

MONITORING DEVICE AND METHOD

Field of Invention

5 This invention is related to monitoring device and method. In particular, the invention relates to a device and method for monitoring conditions in the ground or in a building structure.

Background of Invention

10

Sensors are placed in the ground or in building structures or infrastructures to monitor certain parameters such as vibrations, any displacement or tilting, presence of water, soil pressure, noise level, temperature, gas contents and chemistry, and the like.

15 This is particularly important at construction sites where the earth is being manipulated so that any parameter beyond an acceptable threshold may be alerted and corrective measures taken to prevent damage to property or lives in the surrounding areas. In many cities, there is an increasing number of tunnels for transport, communications, or public utilities. Hence, there is a need for constant monitoring of the ground conditions at
20 construction sites.

In remote areas, in particular mountainous areas, there is a need to determine when ground movement has occurred during bad weather or an earthquake which could lead to landslides.

25

There are a number of sensors available to measure such parameters. However, each sensor occupies a large area and can only measure one parameter. Furthermore, the sensors for underground measurement and above ground measurement for use on building and infrastructure are different.

30

Also, measurements of tilt in soil are generally done manually. For example, a single bore is first drilled into the ground and a single sensor is placed into the bore to detect tilt in the ground at various pre-determined depths – different readings have to be taken at each pre-determined depth and manually recorded. A single bore assigned for the

detection of tilt in the soil cannot be used for detecting or monitoring other parameters, for example water, temperature, soil chemistry etc. As a result, multiple bores have to be drilled into the ground for the measurement of each parameter. This is time and labour intensive, and severely limited by the suitable placement of the numerous bores.

5

The selection of the types of mechanical movement of the probe is required for different orientations (vertical, horizontal and incline) of the instrument. Measurements have to be converted after measurement of the inclination at the top of the casing (ground surface). Under the manual system, a technician will manually lower the measurement probe up to the pre-determined depths, while pausing at regular depth intervals to record the measurement. The technician will then have to repeat the process for the other axis. An automated system uses a machine to lower the probe to the required depths. In either system, the bore needs to be kept free for the probe to run through the entire length for the measurement, hence no other instrument can be used in that same bore.

10

In addition, close interval of vibration measurement is not possible with existing devices. Sensors for the measurement of soil and water pressure, temperature, soil chemical conditions (e.g. pH and salinity) have to be installed in separate boreholes from the tilt measurement of soil for the same reason that the length of borehole has to be kept free from obstruction. These sensors further require different boundary and contact conditions that will prevent the sensors from being installed together. As a result, one bore hole is required for each instrument type. As a result, existing measurement devices are both labour and time intensive, and require multiple instrument with individual bores.

15

There are monitoring devices which include sensors at the tip of a drill bit such that as these sensors are driven into the ground by the drill bit, readings may be taken at various depths in the ground. However, as these sensors are driven deeper into the ground, readings at shallower depths cannot be taken without withdrawing the drill bit.

20

Similar measurement parameters like tilt, vibration, pressure and chemistry can also be applied to above ground conditions in buildings and infrastructures. In above ground condition, noise level and atmospheric conditions measurements and sensors may also

be required. However, the current sensors and related components are generally not compatible.

Therefore, there is a need for an improved integrated monitoring device and system that
5 can measure these parameters quicker, easier and takes up less space than conventional devices and systems.

Summary of Invention

10 In accordance with a first aspect of the present invention, there is provided a monitoring module comprising a processing unit electrically connected to a first line of sensors, the first line of sensors comprising a plurality of inertial measurement units (IMUs) adapted to determine a profile of a structure along a length of the first line of sensors.

15 Preferably, the first line of sensors are disposed along an elongated and/or flexible substrate. The term “substrate” may include any support structure or surface upon which the IMU may be attached or deposited on by adhesion or other known methods. This allows the first line of sensors to be able to bend and move with the ground to detect both small and large ground movement.

20

There may be any suitable number of IMUs disposed along the length of the first line of sensors, i.e. the first line of sensors may be of any suitable length. Preferably, the first line of sensors comprises 20 equally spaced apart inertial measurement units. This allows the curve profile to more accurately measure the movement of the IMUs and
25 ground. Each inertial measurement unit may be 0.5 metres apart (i.e. a spacing of 0.5 metres). The length of the substrate may be 8 metres or less. This prevents signal loss or degradation. The first line of sensors may be placed into a bore in the ground, and grouting the space around the first line of sensors. Advantageously, this flexibility allows the first line of sensors to move with any ground movement without requiring a user’s
30 intervention or physical presence. By “structure”, it is meant to include the ground, or a building structure on or above the ground, or structures in the ground like tunnels, and caves. Likewise, surface of the ground includes the surface of a structure. As such, it follows then that by “profile”, it is meant to refer to the form, contour or shape (particularly a linear shape) of a bore in the ground, or on the surface of the ground, or

on the surface of a building structure. If there is any movement in the structure, then the profile of the line of the sensors corresponds to that movement that occurred in the structure.

- 5 Preferably, the plurality of inertial measurement units are connected in series.

10 Preferably, the processing unit is further electrically connected to a second line of sensors. The second line of sensors comprising at least one sensor selected from the group comprising of: a water pressure sensor, a pore water pressure sensor, a pH sensor, a sound level detector, a gas sensor, a salinity sensor, and a temperature sensor. Advantageously, these sensors are generally digital sensors. Analogue sensors may also be used with an analogue to digital convertor (ADC). The second line of sensors provide additional information about the ground and soil conditions to supplement the information provided by the IMUs, and may be deployed as an
15 integrated sensor probe in a single bore thus reducing the time and labour required to obtain the same amount of sensor data.

20 Preferably, the processing unit comprises: (a) a power source; and (b) a transmitter for transmitting the data obtained from the sensors. The data is transmitted to a central processor or control box (explained in detail below).

Preferably, the first and second lines of sensors are each housed in a housing. Each line of sensors may have its own housing, or a shared housing.

25 In a second aspect of the present invention, there is provided a monitoring device comprising two or more of monitoring modules according to the first aspect of the invention.

Preferably, each module is connected to each other in series.

30

Preferably, the two or more monitoring modules are electrically connected to a control box, the control box comprises a GPS module. The control box further comprises a power source, the power source is a fuel cell or a solar cell. This allows the monitoring

devices to be used in remote locations where an electrical supply may not be readily present, and to be self-sustaining.

Preferably, the device further comprises a ground line of sensors electrically connected to the control box, disposed on a surface of a ground or structure to be monitored. The ground line of sensors comprising at least one sensor selected from the group comprising of: a water pressure sensor, a pore water pressure sensor, a pH sensor, a sound level detector, a gas sensor, a salinity sensor, and a temperature sensor. The ground line of sensors allows above ground measurement in tandem with the underground measurements.

In a third aspect of the present invention, there is provided a monitoring system comprising: (a) at least one monitoring module according to the first aspect of the invention, or at least one device according to the second aspect of the invention; and a central unit, wherein the central unit comprises a communications module for receiving and transmitting data from the at least one monitoring module or from the at least one device.

Preferably, the monitoring system comprises an aggregator device as an intermediary between the at least one monitoring module, or at least one device, and the central unit.

In a fourth aspect of the invention, there is provided a method for monitoring, the method comprising obtaining data from at least one monitoring module according to the first aspect of the invention, or at least one device according to the second aspect of the invention; and determining a position of each inertial measurement unit relative to each other to determine the profile of the first line of sensors.

Preferably, obtaining the data is based on a time schedule, triggered by an event, or upon a user's request. The event may be a preset alert level being reached.

The embodiments of the present invention allows for simultaneous, accurate and sensitive multipoint measurement of ground movement. By determining the position of each IMU relative to each other (i.e. other IMUs), the profile of the first line of sensors may be determined. Therefore, by monitoring the profile of the first line of sensors, a

user is able to determine whether there is movement in the ground or structure, making it possible to detect any ground or structural movement at an early stage. The sensitivity and distance covered by the monitoring module and device may be adjusted by increasing the number of IMUs and/or modules. The flexibility of the monitoring module,
5 low power consumption and size of the module and device allows it to be deployed at various locations to monitor different types of ground conditions or structures.

Brief Description of Figures

10 In order that the present invention may be fully understood and readily put into practical effect, there shall now be described by way of non-limitative examples only preferred embodiments of the present invention, the description being with reference to the accompanying illustrative figures.

15 In the Figures:

Figure 1 is a schematic drawing of the device and system according to an embodiment of the present invention;

20 Figure 2 is a schematic drawing of a part of the monitoring system according to an embodiment of the present invention;

Figure 3 is a schematic drawing of a monitoring device according to an embodiment of the present invention;

25

Figure 4 is a schematic drawing of a monitoring module according to an embodiment of the present invention;

Figures 5A – 5D is a schematic drawing of embodiments of the present invention
30 deployed in the ground.

Detailed Description of The Preferred Embodiments

In Figure 1, a system 5 according to an embodiment of the present invention for monitoring conditions in a ground or in a building structure is shown. Such conditions may include any movement, presence of water, or the like.

5 In the system 5, there is included at least one monitoring device 10, or at least one monitoring module 15, that is inserted into the ground or mounted on the building structure, and a central unit (or user terminal) 30. The central unit 30 comprises a communications module for receiving and transmitting data from the at least one monitoring module 15 or monitoring device 10. The transmission of data could be by
10 wired or wireless means (e.g. Wi-Fi or Low Power Wide Area Network). The central unit 30 should be configured to compile and process the data from the monitoring device 10 or monitoring module 15. The system 5 may further comprise an aggregator device 25 to compile data from the device 10 and/or to extend the range of the system 5, before transmission to the central unit 30 (Figure 1) (i.e. the aggregator device 25 serves as an
15 intermediary between the monitoring module 15, or device 10, and central unit 30). This may be particularly useful when a plurality of monitoring devices 10 are used to monitor a large area. Multiple aggregator devices 25 may be used to cover large areas or distances. A cloud 35 (i.e. network server) may be provided to serve as a link between the aggregator device 25 and central unit 30 (Figure 2). The server 35, or aggregator
20 device 25, may also serve as a backup storage.

The aggregator device 25 may comprise a communications module 40, a serial data interface 45, and a processor 50. The aggregator device 25 serves as an intermediary between the monitoring device/s 10 and the central unit 30. The communications module
25 40 should allow wireless transmission of data across the various units in the system 5, examples of communications module 40 include a Wi-Fi module, and a low power Wide Area Network (WAN) module. The central unit 30 and server 35 if present, will also have the communications module 40.

30 The device 10 comprises a plurality of sensors 17 and a control box 20. As such, in one singular monitoring device 10, a plurality of parameters may be measured in the ground or building structure.

In an embodiment, each monitoring module 15 comprises a processing unit 16 (or sensor hub) electrically connected to a first line 18 of sensors 17, the sensors 17 comprising a plurality of inertial measurement units (IMUs) 65 as shown in Figure 4. The IMUs 65 may be electrically connected in a series manner.

5

In an embodiment, the IMUs 65 may be disposed along or attached to an elongated and/or flexible substrate by adhesion or other known methods. This allow the IMUs 65 and monitoring module 15 to move and bend with the surrounding ground or structure movement. For example, a flexible strip, in particular a flexible circuit board, providing accurate and constant measurement. Examples of flexible plastic substrates include polyimide, polyether ether ketone (PEEK), and polyester. The flexible substrate may be mounted or attached to the profile or surface of any structure or building for monitoring of the parameters as will be explained in greater detail below. The substrate should be sufficiently resilient to withstand a certain degree of bending and movement. The substrate may be used to provide a physical backbone to attach the plurality of IMUs 65. The processing unit 16 may be attached to the flexible substrate or attached separately. This allows the monitoring module 15 and device 10 to be assembled and deployed more quickly. For example, the monitoring module 15 or device 10, may be placed directly into a bore and back filled (or the ground is allowed to collapse into the bore) for remote deployment of the module 15 or device 10. The module 15 or device 10 may be left in place without further intervention from a user to allow continuous monitoring of the ground. The user no longer needs to be physically present to measure the ground conditions.

25 A housing, for example a cover, a sheath, or a flexible tubular pipe for insertion into the borehole, may be provided to enclose the substrate. This allows the borehole to be filled with soil after the insertion of the monitoring module 15, and allows the monitoring module 15 to move with the surrounding soil with greater sensitivity, in particular when the soil movement is uneven.

30

Each monitoring module 15 may contain a suitable number of IMUs 65 arranged at appropriately spaced intervals to span the entire length of the substrate. An inertial measurement unit 65 comprise a gyroscope, an accelerometer and optionally a magnetometer for reference with respect to a magnetic field, for example the earth's

magnetic field. In particular, the accelerometer and gyroscope may each measure in three dimensions or axes. The IMU 65 measures and reports the following parameters: a body's specific force, angular rate, using a combination of the accelerometers and gyroscopes, and the magnetic field surrounding the body when a magnetometer is present. The combination of the three axes accelerometer and three axes gyroscopes produces data with six degrees of freedom. A three axis magnetometer may provide three additional degrees of freedom. By integrating the data from the various components, the IMU 65 is able to determine the position of an IMU 65 relative to other IMUs 65. It is thus possible to determine the profile of the first line 18 of sensors and plot graphically the position of the IMU 65, for example the relative position of an IMU 65 with respect to its original position or with respect to time. The relative motion of the IMU 65 and the first line 18 of sensors may thus be determined. Since the movement of the IMU 65 is correlated to the surrounding ground movement, the surrounding ground movement may be determined using the monitoring module 15.

The use of a plurality of IMUs 65 in series allows for the simultaneous measurement of multiple points along the length of the first line 18 of sensors to determine the profile of the first line 18 of sensors. This allows detection of the movement of the ground at different points along the first line 18 of sensors, and is particularly useful when the soil at different depths move at different rates such that the soil movement may not be noticed until serious damage has occurred. The flexible substrate provides an additional restriction on the movement of the IMUs 65 and monitoring module 15 allowing for the continuous multipoint measurement of the ground conditions.

Figure 5 schematically shows a monitoring module 15 with different number of IMUs 65 in various positions after displacement due to ground movement. For example, in Figures 5A – 5C, one, two and three IMUs 65 are illustrated respectively in the monitoring module 15 with the dashed lines showing the prior positions of the IMUs 65 when first inserted into the bore. The use of a plurality of IMUs 65 in the first line 18 of sensors allow for simultaneous detection of the ground movement at various depths within the same bore. By determining the position of each IMU 65 in the monitoring module 15, a profile of the first line 18 of sensors may be determined. By monitoring the IMUs 65 and profile of the first line 18 of sensors, any ground movement may thus be detected. This could be by plotting or calculating the movement of each IMU 65 and the

entire first line 18 of sensors in the monitoring module 15. Figures 5B and 5C illustrates how the use of a plurality of IMUs 65 allows the measurement of the soil movement conditions at different vertical depths. In particular, the use of at least three IMUs 65 allows for a curve to be plotted for a more accurate determination of the ground movement. The use of more IMUs 65 allows the profile of the curve to be plotted with greater accuracy, in other words the monitoring module 15 provides greater sensitivity and resolution in the measurement. This may be achieved by having more IMUs 65 in each monitoring module 15 or connecting monitoring modules 15 in series to form a device as shown in Figure 5D. The flexible substrate restricts the relative motion of the IMUs 65 with respect to each other, and allows for a more controlled and accurate monitoring of the movement of the IMUs 65 and ground. This may be similarly applied to monitoring in a horizontal direction since the IMUs 65 measure in three dimensional space. Hence, the movement of the plotted line or curve may be determined and monitored continuously. This is not possible with existing devices.

In an embodiment, the IMUs 65 may be placed at regular intervals, for example 0.5 metres or 1 metre. With a spacing of 0.5 metres, and the use of ten and twenty IMUs 65, a distance of five and ten metres may be covered respectively with a single monitoring module 15. By varying the spacing interval and number of IMUs 65 different distances may be covered accordingly. The spacing interval need not be regular as well although it provides for easier data analysis. However, the greater the distance covered the more significant the signal loss such that the accuracy of the data decreases. In an embodiment, an optimal distance for each flexible strip will be ten metres or less. In another embodiment, the optimal distance is eight metres or less.

To measure a greater length or a deeper depth into the ground, a plurality of monitoring modules 15 may be attached in series as shown in Figure 3 and 5D to form a monitoring device 10. A first monitoring module 15 with a first line 18 of IMUs 65 is connected to a second monitoring module 15, at the last IMU 65 of the first line 18. This increases the measurement distance of the monitoring device 10 and allows a much greater distance or depth than may be possible with a single monitoring module 15. For example, if each monitoring module 15 measures up to a distance of five, eight, ten, twenty or more metres, twenty monitoring modules 15 may be combined to extend the measurement distance to a hundred metres while maintain the signal strength and accuracy.

The number and spacing interval of IMUs 65 may be varied according to the ground condition to be surveyed and depth. A higher concentration of IMUs 65 in a particular area or borehole may be desired (either by increasing the number and/or decreasing the spacing interval).

The monitoring module 15 may further comprise a second line 19 of sensors electrically connected to the processing unit 16. The second line 19 of sensors may be any one selected from the group comprising: a water pressure sensor, a pore water pressure sensor, pH sensor, sound level detector, a gas sensor, a salinity sensor, and a temperature sensor. Examples of a temperature sensor, which work by variation of electrical potential with temperature, includes a thermocouple, and a silicon bandgap temperature sensor. Examples of a gas sensor includes an oxygen sensor, a carbon monoxide sensor, and a carbon dioxide sensor. This allows the measurement of additional parameters like the pore water pressure, pH, presence of gas, temperature etc. that supplement the information provided by the IMUs 65.

The inclusion of a water pressure sensor or a pore water pressure sensor in particular will be advantageous as the water pressure relates to the water content in the ground. A certain amount of water increases the strength of the soil as the surface tension between the water and solid grains tend to hold the grains in place. However, when the amount of water increases further, the separation between the grains increases such that the frictional contact and force between the grains decreases or is lost, and the soil becomes liquid or fluid in nature (i.e. the ground becomes soft and has a higher tendency to sink or shift). Therefore, additional data of the water pressure or pore water pressure allows a greater understanding of the soil conditions, and could provide early warning signals of liquefaction of the soil.

The use of a pH sensor, a gas sensor a salinity sensor and/or a temperature sensor may be advantageous in checking the soil conditions for plants to ensure that the plants are able to grow well. This may be useful in agriculture or when vegetation is used to stabilise the soil conditions.

The second line 19 of sensors may be housed in a separate or same housing as for the first line 18 of sensors. The second line 19 of sensors are generally contact type of sensors in that the sensors need to physically contact the surrounding soil or ground to measure the parameter. Advantageously, the second line 19 of sensors allow the monitoring of these parameters within the same bore without having to drill another bore.

The processing unit 16 of the monitoring module 15 may further comprise a data transceiver 70 for receiving and transmitting data to the control box 20; a power converter 77; and an embedded processor 55 with signal processing. Power supply lines (for example two power supply lines) connect the power converter 77 and power supply module 75 of the control box 20 to provide the monitoring module/s 15 with electrical power.

Interface types may be provided to allow for the connection of the sensors 17 (from the first line 18 and/or second line 19) to the processing unit 16. Examples of interface types that may be provided to accommodate different sensor types include I2C 85, UART 90, and ADC 95. In an example, at least one port of each interface type is provided. In another example, there are two ports of each interface type. It will be apparent that the number of ports and interface type to be used may be adjusted accordingly to the number and type of sensors 17 required. The processor 55 and the compatible interface type allows for the sensor to be recognised by its signature signal.

An Inter-integrated circuit 85 (I2C) is a multi-master, multi-slave, packet switched, single-ended, serial computer bus. It is typically used for attaching lower-speed peripheral integrated circuits (ICs) to processors and microcontrollers in short-distance, intra-board communication.

A universal asynchronous receiver/transmitter 90 (UART), is a computer hardware device for asynchronous serial communication in which the data format and transmission speeds are configurable. The electric signalling levels and methods (such as differential signalling, etc.) are handled by a driver circuit external to the UART 90.

An analogue-to-digital converter 95 (ADC) is a system that converts an analogue signal into a digital signal. An ADC 95 may also provide an isolated measurement such as an

electronic device that converts an input analogue voltage or current to a digital number proportional to the magnitude of the voltage or current. This allows both digital and analogue sensors to be used with embodiments herein, if only digital sensors are used an ADC 95 may not be required.

5

A monitoring device 10 comprises two or more the monitoring modules 10 described. The monitoring modules 10 may be electrically connected to each other in series, and may further comprise a control box 20. Each of the monitoring module 10 in the device comprises a first line of sensors, the first line of sensors comprises at least one IMU 65.

10 A plurality of monitoring modules 15 each with one IMU 65 may function in the same manner as a monitoring module with a plurality of IMUs 65 in the first line 18 of sensors.

The control box 20 comprises a processor 55; a data transceiver 70 to receive and transmit data between the control box 20 and the monitoring module 15, preferably via a
15 physical link like a data bus (two data bus may be used for efficient data transmission); a power source 80; and a communications module 40 for transmitting the data collected by the monitoring device 10 to a central unit 30, aggregator device 25, or server 35.

The control box 20 may further comprise a data storage unit 72; and/or a GPS module
20 60 (to determine the coordinate of the device 10). The data storage unit 72 allows for the device 10 to store the sensor data before transmission to the central unit 30, this is particularly useful in the event of a communication failure between the device 10 and central unit 30. The GPS module 60 provides the positional reference of the monitoring device 10, control box 20, and monitoring module/s 15. The GPS module 60 may allow
25 the device 10 to identify its location and serve as an identification means.

The communications module 40 may further allow the device 10 to receive communications, for example a confirmation, from the aggregator device 25, server 35, or central unit 30, that the data has been transmitted successfully. This will allow for the
30 housekeeping of the data storage unit 72 when the storage capacity is full. User defined alert levels and monitoring frequencies may also be transmitted from the user terminal 30, or server 35, to the control box 20.

The power source 80 may be any suitable electrical power supply, for example electrical mains, on site generator, a fuel cell, and a solar cell. The use of a solar cell or a fuel cell will be particularly useful for remote monitoring devices 10, where electrical power may not be readily available and to be self-sustaining. The devices 10 may thus be deployed
5 and do not require regular maintenance to function.

The control box 20 further includes a power supply module 75 that utilises and distributes electrical energy to the modules 15 or sensors 17, preferably via a power supply cable. The processor 55 is an embedded processor to process the sensor data.
10 After the data is received, a signal is sent back to the control box to indicate that data transmission is successful, allowing the control box to clear its on-board storage if required. The data may be converted to suitable engineering units for presentation on tables and charts at the central unit 30.

The control box 20 may further comprise a ground line 21 of sensors electrically connected to the control box 20. The ground line 21 of sensors are disposed on a surface of a ground or structure to be monitored. For example, if the monitoring device 10 is placed in the bore, the ground line of sensors may be placed above ground to measure conditions above ground. The ground line 21 of sensors could supplement the
20 first line 18 and/or second line 19 of sensors, or measure different parameters. The ground line 21 of sensors comprises one or more sensors 17 selected from the group comprising an inertial measurement unit (IMU) 65, a water pressure sensor, a pore water pressure sensor, a sound level detector, a pH sensor, a salinity sensor, a gas sensor and a temperature sensor. Examples of a temperature sensor, which work by variation of electrical potential with temperature, includes a thermocouple, and a silicon
25 bandgap temperature sensor. Examples of a gas sensor includes an oxygen sensor, a carbon monoxide sensor, and a carbon dioxide sensor. The ground line 21 and second line 19 of sensors may or may not be the same. The control box 20 may further comprise one or more ports of various interface types for connecting the ground line 21
30 of sensors.

The control box 20 may be deployed singularly without the monitoring modules 15 for above ground measurements or together with the monitoring modules 15 in soil for measurement of soil parameters. The control box 20 may be above ground or partially

placed in the ground such that at least the GPS module 60, and the solar cell if present, is exposed.

5 The first line 18, second line 19, and ground line 21 of sensors may be programmed to send data periodically to the control box 20 based on a time schedule, when triggered by an event, or upon request from a user.

10 The time schedule and threshold levels may be set by a user, and adjusted as required via the control box 20. For example, the sensors 17 and IMUs 65 may transmit the data every minute, every hour etc. After reviewing the transmitted data, a user may wish to increase or decrease the monitoring frequency or threshold level. This adjustment may be sent from the user terminal 30 to the device 10, optionally via the aggregator device 25, and communication modules 40.

15 The data may also be sent to the central unit 30 when triggered by an event. A user defined alert level for a particular sensor 17, for example the IMU 65, or parameter, may be set. For example, when the IMU 65 detects a sudden surge in the acceleration which could indicate a ground movement event. The alerts may be pre-set according to the user, statutory requirements, or industry defined levels. Upon the sensor detection
20 exceeding the user defined alert level, the particular sensor 17 transmits the sensor data, or an alert signal, to the processing unit 16 and/or control box 20 which could in turn cause a request for sensor data to be send to all the sensors in the monitoring module 15 or monitoring device 10. The sensor data is subsequently forwarded to the central unit 30, or an alert is sent for the user's attention. Advantageously, this minimises
25 power usage and allows the monitoring device 10 or module 15 to be used in many locations for different purposes.

Similarly, the control box 20 may transmit the sensor data periodically, when there is un-transmitted data, and/or when called for by the user terminal, to the aggregator device
30 25, and/or central unit 30 and so forth. The frequency of transmission of the sensors 17 and control box 20 may or may not be the same to allow for efficient functioning of the device 10 and system 5 as a whole. A user may also be able to request for sensor data from a particular sensor 17, module 15, or device 10, from the central unit 30.

In addition, after successful transmission and receipt of the sensor data by the aggregator device 25, and/or central unit 30, a signal is sent back to the control box 20 to indicate that the data transmission is successful, thus allowing the control box 20 to clear its data storage unit 72 as required. The data is subsequently converted to suitable engineering units at the central unit 30.

The monitoring system 5 may be operated by obtaining data from at least one monitoring module 15 or at least one monitoring device 10, and determining the position of the IMUs 65 relative to each other to determine the profile of the first line 18 of sensors. The position of the IMUs may be plotted or calculated with respect to the original position or time to allow identification of any movement detected by the monitoring system. If a plurality of IMUs 65 are used, a line or curve plot may be obtained which provides a more accurate representation of the movement of the IMUs 65 and ground, in particular when the IMUs are disposed on a flexible substrate. This allows a user to study in greater detail the extent of movement at different depths or sections of the ground.

The monitoring module/s 15 and device 10 may be placed in any direction (including vertical and horizontal directions) to measure and monitor ground or structure movement. The flexible substrate allows the monitoring module 15 or device 10 to conform to the shape of the structure and after the displacement of the IMUs 65 for more accurate and sensitive measurements. Therefore, it is possible for the monitoring module/s 15 and device 10 to be used in the ground, boreholes, underground structures like a tunnel, a mine, a cavern, and structures above ground. The monitoring module/s 15 and device 10 may be used for monitoring along the length of the tunnel or cavern (i.e. horizontal direction) as well as being inserted in a bore (i.e. vertical direction).

By varying the number of IMUs 65 and the spacing between them, the sensitivity and resolution of the first line 18 of sensors (and hence monitoring module 15) may be adjusted to allow for measurement of both small and large ground movements. This is important as it allows the detection of the onset of ground movement whereby rectification works may be done to prevent or decrease further ground movement, while also being able to detect a large ground movement.

The flexibility of the monitoring module/s 15 and device allows it to be used on buildings and other structures as well. This is extremely important due to the rapid build-up in cities where structures are increasingly being built both under and above the ground surface. The monitoring module/s 15 and device 10 allows monitoring of a multitude of
5 structures because of its flexibility both physically and in terms of the choice of sensors 17 to be employed.

The monitoring module 15 and device 10 described herein may be used for simultaneous, accurate and sensitive multipoint measurement of ground movement, in
10 particular in a single bore. The monitoring module 15 and device 10 may be placed in position, and do not require regular maintenance or intervention by the user to function. By determining the relative position of the IMUs 65 and profile of the first line 18 of sensors, it is possible to detect movement in the ground or structure at an early stage without requiring a user's intervention or physical presence. The sensitivity and distance
15 covered by the monitoring module 15 and device 10 may be adjusted by increasing the number of IMUs 65 and/or modules 10.

The invention includes any combinations or sub-combinations of any of the embodiments or examples disclosed in the application, such as it is intended that the
20 appended claims be interpreted to include all modifications, permutations, additions and sub-combinations as are within the true spirit and scope of the embodiments discussed.

Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned
25 that many variations or modifications in details of design or construction may be made without departing from the present invention.

Claims

1. A monitoring device comprising two or more monitoring modules electrically connected in series; and a control box electrically connected to the two or more monitoring modules, each monitoring module comprises a first line of sensors adapted to determine a profile of a bore within the ground or a structure along a length of the first line of sensors, wherein the first line of sensors comprises at least one inertial measurement unit (IMU) disposed along a flexible substrate, a processing unit, each IMU is electrically connected to the processing unit, the processing unit comprises: an embedded processor with signal processing, a data transceiver for receiving and transmitting data to the control box, and a power converter.
2. The monitoring device according to claim 1, wherein the monitoring module further comprises a second line of sensors connected in parallel to the first line of sensors.
3. The monitoring device according to claim 2, wherein the second line of sensors comprises at least one sensor selected from the group comprising of: a water pressure sensor, a pore water pressure sensor, a pH sensor, a sound level detector, a gas sensor, a salinity sensor, and a temperature sensor.
4. The monitoring device according to any one of the preceding claims, wherein the first line of sensors comprises 16 or less equally spaced apart inertial measurement units.
5. The monitoring device according to any one of the preceding claims, wherein there at least two inertial measurement unit, each 0.5 metres apart.
6. The monitoring device according to any one of the preceding claims, wherein the length of the flexible substrate is 8 metres or less.
7. The monitoring device according to any one of the preceding claims, wherein the inertial measurement units in each line of sensors are connected in series.
8. The monitoring device according to any one of claims 2 to 7, wherein the first and second lines of sensors are each housed in a housing.

9. The monitoring device according to any one of the preceding claims, wherein each module is connected to each other in series.
10. The monitoring device according to any one of the preceding claims, wherein the control box further comprises a GPS module.
11. The monitoring device according to any one of the preceding claims, wherein the control box further comprises a power source connected to the power convertor, the power source is a fuel cell or a solar cell.
12. The monitoring device according to any one of the preceding claims, further comprising a ground line of sensors electrically connected to the control box, disposed on a surface of a ground or structure to be monitored.
13. The monitoring device according to claim 12, wherein the ground line of sensors comprising at least one sensor selected from the group comprising of: a water pressure sensor, a pore water pressure sensor, a pH sensor, a sound level detector, a gas sensor, a salinity sensor, and a temperature sensor.
14. A monitoring system comprising:
 - (a) at least one monitoring device according to any one of claims 1 to 13; and
 - (b) a central unit,wherein the central unit comprises a communications module for receiving and transmitting data from the at least one monitoring device.
15. The monitoring system according to claim 14 comprising an aggregator device, wherein the aggregator device serves as an intermediary between the at least one monitoring module or at least one device and the central unit.
16. A method for monitoring, the method comprising:
 - (a) obtaining data from at least one device according to any one of claims 1 to 13; and
 - (b) determining a position of each inertial measurement unit relative to each other to determine the profile of the first line of sensors.

17. The method according to claim 16, wherein obtaining the data is based on a time schedule, triggered by an event, or upon a user's request.