monitor of claim 2, further comprising an atmospheric pressure sensor within the sensor module.

* * * * *

专利名称(译)	环境热应激监测仪		
公开(公告)号	US20020009119A1	公开(公告)日	2002-01-24
申请号	US09/780571	申请日	2001-02-12
[标]申请(专利权)人(译)	MATTHEW WILLIAMt STROSCHEIN LEANDER一个 麦克格拉斯约瑟夫M		
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摘要(译)

提供便携式压力监测器，用于监测发生生理活动的条件。监测的条件可以是环境，例如环境温度和湿度，或生理，例如心率或体温。监视器包括主体部分和铰接盖。铰接盖包括可拆卸的传感器模块。一个或多个传感器附接到传感器模块，每个传感器可枢转地安装在桅杆上，使得当传感器模块处于展开位置时传感器从铰接盖向外延伸并且可以枢转以基本上与当传感器模块处于存放位置时，铰接盖。中央处理单元包含在主体内，并且可操作以根据热应变算法处理由传感器获取的数据。显示器附接到主体的外表面以提供读出信息，并且提供输入装置用于用户输入。