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Sadana

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(54) **ASSET-SPECIFIC EQUIPMENT HEALTH MONITORING (EHM) FOR INDUSTRIAL EQUIPMENT USING STANDARDIZED ASSET MODELS**

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CPC ***F02C 9/00*** (2013.01); *F05D 2260/80* (2013.01); *F05D 2270/70* (2013.01); ***F01D 21/003*** (2013.01)
USPC **340/539.1**; 340/3.42; 340/3.43; 340/3.44; 714/40; 714/735; 714/736; 714/737

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See application file for complete search history.

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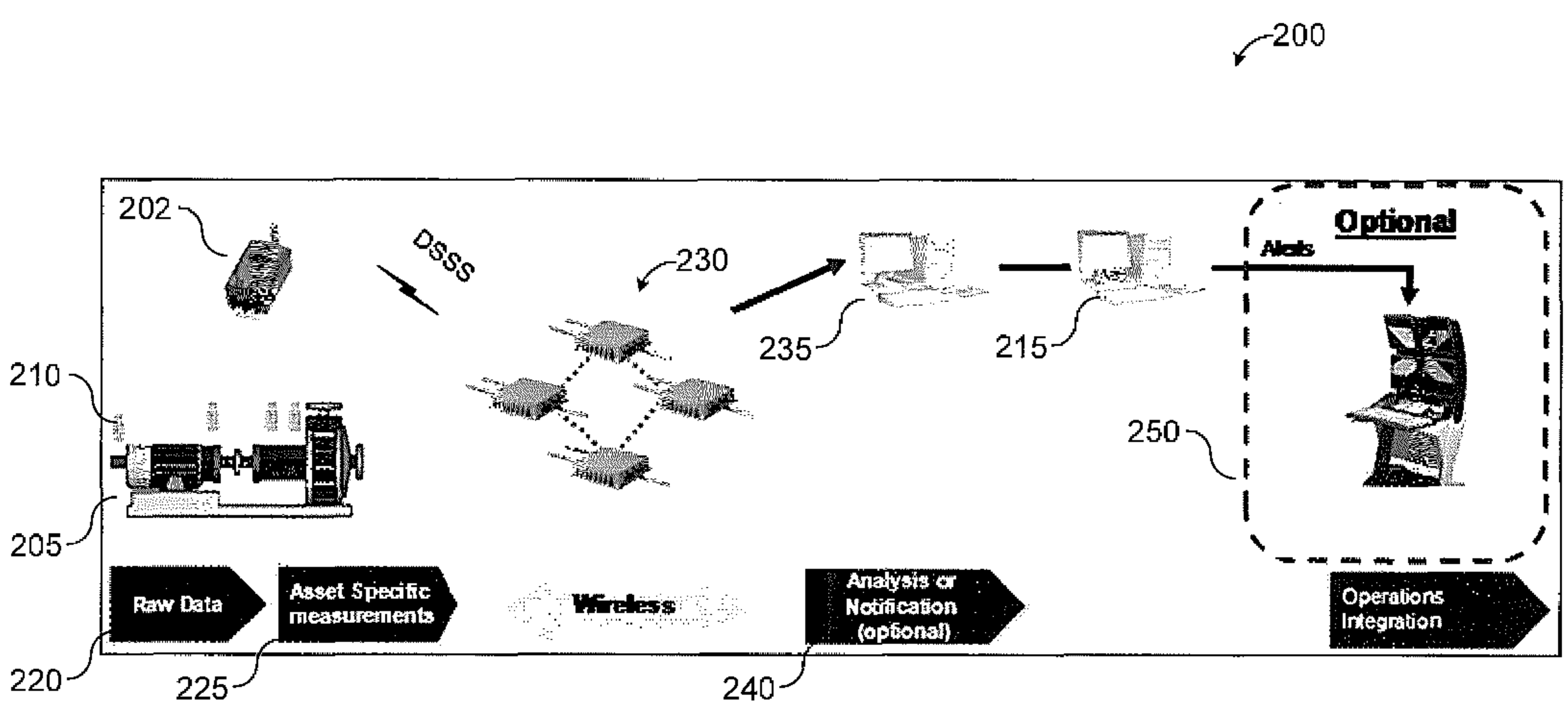
(57) **ABSTRACT**

A system includes at least one sensor and an equipment health monitoring (EHM) unit. The at least one sensor is configured to measure one or more characteristics of an asset, where the asset includes a piece of equipment. The EHM unit includes at least one sensor interface configured to receive at least one input signal associated with the asset from the sensor(s). The EHM unit also includes at least one processing unit operable to be pre-configured to identify a specified fault in the asset using the input signals and an asset-specific model that includes a combination of standard subsystem models. The EHM unit further includes at least one output interface configured to provide an indicator identifying the fault. The standard subsystem models could include standardized fault models configured to identify faults for standard assets.

20 Claims, 3 Drawing Sheets



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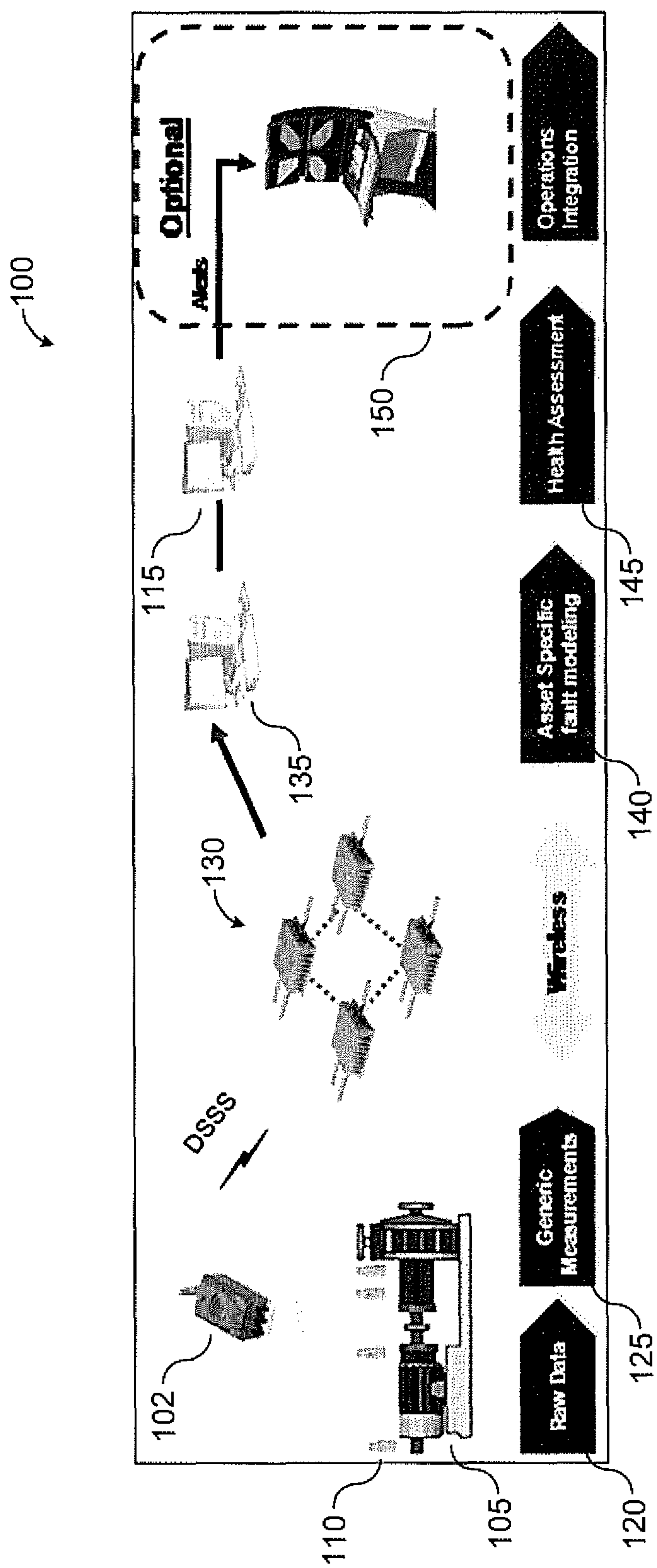
100
102
110
105
120
125
130
135
115
140
145
150
DSSS
Wireless
Alerts
Optional
Raw Data
Generic Measurements
Asset Specific fault modeling
Health Assessment
Operations Integration

FIGURE 1

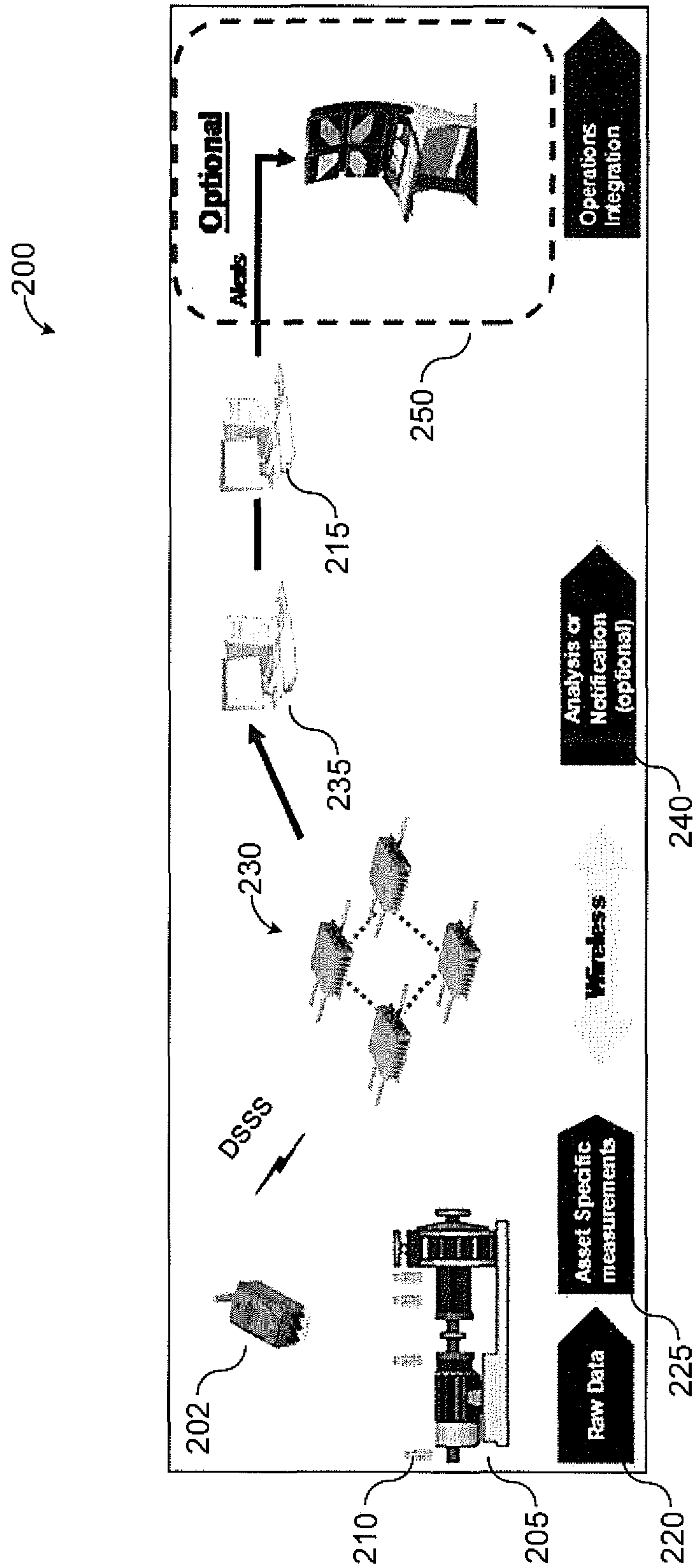
200
Optional
Alerts
Operations Integration
250
215
235
230
Analysis or Notification (optional)
240
Wireless
DSSS
Asset Specific measurements
225
Raw Data
220
202
210
205

FIGURE 2

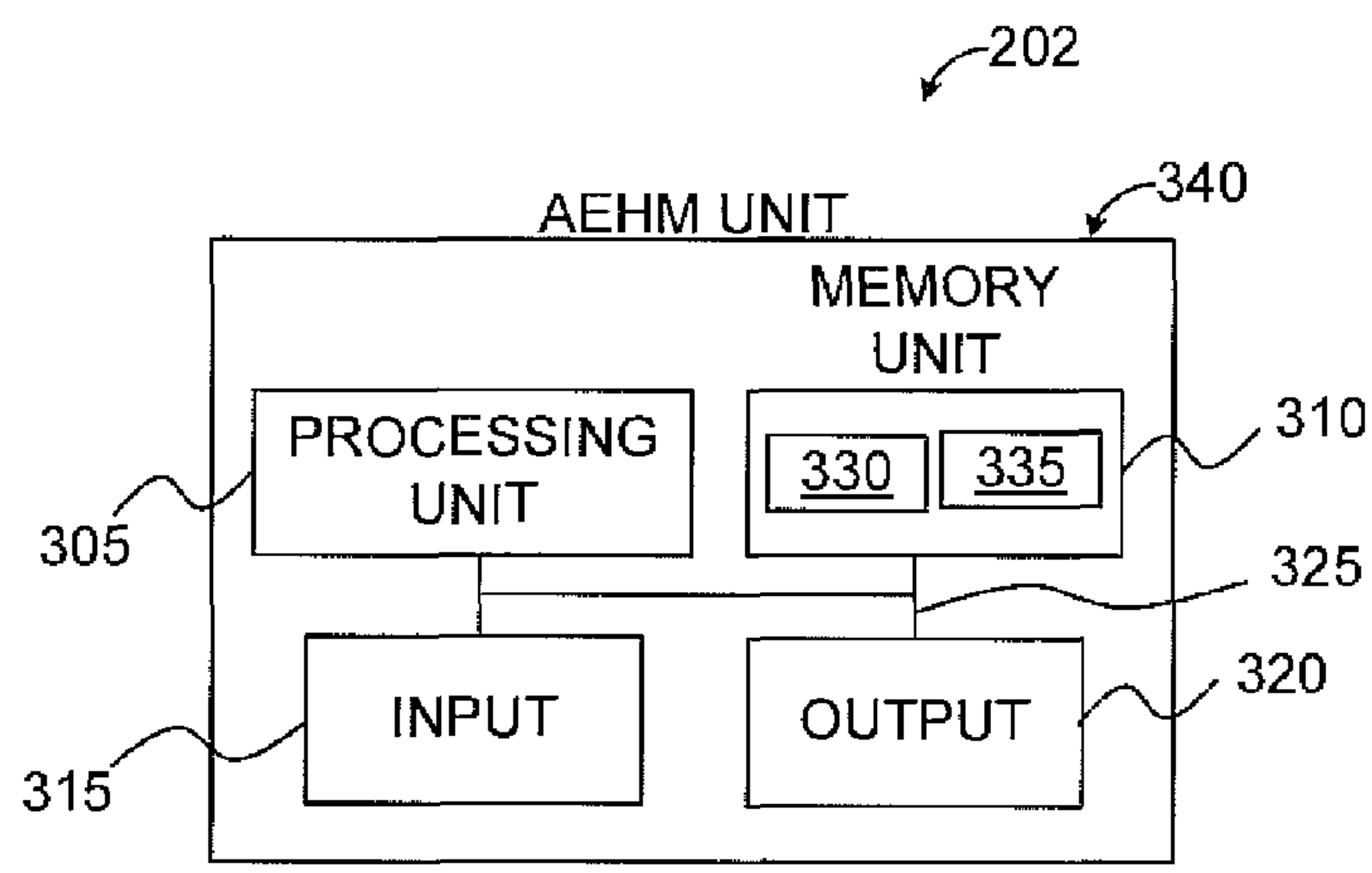

FIGURE 3

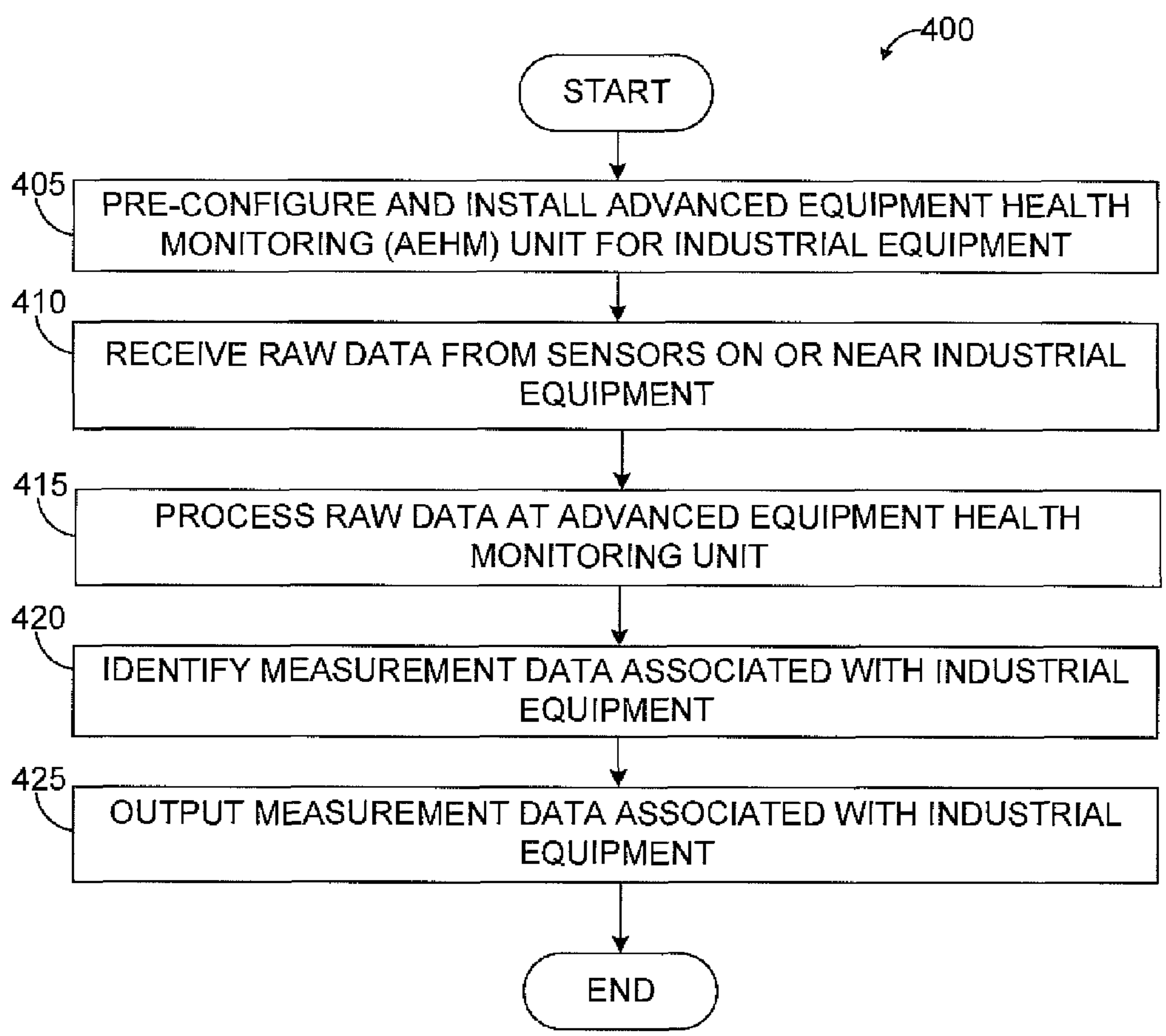

FIGURE 4

ASSET-SPECIFIC EQUIPMENT HEALTH MONITORING (EHM) FOR INDUSTRIAL EQUIPMENT USING STANDARDIZED ASSET MODELS

TECHNICAL FIELD

This disclosure relates generally to industrial equipment. More specifically, this disclosure relates to asset-specific equipment health monitoring (EHM) for industrial equipment using standardized asset models.

BACKGROUND

A wide variety of industrial equipment is used in virtually every industry around the world. For example, rotating equipment, such as gearboxes, are widely used in virtually any industry. As specific examples, gearboxes are often used in speed reduction and power transmission applications. A gearbox can be a single-stage gearbox or a multi-stage gearbox. A gearbox also typically includes external gearing, internal gearing, and rack and pinion gearing.

Because of this wide use, many industries are concerned with equipment failures. For example, one survey found that gearbox failures account for 34% of all failure modes (such as fatigue) in aircraft. Another survey revealed that gearbox failures account for 15% of all failures in a certain industry. Equipment failures typically result in lost revenues due to plant downtime. Accordingly, detecting potential failures (such as faults) in a gearbox or other equipment at an early stage can assist in preventing secondary damage, save maintenance costs, improve plant uptimes, reduce potential financial losses from plant downtime, and assist towards increasing productivity.

Monitoring the health of equipment is typically a time-consuming process in which a specialist custom builds a model for each asset. The specialist often specifies where to install monitoring points on the equipment, specifies how one or more sensors should be mounted, and enters the installed points in modeling software. This process allows extremely precise models to be built, which are specific to particular assets. This also allows for health monitoring hardware and wiring to be optimized.

Since this process is performed separately on each piece of equipment, however, the process is very time-consuming and costly. Even with improvements in modeling and wireless communication technologies, modeling an asset typically remains costly and can discourage the adoption of monitoring equipment on a wide scale basis.

SUMMARY

This disclosure provides a system and method for asset-specific equipment health monitoring (EHM) for industrial equipment using standardized asset models.

In a first embodiment, an apparatus includes at least one input interface configured to receive at least one input signal associated with an asset, where the asset includes a piece of equipment. The apparatus also includes at least one processing unit operable to be pre-configured to identify a specified fault in the asset using the at least one input signal and an asset-specific model that includes a combination of standard subsystem models. The apparatus further includes at least one output interface configured to provide an indicator identifying the fault.

In a second embodiment, a system includes at least one sensor and an equipment health monitoring (EHM) unit. The at least one sensor is configured to measure one or more characteristics of an asset, where the asset includes a piece of equipment. The EHM unit includes at least one sensor interface configured to receive at least one input signal associated with the asset from the at least one sensor. The EHM unit also includes at least one processing unit operable to be pre-configured to identify a specified fault in the asset using the at least one input signal and an asset-specific model that includes a combination of standard subsystem models. The EHM unit further includes at least one output interface configured to provide an indicator identifying the fault.

In a third embodiment, a method includes pre-configuring an equipment health monitoring (EHM) unit with an asset-specific model that includes a combination of standard subsystem models that model an asset, where the asset includes a piece of equipment. The method also includes receiving at least one input signal having measurement data associated with the asset. The method further includes analyzing the at least one input signal to determine if a specified fault has occurred and outputting an indicator identifying the specified fault when it is determined that the specified fault has occurred.

Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates an example custom-built equipment health monitoring (EHM) system;

FIG. **2** illustrates an example asset-specific EHM system using standardized asset models according to this disclosure;

FIG. **3** illustrates an example advanced equipment health monitoring (AEHM) unit according to this disclosure; and

FIG. **4** illustrates an example process for asset-specific EHM for industrial equipment using standardized asset models according to this disclosure.

DETAILED DESCRIPTION

FIGS. **1** through **4**, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the invention may be implemented in any type of suitably arranged device or system.

FIG. **1** illustrates an example custom-built equipment health monitoring (EHM) **100** system. In the example shown in FIG. **1**, an EHM unit **102** monitors industrial equipment **105**. One or more sensors **110** measure one or more characteristics of the industrial equipment **105**. The EHM unit **102** is generic hardware, meaning the same EHM unit **102** can be utilized for a variety of different types of industrial equipment **105**. A specialist can determine a deployment location for the EHM unit **102** so that the EHM unit **102** is located near a target asset, and the EHM unit **102** can receive measurements from the sensors **110**. The EHM unit **102** then sends generic measurements to analysis software **115**. The specialist typically designs and builds asset-specific models corresponding to the specific industrial equipment **105**, and the analysis software **115** uses those models to analyze the data from the EHM unit **102**. The specialist often builds the asset models in software based on the specific assets (industrial equipment **105**) and the specific fault(s) that a customer wants to monitor.

In FIG. **1**, the EHM unit **102** transfers the generic measurements to the analysis software **115**. However, the EHM unit **102** is not aware of the specific asset being monitored or the faults for which the EHM unit **102** is being used to detect. The EHM unit **102** simply receives raw data **120** from the sensors **110** and outputs the raw data **120** as generic measurements **125**. The EHM unit **110** sends the generic measurements **125** via a wired or wireless network **130** to a processing server **135**, which can execute the analysis software **115** with custom-built asset models. The processing server **135** performs asset-specific fault modeling **140** using the asset models to generate a health assessment **145** of the industrial equipment **105**. Thereafter, one or more alerts can optionally be triggered and provided to a user interface **150**.

As noted above, setup of the system **100** typically requires the use of a specialist to place the sensors **110** on or around the industrial equipment **105** and to generate the asset-specific models used by the analysis software **115**. As a result, it is often costly and time consuming to set up and maintain the system **100**.

FIG. **2** illustrates an example asset-specific EHM system **200** using standardized asset models according to this disclosure. In this example, the system **200** includes an advanced EHM (AEHM) unit **202**, industrial equipment **205**, and one or more sensors **210**. The industrial equipment **205** includes any suitable piece(s) of equipment used to perform at least one physical operation in an industrial processing or production facility. The industrial equipment **205** could include rotating equipment, such as a gearbox, a pump system having an impeller, or other rotating components. Each of the sensors **210** includes any suitable structure for measuring one or more characteristics of the industrial equipment **205**, such as vibration, motor current, noise, speed, or other characteristic(s). In some embodiments, one or more of the sensors **210** are accelerometers, and the sensors **210** can capture spectral or time waveform-based measurements.

The AEHM unit **202** is pre-configured to detect specific faults according to the specific type of equipment to be monitored. In other words, rather than outputting generic measurements, the AEHM unit **202** performs various processing operations using raw data **220** to generate asset-specific measurements **225**. As a particular example, the AEHM unit **202** could be configured to detect gear wear in a gearbox, and the AEHM unit **202** can include processing to perform monitoring as disclosed in U.S. patent application Ser. No. 12/417,475; U.S. patent application Ser. No. 12/417,452; and U.S. patent application Ser. No. 12/503,783 (all of which are hereby incorporated by reference).

The AEHM unit **202** includes one or more standardized asset models for assets to be monitored. In some embodiments, through processing techniques and the use of embedded software, the AEHM unit **202** uses built-in asset specific models to model and identify various faults. Also, in some embodiments, the AEHM unit **202** can communicate over both wired and wireless networks **230** and is adapted for use with multiple types of industrial equipment **205**, such as pumps, compressors, turbines, fans, motors, agitators, and fixed equipment like transformers. The embedded models use subsystem modeling-based methodology, where the embedded models are used to build an asset-specific model by a combination of subsystem models.

In some embodiments, the AEHM unit **202** can be pre-configured to monitor faults of a specific type of asset or for a specific asset. The AEHM unit **202** then receives raw data **220** from the one or more sensors **210**, processes the raw data **220** using the embedded software to detect specific faults, and outputs the measurements **225**. For example, the AEHM unit **202** may perform an FFT analysis to detect a specific fault corresponding to a particular type of equipment, such as gear wear in a gearbox. The AEHM unit **202** then outputs the asset-specific measurements **225**, which can include information that indicates the presence or absence of a fault and other information about any detected fault. The measurements **225** can be sent to a processing device **235** or other remote device for further analysis. The processing device **235** could represent any suitable computing device or other processing device, such as a desktop, laptop, or server computer having one or more processors, one or more memories, and one or more network interfaces.

The processing device **235** could execute analysis software **215** or otherwise make the measurements **225** available to the analysis software **215**. The analysis software **215** could analyze the asset-specific measurements and identify any faults, at which point the analysis software **215** could trigger an alarm to a user interface **250**, such as a distributed control system (DCS) or OLE for Process Control (OPC) interface. The analysis software **215** may not require the use of asset-specific models since the AEHM unit **202** performs subsystem modeling of the specific industrial equipment **205**. As a result, the analysis software **215** could simply check whether the AEHM unit **202** has detected a problem and raise an alarm if necessary.

Although FIG. **2** illustrates one example of an asset-specific EHM system **200** using standardized asset models, various changes may be made to FIG. **2**. For example, the system **200** could include any number of AEHM units **202**, equipment **205**, sensors **210**, networks **230**, processing devices **235**, analysis software **215**, and user interfaces **250**. Also, the functional division shown in FIG. **2** is for illustration only. Various components in FIG. **2** could be combined, further subdivided, or omitted and additional components could be added according to particular needs. As a specific example, the analysis software **215** could be combined with the processing device **235** or the user interface **250**, or the analysis software **215** could be executed closer to the industrial equipment **205**.

FIG. **3** illustrates an example AEHM unit **202** according to this disclosure. In FIG. **3**, the AEHM unit **202** can be formed using any device capable of receiving, processing, and transmitting signals via wireless and/or wired communication links. The AEHM unit **202** in this example includes at least one processing unit **305**, at least one memory unit **310**, at least one input unit **315**, and at least one output unit **320**. The processing unit **305** includes any suitable processing device(s), such as a microprocessor, digital signal processor, field programmable gate array, or application specific integrated circuit. The memory unit **310** includes any suitable volatile and/or non-volatile storage and retrieval device(s). The input unit **315** includes any suitable structure(s) for receiving input data, such as one or more sensor interfaces for receiving data from one or more sensors **210**. The output unit **320** includes any suitable structure(s) for providing output data, such as a wireless interface or one or more Ethernet or other wired network interfaces. The components **305-320** can be interconnected by one or more communication links **325** (such as a bus).

It is understood that the AEHM unit **202** may be configured differently and that each of the listed components **305-325** may actually represent several different components. For example, the processing unit **305** may represent a multiprocessor processing system or a distributed processing system, and the memory unit **310** may include different levels of cache memory, main memory, hard disks, and remote storage locations (each of which can be fixed or removable). The input unit **315** may also include touch screens, keyboards, and the like.

The memory unit **310** in this example includes analysis software **330** or other code for execution by the processing unit **305**, where the analysis software **330** can analyze the raw data **220** and generate the measurements **225**. The analysis software **330** can use models **335**, which include embedded subsystem models that are combined in order to build an asset-specific model. As a particular example, a pump system can be modeled using an impeller model, a shaft model, a bearings model, and a motor model. The combination of subsystem models that are used to create an asset-specific model can be defined in any suitable manner, such as by personnel familiar with the industrial equipment **205** (but who do not require specialized expertise in order to create the asset-specific model).

The AEHM unit **202** further includes a housing **340** configured to contain the other components **305-325**. Note that portions of the input unit **315** and output unit **320** could be contained within the housing **340**, while other portions are accessible from outside of the housing **340**. The housing **340** can be dimensioned and constructed to be coupled to or placed near an asset to be monitored.

Although FIG. **3** illustrates one example of an AEHM unit **202**, various changes may be made to FIG. **3**. For example, while the AEHM unit **202** is shown using a processing unit **305** and a memory unit **310** that includes program code, other embodiments of the AEHM unit **202** could be used. As a specific example, the AEHM unit **202** could be implemented with fixed or programmable logic configured to perform the techniques described above.

FIG. **4** illustrates an example process **400** for asset-specific EHM for industrial equipment using standardized asset models according to this disclosure. As shown in FIG. **4**, an AEHM unit is pre-configured and installed for specific industrial equipment at step **405**. The pre-configuration could include, for example, adding custom routines to firmware of the AEHM unit **202** to enable the EHM unit **202** to specialize in monitoring faults of a certain type of asset or for a certain asset. This pre-configuration can be done at any suitable time, such as on the manufacturer's factory floor when the EHM unit **202** is created or at a distribution center. The pre-configured EHM unit **202** can then be deployed on or near the asset.

Once the EHM unit is installed, the EHM unit can start monitoring for the specific faults, possibly as soon as the unit is turned on. At that point, the EHM unit receives raw data from one or more sensors on or near the industrial equipment at step **410**, processes the raw data at step **415**, and generates asset-specific measurements at step **420**. As noted above, this could include the EHM unit **202** performing FFT or other processing, which is based on the customization of the EHM unit **202**. At that point, the asset-specific measurements can be output at step **425**, such as by transmitting the measurements over a wired or wireless connection to an intended destination.

Utilizing the AEHM unit **202**, configuration time can be greatly reduced, saving both time and money. The AEHM unit **202** can also utilize standard fault models for standard assets, and dedicated external analysis software **215** may not be required. For instance, by pre-configuring the AEHM unit **202**, a specialist is not required to custom-build an application to analyze the measurement data, yet the AEHM unit **202** can still be optimized to monitor certain faults.

Although FIG. **4** illustrates one example of a process **400** for asset-specific EHM for industrial equipment using standardized asset models, various changes may be made to FIG. **4**. For example, various steps in FIG. **4** could overlap, occur in parallel, or occur multiple times.

In some embodiments, various functions described above are implemented or supported by a computer program that is formed from computer readable program code and that is embodied in a computer readable medium. The phrase "computer readable program code" includes any type of computer code, including source code, object code, and executable code. The phrase "computer readable medium" includes any type of medium capable of being accessed by a computer, such as read only memory (ROM), random access memory (RAM), a hard disk drive, a compact disc (CD), a digital video disc (DVD), or any other type of memory.

It may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The terms "transmit," "receive," and "communicate," as well as derivatives thereof, encompass both direct and indirect communication. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrases "associated with" and "associated therewith," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like.

While this disclosure has described certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

What is claimed is:

1. An apparatus comprising:

at least one input interface configured to receive at least one input signal associated with an asset, the asset comprising a piece of equipment;

at least one processing unit operable to be pre-configured to identify a specified fault in the asset using the at least one input signal and an asset-specific model that comprises a combination of standard subsystem models, wherein the fault represents damage to the asset; and

at least one output interface configured to provide an indicator identifying the fault.

2. The apparatus of claim **1**, further comprising:

a housing configured to hold the at least one input interface, the at least one processing unit, and the at least one output interface.

3. The apparatus of claim **1**, further comprising:

at least one memory unit configured to store the asset-specific model.

4. The apparatus of claim **1**, wherein the standard subsystem models comprise standardized fault models configured to identify faults for standard assets.

5. The apparatus of claim **1**, wherein the at least one input signal comprises raw data from at least one sensor.

6. The apparatus of claim **1**, wherein the at least one output interface is configured to transmit the indicator identifying the fault to a remote device via a wireless interface.

7. The apparatus of claim **1**, wherein the asset comprises one of: a pump, a compressor, a turbine, a fan, a motor, an agitator, and a transformer.

8. A system comprising:

at least one sensor configured to measure one or more characteristics of an asset, the asset comprising a piece of equipment; and

an equipment health monitoring (EHM) unit comprising:

at least one sensor interface configured to receive at least one input signal associated with the asset from the at least one sensor;

at least one processing unit operable to be pre-configured to identify a specified fault in the asset using the at least one input signal and an asset-specific model that comprises a combination of standard subsystem models, wherein the fault represents damage to the asset; and

at least one output interface configured to provide an indicator identifying the fault.

9. The system of claim **8**, wherein the EHM unit further comprises a housing configured to hold the at least one input interface, the at least one processing unit, and the at least one output interface.

10. The system of claim **8**, wherein the EHM unit further comprises at least one memory unit configured to store the asset-specific model.

11. The system of claim **8**, wherein the standard subsystem models comprise standardized fault models configured to identify faults for standard assets.

12. The system of claim **8**, wherein the at least one output interface is configured to transmit the indicator identifying the fault to a remote device via a wireless interface.

13. The system of claim **8**, wherein the asset comprises one of: a pump, a compressor, a turbine, a fan, a motor, an agitator, and a transformer.

14. The system of claim **8**, wherein the EHM unit further comprises at least one memory unit configured to store software or firmware instructions executed by the at least one processing unit, the software or firmware instructions configured to identify the specified fault in the asset using the at least one input signal.

15. The system of claim **8**, wherein the at least one sensor comprises at least one accelerometer.

16. A method comprising:

pre-configuring an equipment health monitoring (EHM) unit with an asset-specific model that comprises a combination of standard subsystem models that model an asset, the asset comprising a piece of equipment;

receiving at least one input signal comprising measurement data associated with the asset;

analyzing the at least one input signal to determine if a specified fault has occurred wherein the fault represents damage to the asset; and

outputting an indicator identifying the specified fault when it is determined that the specified fault has occurred.

17. The method of claim **16**, wherein outputting the indicator comprises wirelessly transmitting the indicator to a remote device.

18. The method of claim **17**, further comprising:

wirelessly transmitting additional asset-related information along with the indicator.

19. The method of claim **16**, wherein the standard subsystem models comprise standardized fault models configured to identify faults for standard assets.

20. The method of claim **16**, wherein the asset comprises one of: a pump, a compressor, a turbine, a fan, a motor, an agitator, and a transformer.

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