DEVICE AND METHOD OF SENSING AND ACQUIRING DATA

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The application claims the benefit of priority of Singapore patent application No. 10202105665Q, filed 28 May 2021, the content of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] The disclosure relates to a data acquisition device and method of sensing and acquiring data, particularly, but not limited to, strain data.

BACKGROUND

[0003] Various sensors, such as Fiber Bragg grating (FBG) sensors, have been adopted for structural health monitoring (SHM) in civil, mechanical and/or offshore engineering applications. An FBG sensor is an optical sensor which is interrogated using one or more spectrometers so as to receive recorded wavelength shift and data as a function of the applied strain. The spectral/wavelength shift may then be correlated to a change in intensity so as to allow a user to convert the optical intensity to an analog voltage, enabling relatively low-cost electronic components to be adopted in systems which adopt FBG sensors.

[0004] Another type of sensor used for SHM is the electrical strain gauge (ESGs). ESGs may be deployed in dry areas for mechanical strain measurements and are relatively reliable. The ESG can be interrogated by several types of conventional devices or data acquisition systems.

[0005] Currently, FBG sensors and ESGs are deployed and interrogated separately with optical and electrical devices for obtaining tensile or compressive strain measurements. A typical data acquisition system (DAQ) for obtaining strain measurements may include either an FBG or an ESG arranged in data communication with a laptop to display the measurements. In structures where multiple measurements are required, multiple DAQs may need to be deployed. This may lead to increase in components and costs associated with obtaining strain measurements on different civil, mechanical and/or offshore engineering applications. In addition, any collected measurements may be in various data types and often require further

processing before the measurements can be viewed by a user. Such further processing may yet require additional components.

[0006] There exists a need to provide a solution to reduce costs and form factor associated with the sensing and acquiring of data, in particular stain measurements and data.

SUMMARY

[0007] A technical solution in the form of an integrated data acquisition device is proposed where ESG and FBG sensors may be integrated into a single device. The ESG and FBG sensors may form part of a sensing and transducer module such that the transduced signals are standardized in a digitalized differential voltage form to facilitate ease of display on a computer device. The integrated data acquisition device may form part of a complete system-in-box from sensor measurement to data transfer.

[0008] According to an aspect of the present disclosure, a device for sensing and acquiring strain data is provided The device comprises a first sensing and transducer module configured to sense and obtain a first strain signal; a second sensing and transducer module configured to sense and obtain a second strain signal; a data acquisition module arranged in signal or data communication with the first sensing and transducer module and the second sensing and transducer module, the data acquisition module comprises a selector configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital value.

[0009] In an embodiment, the first sensing and transducer module comprises an electrical strain gauge acquisition unit having an electrical foil strain gauge sensor.

[0010] In an embodiment, the first sensing and transducer module comprises a Wheatstone bridge circuit, and the electrical foil strain gauge sensor forms an arm of the Wheatstone bridge. The Wheatstone bridge may be configured such that the potential difference across two nodes of the Wheatstone bridge circuit vary according to a change in measured resistance of the electrical foil strain gauge sensor.

[0011] In an embodiment, the second sensing and transducer module comprises an optical sensor module which comprises an interrogation arm having a CFBG sensor and a sensing arm having an CFBG sensor or UFBG sensor, the interrogation arm is configured to be operating at either an identical or a co-located band as the sensing arm. The band of the CFBG or UFBG

sensor(s) may selected from a linear portion of a slope (rising or falling) of a power intensity vs wavelength graph associated with a wide-band light source.

[0012] In an embodiment, the interrogation arm is built-in with an LED light source, and wherein the sensing arm is operatively arranged to connect externally to obtain strain measurements.

[0013] In an embodiment, the data acquisition module comprises a transceiver module, wherein the transceiver module includes a single board computer for interfacing with the selector using universal asynchronous receiver-transmitter (UART) communication protocol.

[0014] In an embodiment, the first strain signal and/or the second strain signal is the form of an analogue differential voltage, and the analogue differential voltage is amplified before conversion to a digital value.

[0015] According to another aspect of the present disclosure there is provided a system for monitoring strain on a structure comprising a first sensing and transducer module having an ESG sensor attached to the structure, the ESG sensor configured to sense and obtain a first strain signal associated with an application of tensile or compressive strain on the structure; a second sensing and transducer module having a fiber-optic based sensor attached to the structure, the fiber-optic based sensor configured to sense and obtain a second strain signal; a data acquisition module arranged in signal or data communication with the first sensing and transducer module and the second sensing and transducer module, the data acquisition module comprises a selector configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital value.

[0016] In an embodiment, the transceiver module comprises a single board computer arranged in wireless communication with the selector to receive the converted digital value for further transmission to a terminal device for display.

[0017] In an embodiment, the first sensing and transducer module comprises a Wheatstone bridge circuit, and the ESG sensor is a resistive arm of the Wheatstone bridge.

[0018] In an embodiment, the second sensing and transducer module comprises an optical sensor module, the optical sensor module comprises an interrogation arm having a CFBG sensor and a sensing arm having an CFBG sensor or UFBG sensor, the interrogation arm is configured to be of either an identical or a co-located band as the sensing arm.

[0019] In an embodiment, the at least one of the first sensing and transducer module, the second sensing and transducer module, and the data acquisition module is arranged in wireless communication with respect to other modules.

[0020] In an embodiment, the received first strain signal or the received second strain signal, and digital value are stored in a database for transmission to a terminal device.

[0021] According to another aspect of the present disclosure there is provided a method for sensing and acquiring strain data comprising obtaining a first strain signal from an ESG sensor attached to the structure and sending the first strain signal to first sensing and transducer module; obtaining a second strain signal from a fiber-optic based sensor attached to the structure and sending the second strain signal to a second sensing and transducer module; transducing the first strain signal and second strain signal to respective analogue values; and selecting the respective analogue value and converting the analogue value to a digital value.

[0022] In some embodiments, the method further comprises storing the converted digital value in a data set for display on a computer device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The disclosure will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

- FIGS. 1A and 1B illustrates prior art devices of sensing and acquiring strain data based on a resistance based on an electrical strain gauge and an FBG sensor respectively;
- FIG. 2 shows a system diagram of an integrated device for sensing and acquiring strain data based on at least two sensing and transducer module;
- FIG. 3 shows a schematic diagram of a first sensing and transducer module arranged in a Wheatstone bridge configuration according to an embodiment;
- FIGS. 4A, 4B and 4C shows three possible embodiments of a second sensing and transducer module utilizing fiber-optic sensors;
- FIGS. 5A and 5B illustrate a data acquisition module in the form of an integrated circuit prototyping kit and a built-in schematic design according to an embodiment;
- FIG. 6 illustrates a flowchart of the programmed IC prototyping kit for data acquisition;
- FIG. 7 illustrates an integration of the various components shown in FIG. 3, FIG. 4A, FIGS. 5A, and 5B according to an embodiment;

- FIGS. 8A to 8D show an experimental setup having sensors attached along a length of a beam to measure tensile and/or compressive strain to test the integrated device.
- FIG. 9A show plots of light intensity (y-axis) vs wavelength (x-axis) spectra for transmitted light of a sensing CFBG used in the present disclosure for different tensile strain applied with 0.1N load increment; right shift with increasing load.
- FIG. 9B show plots of light intensity (y-axis) vs wavelength (x-axis) spectra for transmitted light of the sensing CFBG for different compressive strain applied with 0.1N load increment; left shift with increasing load.
- FIGS. 10A and 10B show loading and unloading curves of sensors of the integrated device attached to an aluminium cantilever beam, displaying results obtained from a conventional DAQ (NI DAQ) and the integrated device of the present disclosure;
- FIGS. 11A and 11B show tensile and compressive loading strain data (x-axis) respectively plotted in normalized scales (y-axis), displaying results obtained from a conventional DAQ (NI DAQ) and the various sensors of integrated device of the present disclosure;
- FIG. 12A shows loading and unloading curves of sensors attached to the aluminium cantilever beam, displaying results obtained from a conventional DAQ and the second sensing and transducer module of integrated device of FIG. 4B.
- FIG. 12B shows loading and unloading curves of sensors attached to the aluminium cantilever beam, displaying results obtained from a conventional DAQ and the second sensing and transducer module of integrated device of FIG. 4C.
- FIG. 13 shows an embodiment of the data acquisition module of the integrated device capable of receiving input from multiple sensing and transducer modules;
- FIG. 14 is a table showing the key features of the integrated device compared separately with standalone prior art devices of FIG. 1A and FIG. 1B.

DETAILED DESCRIPTION

[0024] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure. Other embodiments may be utilized and structural, logical

changes may be made without departing from the scope of the disclosure. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0025] Embodiments described in the context of one of the systems or methods are analogously valid for the other systems or methods.

[0026] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0027] In the context of some embodiments, the articles "a", "an" and "the" as used with regard to a feature or element include a reference to one or more of the features or elements.

[0028] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0029] As used herein, the term "strain data" broadly include at least one of value, reading, calculation, derivation and measurement associated with the change of length of a material relative to its initial length. Strain may be expressed in a unit known as microstrain ($\mu\varepsilon$). The change in length may be a result of a tensile force (expressed as a positive measurement) or a compressive force (expressed as a negative measurement) applied on the material.

[0030] As used herein, the term "module" refers to, or forms part of, or include an Application Specific Integrated Circuit (ASIC); an electrical/electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor.

[0031] In the following, embodiments will be described in detail.

[0032] FIG. 1A shows a prior art device in the form an electrical strain gauge 1 connected with a laptop device 2 & a data acquisition system 3 to sense and obtain electrical strain data. FIG. 1B shows a prior art device in the form of an optics interrogation system 5 connected with laptop device 6 and FBG sensor 7. In both devices, routers 8 may be connected with the system

3, 5 to facilitate remote data transfer and monitoring. As may be appreciated, multiple sets of devices shown in FIG. 1A and FIG. 1B may be required to sense and obtain strain data from various points of a structure, leading to increased costs associated with components.

[0033] FIG. 2 shows a schematic view of a device 100 for sensing and acquiring strain data. The device 100 may be monitoring device and may include a data acquisition device comprising a first sensing and transducer module 102 configured to sense and obtain a first strain signal; a second sensing and transducer module 104 configured to sense and obtain a second strain signal, and a data acquisition module 106 arranged in data communication with the first sensing and transducer module 102 and the second sensing and transducer module 104, the data acquisition module comprises a selector 108 configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital voltage value. The digital voltage value may be a digital differential voltage or single-ended voltage value associated with signals obtained from multiple channels, depending on configuration and/or programming. In some embodiments, the single-ended voltage may be obtained based on voltage input obtained from an input pin, and a reference voltage (e.g. ground voltage).

[0034] In some embodiments, the device 100 may be implemented in the form of an integrated data sensing and acquisition system capable of sensing and receiving strain data from at least one electrical sensor and at least one optical sensor. The electrical sensor may be a resistive-based sensor wherein the first strain signal is obtained in the form of an electrical resistance value. The optical sensor may be a fiber-optic sensor, in particular a Fiber Bragg Grating (FBG) sensor, wherein the second strain signal may be obtained in the form of light intensity value.

[0035] FIG. 3 shows a schematic diagram of the first sensing and transducer module comprising a resistance sensor whose resistance varies with an applied strain force. It can be used to convert force, pressure, tension into an electrical resistance value or a change in electrical resistance value. The applied strain on a surface the resistance sensor is applied to can be measured by this change in resistance. In an embodiment, the resistance sensor is in the form of an electrical strain gauge 202, such as an electrical foil strain gauge. Due to the relatively small change in resistance values, the electrical strain gauge 202 may be implemented or arranged as to form a resistive arm of a Wheatstone bridge circuit arrangement comprising four resistive arms. In such an arrangement, the electrical strain gauge 202 may be

regarded as a resistor R4 as shown in FIG. 3, while the other three arms R_1, R_2 and R_3 may be fixed and calibrated based on a no-strain resistance value of R4.

[0036] In operation, an excitation voltage V_{EX}, such as 5 volts (V) may be applied across the Wheatstone bridge. The potential difference across two nodes (V_1 & V_2) will change according to the resistance of strain gauge. As the electrical strain gauge may be regarded as a variable resistor correlated to the measured strain applied.

[0037] The output or the potential difference (V_0) between two nodes V_1 and V_2 may be mathematically expressed in Equation (1) as follows:

$$V_o = \left[\frac{R_3}{\{R_3+R_4\}} - \frac{R_2}{\{R_2+R_1\}}\right] * V_{Ex} \quad (1)$$

which may be simplified as follows in Equation (2)

$$V_o = \left[\frac{1}{\{1+R_4/R_3\}} - \frac{1}{\{1+R_1/R_2\}}\right] * V_{Ex} \quad (2)$$

[0038] From Equation (2), it may be noted that if ratio of resistances on side defined by R_1 and R_2 is equal with the side defined by R_3 and R_4, i.e., if condition $R_1/R_2 = R_4/R_3$ is satisfied, then V_O becomes zero. In this case, the Wheatstone bridge is balanced and no strain measurement is detected on the material the electrical strain gauge 202 is positioned or applied on.

[0039] In some embodiments, the fixed resistors R_1, R_2, R_3 in the Wheatstone bridge are chosen to be a fixed value consistent with the standard resistance value of current ESG, for example, but not limited to, 120 ohms (Ω). That is, $R_1=R_2=R_3=120$ Ω. If the excitation voltage V_{EX} provided to the Wheatstone bridge is 5V, Equation (2) may be further simplified to Equation (3) as follows:

$$V_o = \left[\frac{1}{\{2+(\Delta/120)\}} - \frac{1}{2}\right] * 5 \quad (3)$$

where Δ is the change in the resistance of the ESG from 120 Ω when a strain force is applied on a structural surface where the ESG is attached. As may be appreciated, the output voltage is zero if there is no change in resistance. When a strain is induced or detected on the surface where the ESG is mounted, the resistance of the ESG changes, varying from 120 Ω. This change unbalances the bridge and causes the potential difference between the nodes (V_0) becomes non-zero. Although R_1, R_2 and R_3 are chosen to be 120 Ω because of the availability of the 120 Ω strain gauge, it is appreciable that the resistance may be replaced or adjusted to work for any value of resistance of strain gauge and resistors connected. In that case, the required analogue resistance signal can be found by the general Equation (1).

[0040] FIGS. 4A, 4B and 4C show schematic diagrams of three different embodiments of the second transducer 104, each comprising a plurality of fiber optics sensors.

[0041] In the embodiment shown in FIG. 4A, the second sensing and transducer module 104A comprises a LED light source 402, an optical coupler 404, a splitter 406, an interrogation arm 408, strain sensing arm 410, and temperature sensing arm 412. Optical signals detected by the strain sensing arm 410 is output to a transducer 414, which converts the optical signals to electrical signals. Optical signals detected by the temperature sensing arm 412 is output to a transducer 416, which converts the optical signals to electrical signals. The interrogation arm 408, strain sensing arm 410, and temperature sensing arm 412 may each comprise a Chirped Fiber Bragg Grating (CFBG) Fiber-Optic Sensor and in the embodiment shown in FIG. 4A, all three arms 408, 410, 412 comprise CFBGs.

[0042] The operation concept is based on the interrogation of a sensing FBG 410, 412 using another FBG 408 of identical or co-located band. The LED light source 402 may suitably be a wide-band light source and the operating band of the fiber Bragg grating may be selected from a linear portion of a slope (rising or falling) of a power intensity vs wavelength graph associated with the LED light source 402. In some embodiments, the linear portion may correspond to a mid-slope . In some embodiments, the LED source 402 and the interrogation arm 408 may be in-built. The sensing arms 410, 412 can be connected externally when it is used as an optical strain sensor. The three CFBG sensors in the respective arms 408, 410, 412 may operate in a 1300 nanometres (nm) or 1500 nm band. For the sensing arms 410, 412, a bandwidth of 4 – 6 nm may be used. In some embodiments, a bandwidth wider than 6 nm may be contemplated.

[0043] The light source 402 may be a 1300 nm pigtailed LED light source. The fibre coupler 404 may be a (2X2) coupler, i.e. allowing single fiber input to be split into two outputs or vice-versa, and the splitter 406, which is also an optical fiber coupler, is a (1X2) coupler, i.e. allowing single fiber input to be split into two outputs without vice-versa. Light intensity sensed and transmitted from strain sensing arm 410 and temperature sensing arm 412 may be measured, received and/or quantified using photodiodes. One CFBG is used for strain measurement, tensile or compressive, by mounting it at the target point on a structure, and another CFBG is used for temperature compensation without mounting it on the structure.

[0044] The sensing and transducer module 104A is next described in the context of its operation.

[0045] As shown in FIG. 4A, the light from light source 402 enters interrogation arm 408 via the coupler 404. The light is reflected and goes back to coupler 404, and then the reflected light enters splitter (coupler) 406 and gets divided between the strain sensing arm 410 and the temperature sensing arm 412. The transmitting ends of the strain sensing arm 410 and the temperature sensing arm 412 are connected to one or more photodiodes (not shown). The photodiode converts optical power to electrical voltage through the respective optical to analogue transducers 414, 416. The voltage value changes as the strain sensed by the strain sensing arm 410 changes. The temperature sensing arm 412 is used to compensate the effect of ambient or surrounding temperature and the output of the transducer 416 functions as a reference signal. As the transmitted spectra of an FBG is a function of both the temperature and strain, the actual strain can be calculated by taking difference of values between the converted analogue values. The architecture of FIG. 4A is relatively flexible and can be arranged in various combinations to operate in a transmission mode or a reflection mode, depending on the application. Uniform FBGs (UFBG) can also be used as the sensing unit as presented in FIG. 4C.

[0046] FIG. 4B shows another embodiment of the second sensing and transducer module 104B. In this embodiment, the sensing arm 412 and interrogation arm 408 are arranged in a cascaded form or in series. Light emitted from the LED light source 402 is split, via the splitter 406, between input to the sensing arm 412 and input to an optical to electrical transducer 418, which generates a reference voltage signal for comparison with optical to electrical transducer 414. The embodiment 104B comprise two CFBGs which is relatively cheaper compared to the three CFBG architecture shown in FIG. 4A. It provides temperature compensated strain values provided both CFBGs are placed at the same ambient temperature.

[0047] In another embodiment shown in FIG. 4C, the second sensing and transducer module 104C comprises a uniform FBG (UFBG) 411 as the sensing arm. In this embodiment, the UFBG is interrogated with a CFBG 408. The UFBG spectrum is configured to be around the centre of the CFBG spectrum. The light source may be in the form of a SLED can be substituted with a LED and similar data can be obtained with 1300 nm band. This can be another alternate configuration where the optical component of FIG. 4A is replaced by FIG. 4C.

[0048] The optical sensing concept using the FBG is based on the interrogation of sensing CFBG/UFBG using another CFBG of identical or co-located band. The working band is selected at the mid-slope (rising or falling) of a wide-band light source, such as a light emitting

diode (LED). The operating range of the sensor is determined by this configuration. As the sensing UFBG arm bends or senses strain, the intensity of Bragg wavelength increases or decreases (due to the slope or monotonously changing intensity of light coming from CFBG), which is later captured by transducer . Advantage of this combination over other architectures is that it requires only one CFBG sensor and one UFBG sensor, which further decreases the cost of the system due to relatively cheap availability of the UFBG. While FIGS. 4A, 4B and 4C show three possible embodiments, it is contemplated that the further permutations of elements 404, 406, 408, 410, 412 may be envisaged by a skilled person to provide further embodiments. It is further contemplated that in addition to strain data, other data such as temperature data and vibration related data may be obtained from the second transducer 104.

[0049] FIG. 5A shows an embodiment of the data acquisition module 106 in the form of a prototyping kit 500, such as a CY8ckit-059 prototyping kit, may be used for the development and implementation of module 106. It is envisaged that the prototyping kit may be replaceable by a physical integrated circuit or other alternative module. As shown, the kit may comprise a programming and debugging portion 502 and a target portion 504. The target portion 504 comprises a plurality of general-purpose input/output (GIPO) pins 506 for receiving a pair of analogue inputs from each of the first sensing and transducer module 102 and the second sensing and transducer module 104. The kit may include a connector, such as a USB connector, for receiving power supply, for example a 5V power supply, to power the kit.

[0050] FIG. 5B shows a schematic diagram of the programmed target portion 504 to implement the selector 108. In the embodiment shown, the selector 108 comprises an analogue multiplexer (AMux) 510 and an analogue to digital convertor (ADC) 512. The ADC is a high resolution on-chip 20-bit ADC used to convert the acquired analogue voltage signals from the first sensing and transducer module 102 and second sensing and transducer module 104 to digital signals. The ADC may be programmed to be a multi-channel ADC, wherein the pins P3_0 and P3_1 collectively form one channel (506a) and the pins P3_2 and P3_3 collectively form another channel (506b). Based on the number of GPIO pins of the kit 500, up to twenty-three channels may be programmed. The ADC is configured to operate in the differential mode as potential difference of the nodes (e.g. potential difference between pin P3_1 and P3_0) is required to be taken to provide an indication of the sensed strain force associated with the first sensing and transducer module 102. FIG. 5B further shows a universal asynchronous receiver-transmitter (UART) module 514 to facilitate data communication with the transceiver 110. The

UART module 514 may be programmed in a transmit mode to facilitate transmission of data from the selector 108 to the transceiver 110.

[0051] The V_1 terminal from the Wheatstone bridge circuit is connected to pin P3_0 and V_2 is connected to pin P3_1 to take the differential voltage. The output of transducer connected with the strain sensing 414 is connected to pin P3_2 and the output of transducer connected with reference signal 416 is connected to pin P3_3.

[0052] The analogue multiplexer (AMux) 510 is used to switch between receiving inputs from the plurality of channels, which facilitate simultaneous data acquisition from the various types of sensors. After each switching of channel, the ADC 512 is fed with a pair of analogue signals either from the first sensing and transducer module 102 which is based on resistance sensing (P3_0 and P3_1) or from the second sensing and transducer module 104 which is based on optical sensing (P3_2 and P3_3). The ADC 512 receives input from any one electrical sensor or optical sensor one at a time or may receive input in batches. It is envisaged the manner in which the inputs are received may be varied. The ADC 512 then computes the difference of each pair of signals and converts the analogue signal to digital.

[0053] It is appreciable that the number of differential channels can be increased. As one differential pair is formed using two GPIOs, which may be, but not necessarily neighbouring GPIOs, the maximum number of differential pairs can be increased to the half of the total number of GPIOs. Based on the CY8ckit-059 kit, there are 46 GPIOs, the maximum differential channels can go up to twenty-three. A maximum of twenty-three ESGs and/or CFBG sensors can be connected to the kit simultaneously with modifications in the design and program. In other words, up to twenty-three sensing and transducer modules may be accommodated for the device 100 if the kit 500 is utilized.

[0054] However, more channels utilized may imply less sampling frequency per channel because the maximum sampling frequency offered by the ADC will then be distributed among the connected channels. The maximum sampling frequency may vary depending on the resolution of the ADC selected or chosen. In a non-limiting example, the resolution may be around twenty-two samples per second for 20-bit resolution. This sampling rate meets the requirement for static measurement in engineering applications. The sampling frequency per channel can be given by Equation (4) as follows.

$$Sampling\ frequency\ per\ channel\ (differential\ or\ single\ ended) = \frac{Max_m\ sampling\ frequency\ configured\ in\ ADC}{Number\ of\ channels\ (differential\ or\ single\ ended)} \quad (4)$$

[0055] The high-resolution ADC provides for an on-chip gain (on-chip amplifier). The on-chip amplifier can be utilized to amplify the signal received and therefore can detect even one or more microvolts of change in the potential difference between the channels. Advantageously, external amplifier(s) are not required. While further external components may be contemplated, any external circuitry may add noise to signal and therefore it is preferred to use on-chip amplification and high-resolution ADC. In some embodiments, the differential input (e.g. voltage differential between pin P3_0 and P3_1 (first channel) or P3_2 and P3_3 (second channel) may be amplified approximately by a factor of seven before it is sent to the transceiver module 110 for further processing. In other words, the values plotted on any graph for display to a user is approximately seven times the differential analogue voltage sensed by the device 100.

[0056] In some embodiments, the ADC may be configured to continuously sample analogue input from the respective transducers 102, 104. The resulting data (samples) may be processed and sent to the transceiver module 110, which may comprise a Single Board Computer (SBC) to receive data over a universal asynchronous receiver transmitter (UART) connection configured in a receive mode to communicate with the UART module 514. The UART connection configured in a receive mode may include another similar UART module (not shown). The SBC may further be configured to connect with a 4G Internet dongle to function facilitate data transceiving with an optional terminal device (e.g. a personal computer). The transceiver module 110 and selector module 108 may function as separate units which can interface with each other using UART communication protocol.

[0057] The output signal or data via the UART module 514 may be sent to the SBC for further processing. Once the signals are received by the single board computer, they can be further transmitted via for example, a wireless communication protocol, and viewed via any serial terminal program and plotted with graphical user interface (GUI) software. In some embodiments, an internet connection may be provided to the single board computer by connecting a mobile network adapter device, such as a Universal Serial Bus (USB) dongle with the single board computer. The single board computer can be accessed remotely using a suitable protocol for remote access to graphical user interfaces, such as the Virtual Network Computing (VNC) protocol, via internet connection. The user can access and view the data remotely (via wireless network) on a client terminal.

[0058] In some embodiments, the single board computer may be combined or integrated with a data acquisition module 106 to form a single device/module/board.

[0059] FIG. 6 shows a flow chart which illustrates the programming for the data acquisition process 600. The process begins by an initialization process 602 of the analogue multiplexer 510, ADC 512, UART module 514, the total number of channels to obtain sensing input from (corresponding to the number of sensing and transducer module 102, 104), and setting a channel counter to zero.

[0060] After initialization 602, the data acquisition module 106 is configured to receive data from the respective transducers 604, each transducer connected to one channel. For example, the analogue multiplexer 510 selects a channel (e.g. 506a), and converts the differential voltage obtained from the Wheatstone bridge to a digital data by the ADC 512. The digital data is then sent to the single board computer using UART connection between one or more pair of UART modules for further transmission or display, and the channel counter is increased by 1 to select the next channel, e.g. 506b, for receiving data from the transducers 414 and 416 and the same data acquisition process repeats. At the same time, the channel counter value is checked if it has hit the last channel to acquire data from 606, and if so, the channel counter is reset to 0 (608). If not, the data acquisition process repeats for the next channel.

[0061] FIG. 7 shows the integration system design of the embodiments described in FIG. 3 to FIG. 6 with wireless capability to send data to an optional terminal end user device, for example a personal computer. The design illustrates how the device 100 is able to sense strain force from both type of sensors (electrical and optical) simultaneously. In some embodiments, Real-time data from both optical and electrical sensors can be displayed simultaneously on one screen. The unique advantage of combining two different sensing systems into one device/one platform is established with the measurement results.

[0062] FIG. 8A shows an experimental setup 800 having the ESG sensor 202, and CFBG sensor 410 attached to a test structure in the form of a cantilever beam 802 along the length of the cantilever beam 802. The ESG sensor 202 and CFBG sensor 410 may be connected to the remaining components housed in a box 804 via suitable electrical wires 806 and connectors 808 available. For example, the rest of the Wheatstone bridge circuit shown in FIG. 3 and the optical components shown in FIG. 4A may be housed in the box 804. The experiment is conducted to find out the amount of voltage change when the sensors 202, 410 are attached to a structure experiencing certain amount of strain.

[0063] FIG. 8B shows the cantilever beam 802 having a length of 22.2 centimetres (cm). The FBG sensor 410 and ESG sensor 202 are pasted at the distance of 5.5 cm from a fixed point 810 which is mounted onto an elevated structure so as to facilitate the application of strain force on the cantilever beam pivoted about the fixed point 810. FIG. 8C shows the cantilever beam made of aluminium being mounted on the elevated platform 812 and loaded at its free end with metal pieces 814, allowing a change of 0.1 N at each loading/unloading step to simulate a tensile strain force applied. FIG. 8D illustrate the sensors positioned underneath the cantilever beam 802 (i.e. opposite surface from the FIG. 8C) used to measure compressive strain force.

[0064] The measurement procedure comprises four parts:

(a) The setup is referenced with a conventional data acquisition system (DAQ) such as the NI DAQ after calibration.

(b) The loading and unloading data (in microstrain με) are measured from the ESG sensor 202

(c) The loading cycle is referenced for the FBG sensor 410 with an OSA.

(d) The device 100 is then used to record the same cycle of loading and unloading. The acquired data are then compared and graphs were plotted as shown in FIGS. 9A to 9E.

[0065] For calibration purpose, a convention DAQ, the *NI-9237 C Series Strain/Bridge Input Module,* is used to record the strain force experienced by the ESG sensor 202. Loading and unloading tests are conducted with 0.1N load change at the free end of the aluminium cantilever beam 802 at incremental loads of 0.1N up to 0.5N for loading (in increments of 0.1N), and from 0.5N to 0.1N (in decrements of 0.1N) for unloading. The corresponding strain values are recorded and used as reference for further tests on one or more electric strain gauges 202 and CFBG sensors 410. It is appreciable that data obtained by these sensors may be via wireless communication protocol such as broadband mobile communications, for example 4G mobile communication protocol.

[0066] To obtain tensile strain measurement or readings, the experimental setup illustrated in FIG. 8C is used, and the spectra (intensity vs wavelength) for tensile strain is recorded, as shown in FIG. 9A. It can be noted that as the intensity of light increases, the spectra shifts to right when the load increases.

[0067] To get the compressive strain measurement, the experimental setup illustrated in FIG. 8D is used and the spectra (intensity vs wavelength) for compressive strain is plotted in

FIG. 9B. It can be noted that as the intensity of light decreases, the spectra shifts to left when the load increases.

[0068] FIG. 10A show graph plots of change in voltage output (after UART module 514) of the developed device 100 (labelled as InDEO in the various graphs) when strain is experienced by the ESG 202 for the loads 0.1N to 0.5N, compared with the conventional method of measurement for ESGs, i.e., using a conventional DAQ *NI-9237 C Series Strain/Bridge Input Module*. Results show that the device 100 achieves a similar measurement as the conventional DAQ.

[0069] FIG. 10B show graph plots of the change in voltage in the output (after UART module 514) of the developed device 100 when strain is experienced by the CFBG sensor 410, loading and unloading tests are conducted to measure the tensile and compressive strain. Compared with the conventional measurement using a conventional optical spectrum analyser (OSA) for the same test (loading only). Results show that the device 100 achieves a similar measurement as the conventional OSA.

[0070] The data acquired and displayed in the graph of FIG. 10A and FIG. 10B show that linearity is observed in all the graphs. The data collected via the conventional DAQ may be used to calibrate the data collected from the ESG 202. The OSA is the conventional method of measuring CFBG wavelength shift and power, and the data shown in FIG. 10B are used to verify the strain data obtained from the CFBG 410.

[0071] In some embodiments, the voltage output values from the transceiver module 110 may be normalized, as shown in FIG. 11A for tensile strain and FIG. 11B for compressive strain. It was found that the normalized strain data match relatively well with the reference data obtained from the conventional DAQ.

[0072] These results demonstrate that the device 100 is capable of interrogating both optical and electrical sensors, and is suited for deployment as an integrated system for concurrent optical and electrical strain sensing. In addition, the device 100 may be 4G-enabled and therefore facilitates remote and real time structural health monitoring.

[0073] Based on the comparative graphs shown in FIG. 10 and FIG. 11, the device 100 is shown to work seamlessly for the first sensing and transducer module 102, and the second sensing and transducer module 104.

[0074] FIG. 12A shows a comparative graph plot of the second sensing and transducer module 104B shown in FIG. 4B. The test results obtained based on a conventional DAQ and

the device 100 using the experimental setup shown in FIGS. 8A to 8D are presented in FIG. 12A. The graph plots show a response that is comparable to data obtained from a commercial DAQ system.

[0075] FIG. 12B shows a comparative graph plot of the second sensing and transducer module 104C shown in FIG. 4C. The test results obtained based on a conventional DAQ and the device 100 using the experimental setup shown in FIGS. 8A to 8D are presented in FIG. 12B. The graph plots show a response that is comparable to data obtained from a commercial DAQ system.

[0076] Although the aforementioned embodiments have been described with respect to two sensing and transducer modules, it is appreciable that multiple sensing and transducer modules up to a maximum number of channels are contemplated. It is also contemplated the single board computer may be integrated as part of the device in the form of a customized chip or board.

[0077] FIG. 13 shows a system diagram illustrating multiple optical-based sensing and transducer modules and multiple resistive-based sensing and transducer modules. The embodiment of FIG. 13 is capable of multiplexing multiple units up to twenty-three sensing and transducer modules for parallel processing, although it is contemplated that more sensing and transducer modules may be multiplexed depending on configuration and/or hardware improvements. The illustration shows two optical-based sensing and transducers and one resistive-based sensing and transducer arranged in parallel, configured as inputs into the ADC. As mentioned, the device 100 may be equipped with a 4G or 5G mobile network adapter device. This advantageously provides remote monitoring capabilities.

[0078] In some embodiments, the FBG based strain signal obtained from the second sensing and transducer module may be used to reference the ESG based strain signal obtained from the first sensing transducer module before being sent wirelessly to a terminal device. The strain signal may be integrated in the form as expressed in Equation (5).

$$I=K1*[(K2*SO) -(K3*SE)] \quad (5)$$

wherein I is the integrated signal to be sent to and/or received by a recipient device, SO is the optical sensing signal obtained from the fiber-optic based sensor, SE is the electrical sensing signal obtained from the ESG based sensor, and K1, K2, K3 may be a constant or function. I

may be dynamically logged at the rate of 1Hz-100Hz (or higher) based on application requirements.

[0079] Equation (5) may be generalized to Equation (6) for multiple fiber-optic based sensors, as follows

$$I_n = \sum\left[\left(K_i \times SO_i\right) \pm \left(K_j \times SO_j\right) \pm \left(K_m \times SE_m\right)\right] \quad (6)$$

or

$$In \in \{(Ki \times SOi) \pm (Kj \times SOj) \pm (Km \times SEm)\} \mid 1 < n < q\}$$

where q is number of channels & i, j, m, n may be any integers assigned to signal from the optical and electrical sensing units in the device 100. As the device 100 is capable of acquiring data from multiple channels so by exploiting the capability of on-chip programmable multiplexer, it can be configured to monitor multiple channels.

[0080] In some embodiments, the integrated signal I as mathematically expressed in Equation (5) or (6) may be computed by either the selector and/or the SBC.

[0081] Advantageously, the received data do not require postprocessing and there is no additional device required between transmitter and receiver's terminal computer device, e.g. a laptop or smartphone, as the data are transmitted directly using an Internet network from the transmitter. Any smart phone or laptop with internet connectivity can be used to access usable data. The device 100 may be configured as a stand-alone unit at the sensing point/transmission point.

[0082] In some embodiments, one or more idle strain gauges can be attached to the device 100 to mitigate disturbances due to the device itself. The strain data received at a user device is representative of optical sensor and additional device profiling/device drifts can be received explicitly using an idle strain gauge. With the strain gauge, post processing may not be required to monitor the sensing signals. Further, edge processing can be done within the device in real time to mitigate fluctuations. An idle strain gauge may be used to reference the ambient or environmental condition, including any thermal drift of the device 100. The ESG of the idle strain gauge may also be used as a cross-checking sensor to account for such thermal drifts and correct the readings from the respective CFBG1-CFBG2-ESG sensors instantaneously before transmitting the data.

[0083] It is contemplated that the device 100 may be applied to various applications, such as, but not limited to, civil, mechanical and offshore structures etc. It is further contemplated

that the device 100 may form part of or be incorporated into a cloud-based system or platform. The data obtained from the first and second sensing and transducer modules 102, 104 can be unified for optical sensors and electrical strain gauges, which facilitates more efficient analysis and interpretation.

[0084] It is contemplated that the data acquisition module 106 may include additional components for signal processing and wireless transceiving.

[0085] It is contemplated that the sensors on device 100 may be equipped with wireless transmitters and/or receivers, and further include intelligent controllers to receive data from the sensors. Such arrangement advantageously facilitate the integration of the device 100 into existing Internet of Things (IoT) platforms and deployed along with other IoT sensors.

[0086] FIG. 14 shows a brief summary of the cost advantage of the device 100 over prior art devices shown in FIG. 1A and FIG. 1B. Read in conjunction with the results shown in FIGS. 10 to 12, the integrated device 100 of the present disclosure demonstrates consistent measurements with currently established data acquisition systems at a fraction of the costs.

[0087] While the disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the disclosure as defined by the appended claims. The scope of the disclosure is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A device for sensing and acquiring data comprising

a first sensing and transducer module configured to sense and obtain a first strain signal;

a second sensing and transducer module configured to sense and obtain a second strain signal;

a data acquisition module arranged in signal or data communication with the first sensing and transducer module and the second sensing and transducer module, the data acquisition module comprises a selector configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital value; wherein the second sensing and transducer module comprises an optical sensor module, the optical sensor module comprising an interrogation arm and a sensing arm, the interrogation arm is configured to be operating at either an identical or a co-located band as the sensing arm.

2. The device of claim 1, wherein the first sensing and transducer module comprises an electrical strain gauge acquisition unit having an electrical foil strain gauge sensor.

3. The device of claim 2, wherein the first sensing and transducer module comprises a Wheatstone bridge circuit, and the electrical foil strain gauge sensor forms an arm of the Wheatstone bridge.

4. The device of claim 3, wherein the Wheatstone bridge is configured such that the potential difference across two nodes of the Wheatstone bridge circuit vary according to a change in measured resistance of the electrical foil strain gauge sensor.

5. The device of any one of the preceding claims, wherein the interrogation arm comprises a CFBG sensor and the sensing arm comprises an CFBG sensor or UFBG sensor.

6. The device of claim 5, wherein a band of the CFBG or UFBG is selected to be from a linear portion of a slope (rising or falling) of a power intensity vs wavelength graph associated with a wide-band light source.

7. The device of claim 5 or 6, wherein the interrogation arm is built-in or connected to an LED light source, and wherein the sensing arm is operatively arranged to connect externally to obtain strain measurements.

8. The device of any one of the preceding claims, wherein the data acquisition module comprises a transceiver module, wherein the transceiver module includes a single board computer for interfacing with the selector using a universal asynchronous receiver-transmitter (UART) connection.

9. The device of claim 8, wherein the selector and/or the single board computer is configured to integrate the first strain signal and the second strain signal.

10. The device of any one of the preceding claims, wherein the first strain signal and/or the second strain signal is the form of an analogue differential voltage, and the analogue differential voltage is amplified before conversion to a digital value.

11. A system for monitoring strain on a structure comprising

a first sensing and transducer module having an ESG sensor attached to the structure, the ESG sensor configured to sense and obtain a first strain signal associated with an application of tensile or compressive strain on the structure;

a second sensing and transducer module having a fiber-optic based sensor attached to the structure, the fiber-optic based sensor configured to sense and obtain a second strain signal;

a data acquisition module arranged in signal or data communication with the first sensing and transducer module and the second sensing and transducer module, the data acquisition module comprises a selector configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital value;

wherein the second sensing and transducer module comprises an optical sensor module, the optical sensor module comprising an interrogation arm and a sensing arm, the interrogation arm is configured to be operating at either an identical or a co-located band as the sensing arm.

12. The system of claim 11, further comprises a single board computer arranged in wireless communication with the data acquisition module to receive the converted digital value for further transmission to a terminal device for display.

13. The system of claim 11 or 12, wherein the first sensing and transducer module comprises a Wheatstone bridge circuit, and the ESG sensor is a resistive arm of the Wheatstone bridge.

14. The system of any one of claims 11 to 13, wherein the interrogation arm comprises a CFBG sensor and the sensing arm comprises an CFBG sensor or UFBG sensor.

15. The system of any one of claims 11 to 14, wherein at least one of the first sensing and transducer module, the second sensing and transducer module, and the data acquisition module is arranged in wireless communication with respect to other modules.

16. The system of any one of claims 11 to 15, wherein the received first strain signal or the received second strain signal, and digital value are stored in a database for transmission to a terminal device.

17. The system of claim 12, wherein the selector and/or the single board computer is configured to integrate the first strain signal and the second strain signal.

18. A method for sensing and acquiring strain data on a structure comprising

obtaining a first strain signal from an ESG sensor attached to the structure and sending the first strain signal to first sensing and transducer module;

obtaining a second strain signal from a fiber-optic based sensor attached to the structure and sending the second strain signal to a second sensing and transducer module;

transducing the first strain signal and second strain signal to respective analogue values; and

selecting the respective analogue value and converting the analogue value to a digital value;

wherein the second sensing and transducer module comprises an optical sensor module, the optical sensor module comprising an interrogation arm and a sensing arm, the interrogation arm is configured to be operating at either an identical or a co-located band as the sensing arm.

19. The method of claim 18, further comprising storing the converted digital value in a dataset for display on a computer device.

20. A device for sensing and acquiring data comprising

a first sensing and transducer module configured to sense and obtain a first strain signal;

a second sensing and transducer module configured to sense and obtain a second strain signal;

a data acquisition module arranged in signal or data communication with the first sensing and transducer module and the second sensing and transducer module, the data acquisition module comprises a selector configured to select between receiving the first strain signal and the second strain signal and convert the received first strain signal or the received second strain signal into a digital value;

wherein the data acquisition module further comprises a single board computer for interfacing with the selector using a universal asynchronous receiver-transmitter (UART) connection, and wherein the selector and/or the single board computer is configured to integrate the first strain signal and the second strain signal; and wherein the second sensing and transducer module comprises an optical sensor module, the optical sensor module comprising an interrogation arm and a sensing arm, the interrogation arm is configured to be operating at either an identical or a co-located band as the sensing arm.