

A SENSOR DEVICE

Field of the Invention

5 The invention relates to a sensor device for sensing operational characteristics of a component in an industrial facility, such as a vibration and a temperature characteristic of a component in an LNG plant, to a sensor network that includes a plurality of such sensor devices, and to a method of sensing operational characteristics of a component in an industrial facility.

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Background of the Invention

It is known to provide a sensor device for sensing an operational characteristic, such as vibration and temperature, of a component in an industrial facility, and typically such a sensor device is arranged to communicate captured temperature and vibration signals to a remote facility for analysis. Typically, such devices use conventional cabling, or wireless communication arrangements for example based on 802.11x, LTE or 802.15.4 protocols, to communicate the signals, at least in the vicinity of the industrial facility.

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Existing sensor devices for sensing operational characteristics are typically required to be relatively sophisticated because the amount of captured data that is required to be communicated is large. Existing sensor devices also tend to be expensive and tend to consume relatively large amounts of power to the extent that the devices have a life span of the order of 2 years, and in some instances several months, which is a significant burden in an industrial facility because a large number of sensor devices are typically used

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In addition, conventional communication cabling and communication devices based on 802.11x, LTE or 802.15.4 protocols are expensive to the extent that provision of sensor devices in an industrial facility becomes cost prohibitive because of the infrastructure required to support a large number of devices.

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Furthermore, wireless communication arrangements based on protocols such as 802.11x have a relatively high carrier frequency (typically 2.4GHz), and associated limited range (typically less than 100m) and low penetration

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characteristics through obstacles, particularly metallic obstacles. This is highly undesirable in a typical industrial facility that includes many metallic obstacles.

Existing sensor devices for sensing an operational characteristic of a component in an industrial facility are therefore expensive, inefficient and problematic to implement.

Summary of the Invention

10 In accordance with a first aspect of the present invention, there is provided a sensor device comprising:

a sensor arranged to produce time domain data representative of a sensed time dependent characteristic adjacent the sensor;

15 a signal processing component, the signal processing component arranged to use the time domain data to produce frequency domain data indicative of frequency components present in the time domain data; and

a data transmission component arranged to transmit a portion of the frequency domain data;

20 wherein the sensor device is arranged to select a subset of frequency domain data from the frequency domain data based on defined criteria and to transmit the selected subset of frequency domain data.

In an embodiment, the selected subset of frequency domain data corresponds to a defined number of frequency peaks in the frequency domain data.

25 In an embodiment, the selected subset of frequency domain data corresponds to a defined number of the highest frequency peaks in the frequency domain data.

30 In an embodiment, the sensor is arranged to transmit the selected subset of frequency domain data in a single data packet for at least some instances of data capture wherein time domain data is produced.

35 In an embodiment, the defined number of frequency peaks is determined according the amount of data that can be included in the single data packet.

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In an embodiment, the selected subset of frequency domain data corresponds to the highest 33 frequency peaks in the frequency domain data.

5 In an embodiment, the sensor device is also arranged to transmit other data in addition to the selected subset of frequency domain data.

In an embodiment, the amount of other data is determined according the amount of data that can be included in a single data packet.

10 In an embodiment, the other data includes any one or more of the following:
maximum peak acceleration amplitude;
minimum peak acceleration amplitude;
mean acceleration amplitude;
time domain acceleration crest factor;
15 frequency domain rms value;
frequency domain positive peak mean value;
frequency domain negative peak mean value;
peak velocity data values derived by integrating the acceleration
frequency domain data, for example wherein each velocity value is the or one
20 of several maximum values in a bin of a set of bins; and/or
turning speed of a rotatable part of a component to which the sensor is
attached.

25 In an embodiment, the sensor is arranged to produce time domain vibration data representative of vibrations adjacent the vibration sensor.

In an embodiment, the sensor is arranged to produce time domain acceleration data, time domain velocity data and/or time domain displacement data.

30 In an embodiment, the data transmission component is arranged to use a LPWAN protocol. The LPWAN protocol may be a LoRaWAN protocol.

35 In an embodiment, the sensor device includes an external memory separate to the signal processing component and the data transmission component, the sensor device arranged to store the time domain data in the external memory and to load the time domain data into the signal processing component for processing. The sensor device may be arranged to load successive portions of

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the time domain data into the signal processing component so that the time domain data can be processed in several batches.

5 In an embodiment, the selected subset of frequency domain data is selected from a defined frequency band.

10 In an embodiment, the sensor device comprises a power manager arranged to control provision of power to at least one sensor device component based on defined power management criteria. The at least one sensor device component may comprise the sensor, at least one sensor port, an external memory separate to the signal processing component and the data transmission component, and/or a reprogramming port.

15 In an embodiment, the defined power management criteria may cause power to at least one of the sensor device components to be disconnected when the at least one sensor device component is not being used.

20 In an embodiment, the defined power management criteria defines wake up and sleep times whereby power to at least one of the sensor device components is caused to be connected during wake time and power to the at least one of the sensor device components is caused to be disconnected during sleep time.

25 In an embodiment, the sensor device includes at least one power switch responsive to an activation signal from the power manager, the power switch arranged to cause power to be provided to at least one of the sensor device components in response to the activation signal and to cause power to not be provided to at least one of the sensor device components in absence of the activation signal. The at least one power switch may comprise at least one FET
30 that may be a MOSFET.

35 In an embodiment, the power manager is arranged to control transmission of frequency domain data by the data transmission component according to defined criteria so as to control usage of the data transmission component.

In an embodiment, the power manager is arranged to progressively fill a buffer with data until the amount of data in the buffer is sufficient to fill a payload of a

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data packet used by the data transmission component, and to cause the data in the buffer to be sent by the data transmission component when sufficient data is present in the buffer.

- 5 In an embodiment, the power manager is arranged to send the data irrespective of whether there is sufficient data to fill a data packet if at least one defined criterion is met.

10 The at least one defined criterion may include a maximum and/or minimum permissible value associated with a sensor, and the power manager may be arranged such that if a current value associated with the sensor exceeds the maximum or minimum value, the current value is transmitted.

15 The at least one defined criterion may include a maximum permissible difference value associated with a sensor, the permissible difference value representing a difference amount between a current value and a corresponding previous value, and the power manager arranged such that if a current difference value exceeds the maximum difference value, the current value is transmitted.

20 In an embodiment, the sensor device is arranged to transmit a heartbeat communication to indicate that a monitored component is operating as expected based on received sensor values, and to send frequency domain data if the at least one defined criterion is met.

25 In an embodiment, the signal processing component is arranged to carry out a fast Fourier transform (FFT) process to produce FFT data using the time domain data.

30 The sensor device may comprise a sampler arranged to produce time domain data samples, the signal processing component arranged to use the time domain data samples to produce frequency domain data indicative of frequency components present in the time domain samples.

35 In an embodiment, the sensor device comprises at least one further sensor, the data transmission component arranged to transmit at least a portion of sensor

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data derived from the at least one further sensor. The at least one further sensor may include a temperature sensor.

5 In an embodiment, the sensor comprises an accelerometer that may be arranged to sense vibrations in 3 mutually orthogonal axes.

In an embodiment, the accelerometer is arranged to produce time domain data indicative of acceleration, velocity or displacement.

10 In an embodiment, the sensor device includes a processor that may form part of a system on chip (SoC) device, the SoC device including the data transmission component.

15 In an embodiment, the sensor device comprises a decoder to multiplex between data inputs of the SoC device and components of the sensor device.

In an embodiment, the sensor device includes a machine-readable code indicative of a unique identifier associated with the sensor device. The machine-readable code may include a QR code.

20 In an embodiment, components of the sensor device are encapsulated such that the components are isolated from ambient conditions.

25 In an embodiment, the sensor device includes an intrinsically safe switch arranged to control provision of power from a battery to all electrical components of the sensor device. The intrinsically safe switch may include a reed switch and a magnet that is receivable in a recess disposed adjacent the reed switch, wherein when the magnet is not received in the recess, the reed switch is closed, and when the magnet is received in the recess, the magnetic
30 force provided by the magnet causes the reed switch to open.

In an embodiment, the sensor device comprises at least one magnetic portion, such as a magnetic foot, for attaching the sensor device to an industrial facility component.

35 In accordance with a second aspect of the present invention, there is provided a sensor network comprising:

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a plurality of sensor devices according to the first aspect of the present invention;

a communications network capable of facilitating data transmissions from the data transmission components of the sensor devices; and

5 a remote facility in network communication with the plurality of sensor devices through the communications network such that the data transmissions from the data transmission components are receivable at the remote facility.

In accordance with a third aspect of the present invention, there is provided a method of sensing an operational characteristic of a component using a sensor device, the method comprising:

disposing the sensor device on the component;

10 providing the sensor device with a sensor arranged to produce time domain data representative of a sensed time dependent characteristic adjacent the sensor;

using a signal processing component of the sensor device to produce frequency domain data using the time domain data, the frequency domain data indicative of frequency components present in the time domain data;

15 transmitting a portion of the frequency domain data using a data transmission component of the sensor device;

wherein the sensor device is arranged to select a subset of frequency domain data from the frequency domain data and to transmit the selected subset of frequency domain data.

25 Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

30 Figure 1 is a diagrammatic representation of a sensor device in accordance with an embodiment of the present invention;

Figure 2 is a diagrammatic cross-sectional view of the sensor device of Figure 1 showing an intrinsically safe switch;

Figure 3 is a diagrammatic representation of a sensor network according to an embodiment of the present invention, the sensor network including multiple sensor devices shown in Figures 1 and 2;

35 Figure 4 is a block diagram illustrating components of the sensor device shown in Figures 1 and 2;

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Figure 5 is a diagrammatic representation of functional components of and functional components implemented by a processor of the sensor device shown in Figures 1 and 2;

5 Figures 6a to 6c show raw sample vibration data captured from a 3-axis accelerometer;

Figures 7a to 7c show FFT data obtained from the raw sample vibration data shown in Figures 6a to 6c; and

Figure 8 is a flow diagram illustrating a process of operation of the sensor device shown in Figures 1 to 5.

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Description of an Embodiment of the Invention

Referring to the drawings, in Figure 1 there is shown a sensor device 10 suitable for use in an industrial facility to obtain operational characteristics of a component in the industrial facility, in this example vibration and temperature characteristics of a component in an LNG plant. Such components may include, for example, components that incorporate at least one moving part including compressors, pumps, motors and fans; heat exchangers; switch gear; and structural monitoring devices. Other operational characteristics may in addition or alternatively be obtained, including velocity and/or displacement of a component.

The sensor device 10 includes a housing 12 that encapsulates components of the sensor device such that the components are isolated from ambient conditions, and a plurality of feet 14, in this example 4, that in this example are magnetic to facilitate magnetic attachment of the sensor device 10 to a component in the industrial facility that has a characteristic desired to be monitored. As an alternative to magnetic attachment, it will be understood that the sensor device 10 may be attached to an industrial facility component in any other way, for example using cable ties.

In this example, identification indicia is disposed on the housing 12 to uniquely identify the sensor device, for example as part of a commissioning process wherein it is desirable to associate the sensor device 10 with the particular industrial facility component that the sensor device will monitor. In this example, the identification indicia include a machine-readable code such as a QR code 16.

The sensor device 10 also includes an intrinsically safe switch 17 that serves to activate or deactivate the sensor device by connecting power to or disconnecting power from components of the sensor device 10. In this example, the intrinsically safe switch 17 includes a reed switch 18 and an elongate magnet 20 that is receivable in an elongate recess 22 disposed adjacent the reed switch 18. The arrangement is such that when the magnet 20 is not received in the recess 22, the reed switch 18 is closed, and when the magnet 20 is received in the recess 22, the magnetic force provided by the magnet causes the reed switch 18 to open.

It will be understood that the intrinsically safe switch 17 enables the sensor device components to remain encapsulated and isolated from ambient whilst providing an effective arrangement for activating and deactivating the sensor device by a user.

In an alternative arrangement, instead of using the reed switch 18 and magnet 20 to facilitate activation and deactivation of the sensor device, the sensor device may include a mechanical switch and a MOSFET, for example with the switch current limited using resistors of a voltage divider.

A sensor network 30 showing a plurality of sensor devices 10a, 10b disposed at multiple industrial facilities, in this example 2 industrial facilities 32a, 32b, is shown in Figure 3.

Each industrial facility 32a, 32b includes multiple industrial facility components 34a, 34b, each of which has an associated sensor device 10a, 10b attached to the industrial facility component, in this example using the magnetic feet 14.

Each sensor device 10a, 10b communicates with a gateway 36a, 36b arranged to receive wireless communications from multiple sensor devices 10a, 10b and to communicate wirelessly with a local server 40a, 40b, in this example through a firewall 38a, 38b. Each local server 40a, 40b then communicates, for example in a conventional way, through a wide area network such as the Internet 42 with a common remote analysis facility 44 that for example may be used to analyse data received from the sensor devices 10a, 10b.

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In this example, the analysis facility 44 includes a firewall 46 and a remote server 48 accessible either directly by a local terminal 50 or remotely, for example through the Internet 42, by a remote terminal 52.

- 5 The communications network at each industrial facility 32a, 32b is configured according to a low power wide area network (LPWAN) that is arranged to facilitate long range communications at low power (but at a low bit rate). LPWAN typically has a range up to 10km, has a bit rate of about 0.3kbit/s to 50kbit/s per channel, and LPWAN based devices can typically operate for 10
10 years or more before battery replacement is required. In the present example, a low power, long range, readily scalable LoRaWAN wireless communication network protocol is used, although it will be understood that other LPWAN protocols may be used.
- 15 LoRaWAN in Australia operates using a 915-930 MHz carrier frequency. A communications network using the LoRaWAN protocol is capable of communicating over distances of the order of 16km and LoRaWAN signals more readily travel through a dense, metallic environment than for example 802.11x protocol signals. In addition, the LoRaWAN protocol uses spread
20 signal chirp technology that allows thousands of nodes to be connected to each gateway, which provides a network that is highly scalable compared to, for example, 802.11x, LTE and 802.15.4 protocols.

- In addition, since a device that uses a LPWAN protocol uses significantly less
25 power than a device that uses for example an 802.11x, LTE or 802.15.4 protocol, the power consumption of the present sensor devices 10a, 10b is significantly less than related sensor devices known hitherto.

- Furthermore, since components of a communications network that uses a
30 LPWAN protocol are significantly less expensive than components required for an 802.11x, LTE or 802.15.4 network, the present sensor devices 10a, 10b are significantly less expensive than related sensor devices known hitherto.

- However, since LPWAN uses a significantly lower frequency than for example
35 802.11x, the bandwidth available to the sensor device 10 to transmit data is significantly reduced relative to 802.11x.

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Referring to Figure 4, components 60 of the sensor device 10 are shown. Interconnections between the components 60 include data connections 70 and power connections 72.

5 The components 60 include a communications system on a chip (SoC) device 62 that has a processor 64 and associated internal memory 66, and a radio frequency modem 68 arranged to wirelessly send RF signals to and wirelessly receive RF signals from a gateway 36. In this example, the SoC device 62 is a Multitech xDot device that includes an Arm Cortex 3 microcontroller, although it
10 will be understood that any suitable SoC device is envisaged.

A SoC was selected that has very low power usage characteristics, but a consequence of this is that the amount of internal memory 66 is too small to handle the desired number of vibration data samples. For this reason, external
15 memory 90 is also included.

The components 60 include a battery 74 that in this example is a 3.7V battery, and a battery monitoring device 76 arranged to monitor the battery voltage and for example to send a communication indicative of the battery voltage, for
20 example periodically, to the analysis facility 44.

The components 60 also include the intrinsically safe switch 17 arranged to control communication of an activation signal to a first power switch 80 that in response to receipt of the activation signal provides power from the battery 74
25 to the processor 64, the RF modem 68 and a decoder 82.

In this example, the first power switch 80 comprises a FET device such as a MOSFET.

30 Similarly, a second power switch 84 is responsive to an activation signal from the processor 64 such that in response to receipt of the activation signal, the second power switch 84 provides power from the battery 74 to an accelerometer 86, a temperature sensor 88, an external memory 90, a reprogramming port 92, a first sensor port 94 and a second sensor port 96.

35 In this example, the second power switch 84 comprises a FET device such as a MOSFET.

It will be understood that while the SoC device 62 has very low inherent power usage characteristics, the power usage profile of the sensor device 10 is maintained at a low level by actively removing power from components of the sensor device 10 using the second power switch 84 when the components are not being used.

Based on the type of selected SoC device 62 and the power management arrangements of the sensor device 10, it is envisaged that the present sensor device 10 will have a productive life of the order of 10 years.

The decoder 82 is included so that the effective number of ports connected to the SoC device 62 can be increased, the decoder 82 functioning as a multiplexer between data inputs of the SoC device 62 and the accelerometer 86 / the external memory 90 / the first sensor port 94 / and the second sensor port 96. The decoder 82 may use a Chip Select control line of the processor 64 to control the multiplexing function of the decoder 82.

The accelerometer 86 is arranged to sense vibrations and to generate a signal indicative of the vibrations. In this example, the accelerometer 86 senses vibrations in 3 mutually orthogonal axes and produces 3 signals indicative of x, y and z orthogonal vibrations. The signals indicative of the vibrations may be signals indicative of acceleration, velocity and/or displacement, in this example in 3 mutually orthogonal directions.

In this example, the accelerometer 86 is an ADXL345 MEMS based accelerometer, although it will be understood that any suitable accelerometer is envisaged.

Data indicative of the raw vibration signals received from the accelerometer 86 is, under control of the processor 64, temporarily stored in the external memory 90, the vibration data being subsequently loaded into the processor internal memory 66 so that a fast Fourier transform (FFT) process can be carried out on the vibration data by the processor 64. In this example, the FFT process carried out is based on about 65,536 vibration data points obtained by sampling the raw vibration signals produced by the accelerometer 86.

It will be understood that on-board FFT analysis by the sensor device 10 is necessary because the bandwidth associated with the LPWAN, in this example LoRaWAN, protocol is low to the extent that it would not be possible to transmit the large amount of sampled vibration data, but the bandwidth is sufficient to
5 transmit data indicative of the results of the FFT analysis. Accordingly, implementation of the FFT analysis on the sensor device 10 enables an information rich relatively small data set to be transmitted. In this example, the transmitted data set is of the order of 200 bytes as this is the size of a LoRaWAN packet payload.

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In this example, the temperature sensor 88 is a DS18B20 temperature sensor, although it will be understood that any suitable temperature sensor is envisaged.

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In this example, the external memory 90 is 4Mb of SRAM, SRAM being used because SRAM is volatile and is capable of withstanding a large number of writes, unlike Flash memory, although it will be understood that any suitable external memory is envisaged.

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The reprogramming port 94 is used to communicate directly with the sensor device 10, for example so as to reprogram the SoC device 62.

The first and second sensor ports 94, 96 are for connection to other sensors, for example an audio sensor.

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Referring to Figure 5, functional components 100 of or implemented by the processor 64 are shown. The processor 64 includes associated temporary memory 66 used to implement processes and temporarily store data. The processor 64 also implements processes, for example using programs stored in
30 non-volatile memory (not shown).

The functional components 100 implemented by the processor 64 include:

a data capturer 102 arranged to control and coordinate capture of data indicative of temperature from the temperature sensor 88, and to store the
35 captured temperature data in the external memory 90;

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a sampler 104 arranged to control and coordinate capture of samples of vibration data from the accelerometer 86 and to store the samples in the external memory 90;

5 a fast Fourier transform (FFT) implementer 106 arranged to implement a fast Fourier transform on the sampled vibration data to produce FFT vibration data and to store the FFT vibration data in the external memory 90;

a power manager 108 arranged to manage power usage by the sensor device 10, in particular by managing supply of power to some of the sensor device components 60 using the second power switch 84;

10 a data handler 110 arranged to manage transfer of data between the processor 64 and the external memory 90; and

a transmitter controller 112 arranged to control the RF modem 68 and coordinate transmission and reception of data by the RF modem.

15 The functional components 100 also include configuration settings 114, for example that relate to:

timing of capture of data indicative of temperature from the temperature sensor 88;

20 timing of capture of samples of vibration data from the accelerometer 86 and sampling characteristics including the sampling rate;

FFT characteristics;

transmission data characteristics including characteristics that define the set of data derived from the FFT vibration data to be provided to the RF modem 68 for transmission; and

25 power management characteristics, including sleep and wake times, and arrangements to minimise the number of transmissions carried out by the RF modem 68.

30 In this example, the settings define that the data indicative of temperature is captured periodically, such as every 15 minutes, although it will be understood that any suitable data capture timing regime is envisaged.

In this example, the settings define that the samples of vibration data are captured periodically, such as every 15 minutes, although it will be understood
35 that any suitable data capture timing regime is envisaged. In this example, the sampling rate is about 3.2 kHz, although it will be understood that any suitable sampling rate is envisaged.

In this example, the FFT implementer 106 uses a Cooley-Tukey algorithm, although it will be understood that any suitable FFT algorithm is envisaged.

- 5 In this example, the set of data derived from the FFT vibration data for transmission by the RF modem 68 is selected based on a defined number of frequency peaks, for example the 33 highest frequency peaks in the FFT vibration data, although it will be understood that any suitable criterion may be used to select the set of data from the FFT vibration data for transmission. For
- 10 example, the set of data may be selected based on a defined number of frequency peaks within a defined frequency band. Alternatively, the set of data for transmission may be based on defined criteria, such as all peaks above a defined value up to a maximum number of peaks.
- 15 In this example, after activation of the sensor device 10 by removal of the magnet 20 from the recess 22, power management of the sensor device 10 is controlled by the second power switch 84 based on the power management characteristics managed by the processor 64. The power management
- 20 characteristics may define that power is provided to the accelerometer 86, the temperature sensor 88, the external memory 90, the reprogramming port 92, the first sensor port 94 and the second sensor port 96 only when an action is required to be carried out by any one of these components. For example, the power management characteristics may define that power is provided to the
- 25 vibration data is required to be captured, and power is removed from the components after the temperature data and FFT vibration data are transmitted by the RF modem 68.

30 Examples of raw vibration data and FFT vibration data are shown in Figures 6 and 7.

Figures 6a to 6c show raw sample vibration data captured from the accelerometer 86. Figure 6a shows raw sample vibration data in an x-axis, Figure 6b shows raw sample vibration data in a y-axis, and Figure 6c shows

35 raw sample vibration data in a z-axis.

Figures 7a to 7c show FFT data obtained from the raw sample vibration data shown in Figures 6a to 6c. Figure 7a shows FFT data in an x-axis, Figure 7b shows FFT data in a y-axis, and Figure 7c shows FFT data in a z-axis.

- 5 In this example, for each of the FFT x, y and z axis data, the data corresponding to the 33 highest peaks is selected and transmitted using the RF modem 68 to the remote analysis facility 44.

10 At the remote analysis facility 44, the received selected FFT data and received temperature data can be used to analyse the vibration and temperature characteristics of the monitored components 34, for example in order to determine whether any problems exist in relation to the components 34.

15 Depending on the type of sensor used, or depending on the configuration used for the sensor, the received FFT data may be indicative of acceleration, velocity or displacement.

20 It will be understood that the remote analysis facility 44 in this example is arranged to monitor operational characteristics of components 34 associated with multiple industrial facilities 32, and in this way by using appropriate software at the remote analysis facility 44, it is possible to develop useful data indicative of operational trends that may enable operators to improve aspects of the industrial facility.

- 25 The sensor device 10 is constructed in order to comply with IECEx certification requirements by including the following features:

encapsulating the sensor device components in a material that can tolerate temperatures generated by internal heat dissipation plus a factor of safety;

30 current limiting all external electronic elements using 40 ohm resistors; including in the encapsulant material a 3.7V battery which is sufficient to power the device;

including in the encapsulant material an antenna;

ensuring that all unprotected internal circuit traces have a spacing of at

35 least 0.5 mm.

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In the present embodiment, in order to further minimise power usage, the sensor device 10 may be arranged to transmit the data based on defined criteria so that usage of the RF modem 68, which is a relatively high draw on power, is minimised. For example, rather than transmitting data immediately
5 after data is collected, the power manager 108 may be arranged to maintain a buffer of data, for example implemented in the CPU 64, and to progressively fill the buffer until the amount of data in the buffer is sufficient to fill the payload of a LoRaWAN packet. After the required packet length has been achieved, the power manager 108 causes the data to be sent.

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In the present embodiment, FFT vibration data is transmitted immediately after it is obtained, and temperature data is used to fill the buffer and is only sent when the buffer is full.

15 In a variation to this arrangement, the power manager 108 may nevertheless be arranged to send data as it is created if at least one defined criterion is met irrespective of whether there is sufficient data to fill a LoRaWAN packet.

For example, a record of maximum and minimum permissible temperature
20 values may be stored and the power manager 108 arranged such that if detected temperature data values exceed the maximum or minimum values, the current temperature data is transmitted.

Similarly, a record of maximum permissible FFT vibration or temperature
25 difference values may be stored, the permissible difference values representing difference amounts between the current values and corresponding previous values. With this example, the power manager 108 may be arranged such that if difference values exceed a maximum difference value, the current data is transmitted. In addition, with this arrangement, the sensor device 10 may be
30 arranged to transmit a heartbeat communication if the difference threshold is not exceeded to indicate to the analysis facility 44 that the monitored component is operating as expected, with data only transmitted if the threshold is exceeded, to indicate that component characteristics have notably changed.

35 Referring to Figure 8, a flow diagram 130 illustrating an example process of operation of a sensor device 10 is shown.

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Based on the data capture and power management configuration settings 114 that define a wake up time, the processor 64 sends an activation signal to the second power switch 84 to cause the sensor device 10 to wake 132, by causing power to be provided to the accelerometer 86, the temperature sensor 88, the external memory 90, the reprogramming port 92, the first sensor port 94 and the second sensor port 96. After waking, the processor 64 reads 134 the stored configuration settings 114 to determine the settings to use for capture of the temperature and vibration data from the temperature sensor 88 and the accelerometer 86, and using the settings the temperature data and samples of the raw 3-axis vibration data are obtained 136, 138, 140 and stored 142 in the external memory 90.

At least some of the components, of the sensor device 10, including the accelerometer 86, may include an input responsive to a sleep signal such that although power is still provided to the component, in response to receipt of the sleep signal, the component is placed in a sleep state so that the component uses less power.

In the present example, the accelerometer 86 is placed in a sleep state 144 after accelerometer signal have been captured.

The processor 64, using the data handler 110, loads 146 successive portions of the raw vibration data into the internal memory 66 from the external memory 90, and using the FFT implementer 106, carries out 148 a FFT process on the raw vibration data to produce FFT vibration data. The FFT vibration data is stored 150 in the external memory.

Using the stored FFT vibration data, data is selected 152 from the stored FFT data based on the defined FFT characteristics in the configuration settings 114, and the selected FFT data is transmitted to the remote analysis facility 44 using a LoRaWAN protocol by the RF modem 68.

After receipt of the selected FFT data from the sensor device 10 by the remote analysis facility 44, the remote analysis facility 44 may take the opportunity to send instructions to the sensor device 10 while the sensor device 10 is awake. For example, the instructions may include new configuration data to change sample times, wake/sleep times, sample rates, and so on, or the instructions

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may include instructions to reboot the sensor device 10. Any received new configuration data is stored 160, and based on the power management configuration settings 114 that define a sleep time, the processor 64 sends a deactivation signal to the second power switch 84 to cause the sensor device

5 10 to sleep 164 until the next scheduled wake time.

The above embodiments are described in relation to an arrangement wherein FFT frequency domain data is obtained from time domain vibration data, and a subset of the FFT data is selected for transmission by the RF modem 68, such

10 as a defined number (such as 33) of the highest peaks in the frequency domain data. Such data may be sent in each LPWAN packet. For example, the LPWAN packet may comprise about 200 bytes that includes the data shown in the following table.

Item	No. of bytes	Decimal places	Min value	Max value
Description	1			
33 peaks (frequency & amplitude values)	198			
Each peak frequency (Hz)	2	1	0	6500
Each peak amplitude (m/s ²)	4	5	0	42200

15 It will be understood that with this arrangement, after capture of data from the sensor 10, the data may typically be transmitted in a single LPWAN packet, and as a consequence power consumption by the sensor 10 is low. However, notwithstanding that data associated with each data capture instance is

20 typically transmitted using a single LPWAN packet, in some circumstances more than one packet may be transmitted, depending on the data that is required to be sent.

In an alternative embodiment, the selected subset of FFT data may include a

25 different number of the highest peaks, and/or a different number of bytes used to communicate the peak data. For example, the inventors have realised that 165 m/s² is a sufficiently high maximum value for acceleration amplitude in the frequency domain data, and consequently it is possible to use a lower number of bytes to represent the amplitude data in a LPWAN packet. Since with this

30 example 3 bytes are used for the peak amplitude data instead of 4, it is possible

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to include in each LPWAN packet additional data that is derivable from the captured time domain vibration data because 1 bit is available in the LPWAN packet for each frequency peak in the data.

- 5 For example, a LPWAN packet may include data indicative of any one or more of the following:
- maximum peak acceleration amplitude;
 - minimum peak acceleration amplitude;
 - mean acceleration amplitude;
 - 10 time domain acceleration crest factor;
 - frequency domain rms value;
 - frequency domain positive peak mean value;
 - frequency domain negative peak mean value;
 - peak velocity data values derived by integrating the acceleration
 - 15 frequency domain data, for example wherein each velocity value is the or one of several maximum values in a bin of a set of bins; and/or
 - turning speed of a rotatable part of a component to which the sensor is attached.
 - 20 An embodiment that transmits the above data may include a LPWAN packet that includes the data shown in the following table.

Item	No. of bytes	Decimal places	Min value	Max value
Main Group	198			
Common Sub-Group	26			
Description	1			
34 peaks (frequency & amplitude values)	170			
Each peak frequency (Hz)	2	1	0	6500
Each peak amplitude (m/s ²)	3	5	0	165
Common Sub-Group				
Acceleration peak-peak (m/s ²)	2	3	0	65
Crest Factor	2	3	0	65
Velocity bin 1 (mm/s)	2	3	0	65

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Velocity bin 2 (mm/s)	2	3	0	65
Velocity bin 3 (mm/s)	2	3	0	65
Velocity bin 4 (mm/s)	2	3	0	65
Velocity bin 5 (mm/s)	2	3	0	65
Velocity bin 6 (mm/s)	2	3	0	65
Velocity bin 7 (mm/s)	2	3	0	65
Turning Speed (Hz)	2	2	0	650
Acceleration rms	2	3	0	65
Acceleration positive peak	2	3	0	65
Acceleration negative peak	2	3	-65	0

It will therefore be understood that additional information is sent with this arrangement even though only a single LPWAN packet is still typically transmitted with each data capture instance.

5

However, it will be understood that any suitable data derivable at the sensor from the time domain and/or frequency domain data may be included in a LPWAN packet.

10 It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

15 In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

20

Modifications and variations as would be apparent to a skilled addressee are deemed to be within the scope of the present invention.

CLAIMS:

1. A sensor device comprising:
 - a sensor arranged to produce time domain data representative of a
 - 5 sensed time dependent characteristic adjacent the sensor;
 - a signal processing component, the signal processing component
 - arranged to use the time domain data to produce frequency domain data
 - indicative of frequency components present in the time domain data; and
 - a data transmission component arranged to transmit a portion of the
 - 10 frequency domain data;
 - wherein the sensor device is arranged to select a subset of frequency
 - domain data from the frequency domain data based on defined criteria and to
 - transmit the selected subset of frequency domain data.
- 15 2. A sensor device as claimed in claim 1, wherein the selected subset of
- frequency domain data corresponds to a defined number of frequency peaks in
- the frequency domain data.
3. A sensor device as claimed in claim 2, wherein the selected subset of
- 20 frequency domain data corresponds to a defined number of the highest
- frequency peaks in the frequency domain data.
4. A sensor device as claimed in claim 3, wherein the selected subset of
- frequency domain data corresponds to the highest 33 frequency peaks in the
- 25 frequency domain data.
5. A sensor device as claimed in any one of claims 2 to 4, wherein sensor
- is arranged to transmit the selected subset of frequency domain data in a single
- data packet for at least some instances of data capture wherein time domain
- 30 data is produced.
6. A sensor device as claimed in claim 5, wherein the defined number of
- frequency peaks is determined according the amount of data that can be
- included in the single data packet.

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7. A sensor device as claimed in any one of the preceding claims, wherein the sensor device is also arranged to transmit other data in addition to the selected subset of frequency domain data.
- 5 8. A sensor device as claimed in claim 7, wherein the amount of other data is determined according the amount of data that can be included in a single data packet.
9. A sensor device as claimed in claim 7 or claim 8, wherein the other data
10 includes any one or more of the following:
maximum peak acceleration amplitude;
minimum peak acceleration amplitude;
mean acceleration amplitude;
time domain acceleration crest factor;
15 frequency domain rms value;
frequency domain positive peak mean value;
frequency domain negative peak mean value;
peak velocity data values derived by integrating the acceleration
frequency domain data, for example wherein each velocity value is the or one
20 of several maximum values in a bin of a set of bins; and/or
turning speed of a rotatable part of a component to which the sensor is attached.
10. A sensor device as claimed in any one of the preceding claims, wherein
25 the sensor is arranged to produce time domain vibration data representative of vibrations adjacent the vibration sensor.
11. A sensor device as claimed in claim 10, wherein the sensor is arranged
to produce time domain acceleration data, time domain velocity data and/or
30 time domain displacement data.
12. A sensor device as claimed in any one of the preceding claims, wherein the data transmission component is arranged to use a LPWAN protocol.
- 35 13. A sensor device as claimed in claim 12, wherein the data transmission component is arranged to use a LoRaWAN protocol.

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14. A sensor device as claimed in any one of the preceding claims, wherein the sensor device includes an external memory separate to the signal processing component and the data transmission component, the sensor device arranged to store the time domain data in the external memory and to
5 load the time domain data into the signal processing component for processing.

15. A sensor device as claimed in claim 14, wherein the sensor device is arranged to load successive portions of the time domain data into the signal processing component so that the time domain data can be processed in
10 several batches.

16. A sensor device as claimed in any one of the preceding claims, wherein the selected subset of frequency domain data is selected from a defined frequency band.
15

17. A sensor device as claimed in any one of the preceding claims, comprising a power manager arranged to control provision of power to at least one sensor device component based on defined power management criteria.

20 18. A sensor device as claimed in claim 17, wherein the at least one sensor device component comprises the sensor, at least one sensor port, an external memory separate to the signal processing component and the data transmission component, and/or a reprogramming port.

25 19. A sensor device as claimed in claim 17 or claim 18, wherein the defined power management criteria is arranged to cause power to at least one of the sensor device components to be disconnected when the at least one sensor device component is not being used.

30 20. A sensor device as claimed in any one of claims 17 to 19, wherein the defined power management criteria define wake up and sleep times whereby power to at least one of the sensor device components is caused to be connected during wake time and power to the at least one of the sensor device components is caused to be disconnected during sleep time.
35

21. A sensor device as claimed in any one of claims 17 to 20, wherein the sensor device includes at least one power switch responsive to an activation

signal from the power manager, the power switch arranged to cause power to be provided to at least one of the sensor device components in response to the activation signal and to cause power to not be provided to at least one of the sensor device components in absence of the activation signal.

5

22. A sensor device as claimed in claim 21, wherein the at least one power switch comprises at least one FET that may be a MOSFET.

23. A sensor device as claimed in any one of claims 17 to 22, wherein the power manager is arranged to control transmission of frequency domain data by the data transmission component according to defined criteria so as to control usage of the data transmission component.

10

24. A sensor device as claimed in claim 23, wherein the power manager is arranged to progressively fill a buffer with data until the amount of data in the buffer is sufficient to fill a payload of a data packet used by the data transmission component, and to cause the data in the buffer to be sent by the data transmission component when sufficient data is present in the buffer.

15

25. A sensor device as claimed in claim 24, wherein the power manager is arranged to send the data irrespective of whether there is sufficient data to fill a data packet if at least one defined criterion is met.

20

26. A sensor device as claimed in claim 25, wherein the at least one defined criterion includes a maximum and/or minimum permissible value associated with a sensor, and the power manager is arranged such that if a current value associated with the sensor exceeds the maximum or minimum value, the current value is transmitted.

25

27. A sensor device as claimed in claim 25 or claim 26, wherein the at least one defined criterion includes a maximum permissible difference value associated with a sensor, the permissible difference value representing a difference amount between a current value and a corresponding previous value, and the power manager arranged such that if a current difference value exceeds the maximum difference value, the current value is transmitted.

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28. A sensor device as claimed in any one of claims 25 to 27, wherein the sensor device is arranged to transmit a heartbeat communication to indicate that a monitored component is operating as expected based on received sensor values, and to send frequency domain data if the at least one defined criterion
5 is met.

29. A sensor device as claimed in any one of the preceding claims, wherein the signal processing component is arranged to carry out a fast Fourier transform (FFT) process to produce FFT data using the time domain data.
10

30. A sensor device as claimed in any one of the preceding claims, comprising a sampler arranged to produce time domain data samples, the signal processing component arranged to use the time domain data samples to produce frequency domain data indicative of frequency components present in
15 the time domain samples.

31. A sensor device as claimed in any one of the preceding claims, comprising at least one further sensor, the data transmission component arranged to transmit at least a portion of sensor data derived from the at least
20 one further sensor.

32. A sensor device as claimed in any claim 31, wherein the at least one further sensor includes a temperature sensor.

25 33. A sensor device as claimed in any one of the preceding claims, wherein the sensor comprises an accelerometer arranged to sense vibrations in 3 mutually orthogonal axes.

30 34. A sensor device as claimed in claim 33, wherein the accelerometer is arranged to produce time domain data indicative of acceleration, velocity or displacement.

35 35. A sensor device as claimed in any one of the preceding claims, comprising a processor that forms part of a system on chip (SoC) device, the SoC device including the data transmission component.

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36. A sensor device as claimed in claim 35, comprising a decoder to multiplex between data inputs of the SoC device and components of the sensor device.

5 37. A sensor device as claimed in any one of the preceding claims, comprising a machine-readable code indicative of a unique identifier associated with the sensor device.

38. A sensor device as claimed in claim 37, wherein the machine-readable
10 code includes a QR code.

39. A sensor device as claimed in any one of the preceding claims, wherein components of the sensor device are encapsulated such that the components are isolated from ambient conditions.

15 40. A sensor device as claimed in any one of the preceding claims, comprising an intrinsically safe switch arranged to control provision of power from a battery to all electrical components of the sensor device.

20 41. A sensor device as claimed in claim 40, wherein the intrinsically safe switch includes a reed switch and a magnet that is receivable in a recess disposed adjacent the reed switch, wherein when the magnet is not received in the recess, the reed switch is closed, and when the magnet is received in the recess, the magnetic force provided by the magnet causes the reed switch to
25 open.

42. A sensor device as claimed in any one of the preceding claims, comprising at least one magnetic portion for attaching the sensor device to an industrial facility component.

30 43. A sensor network comprising:
a plurality of sensor devices as claimed in any one of the preceding claims;
a communications network capable of facilitating data transmissions from
35 the data transmission components of the sensor devices; and

a remote facility in network communication with the plurality of sensor devices through the communications network such that the data transmissions from the data transmission components are receivable at the remote facility.

- 5 44. A method of sensing an operational characteristic of a component using a sensor device, the method comprising:
- disposing the sensor device on the component;
 - providing the sensor device with a sensor arranged to produce time domain data representative of a sensed time dependent characteristic adjacent
 - 10 the sensor;
 - using a signal processing component of the sensor device to produce frequency domain data using the time domain data, the frequency domain data indicative of frequency components present in the time domain data;
 - transmitting a portion of the frequency domain data using a data
 - 15 transmission component of the sensor device;
 - wherein the sensor device is arranged to select a subset of frequency domain data from the frequency domain data and to transmit the selected subset of frequency domain data.
- 20 45. A method as claimed in claim 44, wherein the selected subset of frequency domain data corresponds to a defined number of frequency peaks in the frequency domain data.
46. A method as claimed in claim 45, wherein the selected subset of
- 25 frequency domain data corresponds to a defined number of the highest frequency peaks in the frequency domain data.
47. A method as claimed in claim 46, wherein the selected subset of frequency domain data corresponds to the highest 33 frequency peaks in the
- 30 frequency domain data.
48. A method as claimed in any one of claims 45 to 47, comprising transmitting the selected subset of frequency domain data in a single data packet for at least some instances of data capture wherein time domain data is
- 35 produced.

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49. A method as claimed in claim 48, comprising determining the defined number of frequency peaks according the amount of data that can be included in the single data packet.

5 50. A method as claimed in any one of claims 44 to 49, wherein the sensor device is also arranged to transmit other data in addition to the selected subset of frequency domain data.

10 51. A method as claimed in claim 50, wherein the amount of other data is determined according the amount of data that can be included in a single data packet.

52. A method as claimed in claim 50 or claim 51, wherein the other data includes any one or more of the following:

15 maximum peak acceleration amplitude;
 minimum peak acceleration amplitude;
 mean acceleration amplitude;
 time domain acceleration crest factor;
 frequency domain rms value;

20 frequency domain positive peak mean value;
 frequency domain negative peak mean value;
 peak velocity data values derived by integrating the acceleration frequency domain data, for example wherein each velocity value is the or one of several maximum values in a bin of a set of bins; and/or

25 turning speed of a rotatable part of a component to which the sensor is attached.

53. A method as claimed in claim 52, comprising producing time domain vibration data representative of vibrations adjacent the vibration sensor.

30 54. A method as claimed in claim 52 or claim 53, comprising transmitting the subset of the frequency domain data using a LPWAN protocol.

55. A method as claimed in claim 54, comprising transmitting the subset of
35 the frequency domain data using a LoRaWAN protocol.

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56. A method as claimed in any one of claims 52 to 55, comprising storing the time domain data in an external memory and loading the time domain data into the signal processing component for processing.

5 57. A method as claimed in claim 56, comprising loading successive portions of the time domain data into the signal processing component so that the time domain data can be processed in several batches.

58. A method as claimed in any one of claims 52 to 57, comprising selecting
10 the subset of frequency domain data from a defined frequency band.

59. A method as claimed in claim 58, comprising progressively filling a buffer with data until the amount of data in the buffer is sufficient to fill a payload of a data packet used by the data transmission component, and causing the data in
15 the buffer to be sent by the data transmission component when sufficient data is present in the buffer.

60. A method as claimed in claim 59, comprising sending the data irrespective of whether there is sufficient data to fill a data packet if at least one
20 defined criterion is met.

61. A method as claimed in claim 60, wherein the at least one defined criterion includes a maximum and/or minimum permissible value associated with a sensor, wherein if a current value associated with the sensor exceeds
25 the maximum or minimum value, the current value is transmitted.

62. A method as claimed in claim 60 or claim 61, wherein the at least one defined criterion includes a maximum permissible difference value associated with a sensor, the permissible difference value representing a difference
30 amount between a current value and a corresponding previous value, wherein if a current difference value exceeds the maximum difference value, the current value is transmitted.