United States Patent Application Publication	20250264403
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	Mimeault; Yvan et al.

SPECTROMETER SYSTEMS AND METHODS OF REMOTE DATA ACQUISITION FOR DETECTING CHEMICAL COMPOSITIONS

Abstract

A spectrometer system for remote data acquisition in detecting chemical compositions of a sample is provided. The spectrometer system includes an analyzer including an interferometer configured to modulate light. The spectrometer system further includes a sampler positioned remotely from the analyzer and connected with the interferometer via a fiber optic cable. The fiber optic cable is configured to transmit modulated light from the interferometer to the sampler. The sampler includes an optical detector positioned adjacent to a sampling module. The sampling module is configured to receive a sample and configured to position the sample in an optical path of the modulated light. The optical detector is configured to detect modified light by the sample. The sampler also includes an interface module configured to transmit detected signals by the optical detector to the analyzer.

Inventors: **Mimeault; Yvan (Quebec City, CA), Laplante; Sylvio (Quebec City, CA)**

Applicant: **ABB Schweiz AG** (Baden, CH)

Family ID: **1000007686591**

Appl. No.: **18/443040**

Filed: **February 15, 2024**

Publication Classification

Int. Cl.: **G01N21/31** (20060101)

U.S. Cl.:

CPC **G01N21/31** (20130101); G01N2201/08 (20130101)

Background/Summary

BACKGROUND

[0001] The field of the disclosure relates generally to spectrometers, and more particularly, to spectrometer systems and methods for detecting chemical compositions.

[0002] A spectrometer has been used in detecting chemical compositions of a sample in a broad range of applications, such as semiconductor microchip fabrication and detection of contaminants in fuel gas production. In a spectrometer, a light is emitted from a light source and then modulated by an interferometer. The modulated light is emitted toward a sample. Chemical components of the sample absorb the light with absorption spectra specific to the chemical components, thereby facilitating the use of the light modified by the sample for detecting the chemical compositions of the sample. Known systems and methods are disadvantaged in some aspects in meeting the needs for the accuracy of measurements and improvements are desired.

BRIEF DESCRIPTION

[0003] In one aspect, a spectrometer system for remote data acquisition in detecting chemical compositions of a sample is provided. The spectrometer system includes an analyzer including an interferometer configured to modulate light. The spectrometer system further includes a sampler positioned remotely from the analyzer and connected with the interferometer via a fiber optic cable. The fiber optic cable is configured to transmit modulated light from the interferometer to the sampler. The sampler includes an optical detector positioned adjacent to a sampling module. The sampling module is configured to receive a sample and configured to position the sample in an optical path of the modulated light. The optical detector is configured to detect modified light by the sample. The sampler also includes an interface module configured to transmit detected signals by the optical detector to the analyzer.

[0004] In another aspect, a method of remotely acquiring data using a spectrometer system for detecting chemical compositions of a sample is provided. The method includes transmitting, to a sampler, light modulated by an interferometer of an analyzer in a spectrometer system. The sampler is positioned remotely from the analyzer. The method also includes positioning a sample in a sampling module and in an optical path of the modulated light, and positioning an optical detector of the sampler adjacent to the sampling module and in an optical path of light exiting from the sampling module. The method further includes detecting, by the optical detector, light modified by the sample, and transmitting, via an interface module of the sampler, detected signals to the analyzer.

[0005] In one more aspect, a sampler of a spectrometer system for detecting chemical compositions of a sample is provided. The sampler includes an optical detector positioned adjacent to a sampling module and in an optical path of light exiting from the sampling module. The sampling module is configured to receive a sample and configured to position the sample in an optical path of light modulated by an interferometer such that the modulated light travels through the sample and is modified by the sample. The optical detector is configured to detect the modified light by the sample. The sampler further includes an interface module configured to transmit detected signals by the optical detector to an analyzer positioned remotely from the sampler.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0006] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings.

[0007] FIG. **1** is a schematic diagram of a known spectrometer system.
[0008] FIG. **2** is a schematic diagram of an example spectrometer system.
[0009] FIG. **3** is a schematic diagram of an example sampler of the spectrometer system shown in FIG. **2**.
[0010] FIG. **4** is a schematic diagram of another example sampler of the spectrometer system shown in FIG. **2**.
[0011] FIG. **5** is a schematic diagram of another example spectrometer system.
[0012] FIG. **6** is a flow chart of an example method of remote data acquisition using the spectrometer systems shown in FIGS. **2-5**.

DETAILED DESCRIPTION

[0013] The disclosure includes spectrometer systems and methods for detecting chemical compositions of a sample. The sample may be in any state such as solid, liquid, gaseous, other states, or any combination thereof. Method aspects will be in part apparent and in part explicitly discussed in the following description.

[0014] In a spectrometer system, a light is emitted from a light source. The light may be in the range of far infrared (FIR), mid infrared (IR), near IR, visible, and/or ultraviolet (UV) light. The light is modulated by an interferometer, which typically includes a sliding mirror that moves in a pattern needed for an application. The movement modulates the light. The modulated light is then emitted toward a sample. Different chemical components absorb light with different absorption spectra, where each absorption spectrum is specific to a chemical component. Therefore, light modified by the sample may be used to determine the chemical compositions of the sample by detecting the modified light and processing the detected signals. Fourier transform may be used to process the signals in deriving the absorption spectra of the sample.

[0015] FIG. **1** is a schematic diagram of a known spectrometer system **100**. In known spectrometer system **100**, light is modulated by an interferometer module **102** that includes an interferometer configured to modulate light. The modulated light is transmitted to a sampler **104** via a fiber optic cable **106-1**. The light travels through a sample positioned in sampler **104** and exits from sampler **104**. The light exiting from sampler **104** is modified by the sample. The modified light is transmitted back to a detection module **108** in an analyzer **109** via another fiber optic cable **106-2**. Detection module **108** detects the modified light and processes the detected signals. For example, the detected signals are converted to digital signals. The processed signals are transferred to a main processing unit **111** and/or an external computing device **112** for further processing, such as determining the absorption spectra of the sample and chemical compositions of the sample based on the absorption spectra. Sampler **104** is typically positioned remotely from analyzer **109**. For example, sampler **104** is coupled with a conduit section of a process line in a processing plant, which is typically remote from the analyzer with a distance of meters or even hundreds of meters from the analyzer. To cover that distance with optical fiber may become expensive. Further, due to the temperature changes, bending, optical vibration, or other factors of optical fiber, noise and/or spectral distortion is introduced to the light. As a result, light received at the sampler is different from the light exiting from interferometer module **102**, and light received at detection module **108** is different from the light exiting from sampler **104**, compromising the accuracy of measurements.

[0016] In data acquisition and processing, the accurate positions of the sliding mirror are needed to differentiate acquired signals of modified light by the sample to correspond to specific positions of the sliding mirror. A reference light, typically in a monochromatic spectrum, is used to determine the positions. The reference light is generated by a monochromatic light source such as a laser. The reference light travels approximately in parallel with the measurement light in the system. The signals of the reference light are used to determine the positions of the sliding mirror.

[0017] Interferometer module **102** and digitization in detection module **108** need to be synchronized in order to use the reference light to determine the accurate positions of the sliding mirror in interferometer module **102** and therefore to produce detected signals corresponding to specific positions of the sliding mirror. In known spectrometer system **100**, a synchronization cable **116** is needed, where synchronization cable **116** connects interferometer module **102** with detection module **108**. Synchronization signals, such as electrical pulses indicating the timing, are sent via synchronization cable. The synchronization signals are used to determine the positions of the sliding mirror in the detected signals acquired by detection module **108**.

[0018] Systems and methods described herein solve the above-described problems in at least some known systems. Spectrometer systems described herein integrate detection modules into samplers. As a result, the need of the return fiber optic cables that extend from the samplers to the detection modules in at least some known systems is eliminated, thereby reducing the costs of the systems in fiber optic cables and increasing the accuracy of measurements by eliminating the noise caused by the return fiber optic cables. In some embodiments, an optical detector reference module is included in a spectrometer system to remove or reduce the noise caused by the fiber optic cable extending from the interferometer and the sampler, further increasing the accuracy of measurements. In addition, a synchronization cable may be eliminated in the systems and methods described herein. Synchronization signals may be derived via software, thereby reducing costs from a synchronization cable while facilitating the integration of a detection module into a sampler and remote data acquisition by a spectrometer system.

[0019] FIG. **2** is a schematic diagram of an example spectrometer system **200**. In the example embodiment, spectrometer system **200** includes an analyzer **202**. In the depicted embodiments, analyzer **202** includes an analyzer enclosure **204** that contains other components of analyzer **202**. Alternatively, at least some components of analyzer **202** are assembled into separate units. Analyzer **202** further includes an interferometer module **206**. Interferometer module **206** includes a measurement light source **208** configured to emit light for measurements of the sample. The light may be in any bandwidth. In some embodiments, the light has a relatively broad spectrum such as in the spectra of IR light, visible light, and/or UV light. Interferometer module **206** also includes a reference light source **210** such as a laser generator. Reference light source **210** is configured to emit light having a monochromatic spectrum. Interferometer module **206** further includes an interferometer **212**. Light emitted from measurement light source **208** and a reference light from reference light source **210** are modulated by interferometer **212**. For example, movement of a sliding mirror (not shown) in interferometer **212** modulates the measurement light and the reference light.

[0020] In the example embodiments, interferometer module **206** further includes an interferometer electronic board **214** configured to control operation of interferometer module **206**. For example, interferometer electronic board **214** is configured to control the operation of interferometer **212**, and/or the light generation of measurement light source **208** and/or reference light source **210**. Interferometer electronic board **214** may include a microcontroller.

[0021] In the example embodiments, analyzer **202** further includes an analyzer computing device **230**. Analyzer computing device **230** may be a single board computing device. Alternatively, analyzer computing device **230** is a computing device having a plurality of electronic boards. Analyzer computing device **230** is configured to communicate with an external computing device **232**, which is configured to further process signals acquired by a sampler **216**. External computing device **232** may be a user computer device or a server computing device such as a cloud computing device. Analyzer computing device **230** communicates with external computing device **232** via wired communication such as Ethernet or via wireless communication such as wireless local area network (LAN).

[0022] In the example embodiments, analyzer **202** further includes a power supply **234**. Power supply **234** is configured to receive power from an external power source. Power supply **234** may include one or more converters (not shown) configured to convert the external power to supply power at a desired range of voltage, current, and/or power levels.

[0023] In the example embodiments, spectrometer system **200** further includes sampler **216**. One sampler **216** is depicted as an example for illustration purposes only. A plurality of samplers **216** (see FIG. **5** described later) may be included in spectrometer system **200**. Sampler **216** is connected with interferometer **212** via a fiber optic cable **218**.

[0024] In the depicted embodiments (also see FIGS. **3-5** described later), sampler **216** includes a sampling module **220** configured to receive a sample. In some embodiments, sampler **216** does not include sampling module **220**. Sampling module **220** may be positioned separate from and/or outside of sampler enclosure **205**. In operation, sampler **216** is coupled with sampling module **220** by positioning sampler **216** onto sampling module **220**. For example, sampler **216** is coupled with sampling module **220** by clipping sampler **216** onto tubing **302** (see FIG. **3**). Modulated light from interferometer **212** is transmitted via fiber optic cable **218** and emitted toward the sample contained in sampling module **220**.

[0025] In the example embodiment, sampler **216** further includes an optical detector **222**. One or more optical devices such as lenses may be provided to focus the light into sampling module **220** and/or optical detector **222**. Optical detector **222** is positioned adjacent to sampling module **220** such that light exiting from sampling module **220** enters into optical detector **222** directly or after being directed by one or more optical devices such as mirrors or lenses. Optical detector **222** is integrated into sampler **216** such that a fiber optic cable is not needed to transmit light modified by the sample to optical detector **222** for detection. In the depicted embodiment, sampling module **220**, optical detector **222**, and other components such as a controller **228** and an interface module **226** are assembled inside one sampler enclosure **205**. Alternatively, at least some components of sampler **216** are assembled into separate units. Signals detected by optical detector **222** may be processed such as being amplified and/or digitized in sampler **216**.

[0026] In the example embodiments, sampler **216** further includes interface module **226** configured to communicate with another device, such as analyzer **202**. Interface module **226** may include a network interface, which is configured to connect sampler **216** to a computer network. The network interface is sized to receive a networking cable **238**. For example, the network interface may be an Ethernet interface sized to receive an Ethernet cable. Alternatively or additionally, the network interface may include a wireless communication port. Sampler **216** may communicate with analyzer **202** via a wired communication mechanism such as via Ethernet. Alternatively or additionally, sampler **216** may communicate with analyzer **202** via a wireless communication mechanism such as through wireless LAN like Wi-fi®.

[0027] In the depicted embodiments, spectrometer system **200** may include one or more networking cables **238** (also see FIGS. **3** and **4** described later) connecting analyzer **202** with sampler **216**. Networking cable **238** may be an Ethernet cable. Networking cable **238** may be a Power over Ethernet (PoE) cable configured to supply electric power and serve communication purposes via the same cable. A PoE cable complies with the PoE standards. In some embodiments, networking cable **238** may be a cable complying with Ethernet Advanced Physical Layer (APL), where the cable includes a physical layer for Ethernet communication and supply of power with protected measures for safe use in hazardous areas. Networking cable **238** complying with Ethernet APL standards is configured to be used in a hazardous environment.

[0028] Communication between analyzer **202** and sampler **216** via a networking cable **238** is depicted as example for illustration purposes only. Communication between analyzer **202** and sampler **216** may be wireless.

[0029] In the example embodiments, sampler **216** further includes a controller **228**. Controller **228** is configured to control the operations of sampler **216**. For example, controller **228** sends control signals to other components in sampler **216**, such as sampling module **220**, optical detector **222**, and/or interface module **226**, and controls the operations of sampler **216**. Signals detected by optical detector **222** or received by interface module **226** may be transferred to controller **228**, where controller **228** may adjust the controls based on the signals.

[0030] In the example embodiments, controller **228** includes a processor-based microcontroller including a processor **229** and a memory device **231** wherein executable instructions, commands, and control algorithms, as well as other data and information needed to satisfactorily operate spectrometer system **200** and sampler **216**, are stored. Memory device **231** may be, for example, a random access memory (RAM), and other forms of memory used in conjunction with RAM memory, including but not limited to flash memory (FLASH), programmable read only memory (PROM), and electronically erasable programmable read only memory (EEPROM).

[0031] As used herein, the term "processor-based" microcontroller shall refer not only to controller devices including a processor or microprocessor as shown, but also to other equivalent elements such as microcomputers, programmable logic controllers, reduced instruction set circuits (RISC), field programmable gate arrays (FPGA), application specific integrated circuits and other programmable circuits, logic circuits, equivalents thereof, and any other circuit or processor capable of executing the functions described herein. The processor-based devices listed above are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of the term "processor-based."

[0032] In operation, light modulated by interferometer **212** travels along fiber optic cable **218** to sampling module **220**. The modulated light then travels through the sample in sampling module **220**. The light exiting from sampling module **220** is modified by the chemicals in the sample. The modified light is detected and converted into electrical signals by optical detector **222**. The electrical signals may be processed and digitized into digital signals by optical detector **222**. The digital signals may be transmitted to analyzer **202** via the communication channels between sampler **216** and analyzer **202**. Analyzer **202** may further process the signals. In some embodiments, analyzer **202** relays signals received from sampler **216** without processing. Analyzer **202** is in communication with external computing device(s) **232**, which is configured to process and analyze the signals and determine the chemical compositions of the sample based on the analysis.

[0033] In known spectrometer system **100**, light modified by a sample is transmitted via a fiber optic cable to detection module **108**. In contrast, in spectrometer system **200**, modified light enters into optical detector **222** positioned adjacent to sampling module **220**, thereby eliminating the return fiber optic cable and noise caused by the fiber optic cable due to factors such as temperature changes, optical vibration, bending of the optical fiber, and/or other changes in the optical fiber. Accordingly, eliminating a return fiber optic cable increases accuracy of measurements, and reduces costs of a spectrometer system. Integrating an optical detector into a sampler also simplifies the design of spectrometer system **200** and reduces the number of optical components in the system.

[0034] In the example embodiments, the synchronization between interferometer **212** and optical detector **222** may be accomplished via software, thereby eliminating the synchronization cable in known spectrometer systems. As used herein, in synchronizing two or more devices via software, synchronization signals are digital signals and are derived based on digital signals by a software program used to process the digital signals and derive synchronization signals. The digital signals for synchronization may be clock signals and/or communication signals of spectrometer system **200**. Synchronization via software may achieve a precision within several nanoseconds.

[0035] Synchronization signals may be derived from communication signals between analyzer **202** and sampler **216**. For example, because analyzer **202** and sampler **216** is in communication with one another, clock signals embedded in the communication are used for synchronization. In some embodiments, synchronization signals are transmitted via a spare pin of networking cable **238** between analyzer **202** and sampler **216**.

[0036] In some embodiments, the synchronization is performed using wireless communication signals. For example, the clock signals in synchronization are global positioning system (GPS) clock data, where the GPS clock data are received by interferometer module **206**, sampler **216**, and analyzer computing device **230** and are used to synchronize interferometer electronic board **214** with controller **228**. In another example, analyzer **202** and sampler **216** communicate with one another via wireless communication, such as wireless LAN. The clock signals are transmitted wirelessly between analyzer **202** and sampler **216** and used in synchronization.

[0037] In the example embodiments, the communication signals may be in a precision time protocol (PTP), such as standard IEEE 1588. The protocol is used to synchronize clocks among different devices or systems at different locations in a computer network. PTP may be used in wired communication such as through networking cable **238**, or in wireless communication such as via a wireless LAN. Communication signals including clock signals in PTP may be transmitted among analyzer computing device **230**, interferometer electronic board **214**, and controller **228**. For example, clock signals generated by analyzer computing device **230** serve as master clock signals and are embedded in communication from analyzer computing device **230** to interferometer electronic board **214** and controller **228**. Alternatively or additionally, clock signals from interferometer electronic board **214** or controller **228** may serve as master clock signals. The signals communicated from interface module **226** are embedded with clock signals provided by controller **228**. The clock signals from sampler **216** are compared with clock signals provided by analyzer **202** and used to synchronize digitization of the detected signals with the positions of the sliding mirror in interferometer **212**.

[0038] In some embodiments, a synchronization cable **116** (see FIG. **1**) is used for synchronization. The synchronization cable **116** is coupled between interferometer module **206** and optical detector **222**. Synchronization cable **116** may be relatively long to cover the distance from analyzer **202** to sampler **216**.

[0039] FIG. **3** is a schematic diagram of an example sampler **216-3**. In the example embodiment, sampler **216** includes a sampling module **220**. Sampling module **220** may include a tubing **302** that carries a sample therethrough. Tubing may be a length of tube or conduit of a processing line in a plant. Tubing **302** is fabricated from a light transmitting material to avoid light modification by tubing **302**. In some embodiments, sampling module **220** is a chemical bath (not shown) including chemical fluid, which is gaseous and/or liquid. Modulated light from interferometer **212** (see FIG. **2**) is transmitted to sampler **216** via fiber optic cable **218** and emitted toward the sample contained in sampling module **220**.

[0040] In the example embodiment, sampler **216** further includes optical detector **222**. Optical detector **222** includes optical detector signal module **304** that is configured to convert optical signals to electrical signals. Optical detector signal module **304** may include devices configured to convert light into electrical signals, such as PIN photodiodes and/or pyroelectric IR sensors like deuterated L-alanine doped triglycine sulphate (DLATG) detectors. Optical detector **222** may further include an analog to digital converter (ADC) **306** configured to digitize analog electrical signals into digital electrical signals. In some embodiments, ADC **306** may be integrated in controller **228**. Optical detector **222** may further include a conditioning amplifier **308**. Conditioning amplifier **308** is configured to amplify the electrical signals detected by optical detector signal module **304**. The operation of conditioning amplifier **308** may be turned on or off based on whether a certain condition is met. For example, if the signals are below a threshold, the signals are amplified, while if the signals are at or above the threshold, the signals are not amplified. As a result, the range of the signals output from conditioning amplifier **308** is optimal for ADC **306** in digitization.

[0041] In the example embodiment, sampler **216** further includes controller **228** configured to control operation of sampler **216**. Controller **228** is in communication with conditioning amplifier **308**, ADC **306**, interface module **226**, and/or other sensors **310** and configured to control operation of components of sampler **216**. Other sensors **310** such as a temperature sensor and/or a GPS sensor may be included in sampler **216** for compensation purposes or synchronization between interferometer **212** and data acquisition in optical detector **222**. Controls are transmitted from controller **228** to other components. Signals and data may be transmitted between controller **228**

and other components.
[0042] In the example embodiment, sampler **216** further include interface module **226**. Interface module **226** may include a network interface. Interface module **226** may be configured to communicate with other devices and receive power from an external power source, thereby facilitating power, data, and synchronization signals being transmitted to and/or from interface module **226**. Interface module **226** is coupled with another device via one or more networking cables **238**. Networking cable **238** may transmit power, communication, and/or synchronization signals. Networking cables **238** may include a PoE cable or a cable that meets the Ethernet APL standards. In some embodiments, power is transmitted separately from signals, where power and signals are transmitted via different cables or channels. In other embodiments, sampler **216** may include an internal power source such as one or more batteries (not shown), configured to supply power to sampler **216**. Data may be transmitted to and from sampler **216** via wired communication such as via networking cable **238**, wireless communication such as via wireless LAN, or a combination of both. Synchronization may be transmitted via wired and/or wireless communication. Synchronization signals may be in PTP protocols, via wired or wireless communication. In some embodiments, synchronization signals include GPS signals.
[0043] FIG. **4** is a schematic diagram of another example sampler **216-4**. Compared to sampler **216-3** shown in FIG. **3**, sampler **216-4** further includes an optical detector reference module **402** in optical detector **222**. In the example embodiment, optical detector reference module **402** is positioned at a different optical path from sampling module **220**. Like optical detector signal module **304**, optical detector reference module **402** includes photodetectors configured to convert light into electrical signals. Light modulated by interferometer **212** travels from interferometer **212**, along optical fibers in fiber optic cable **218**, and to sampler **216**. Due to factors such as temperature changes, fiber bending, optic vibration, and/or other factors, noise is introduced by optical fibers in fiber optic cable **218** into light received by sampler **216**. Fiber optic cable **218** may span a relatively long distance, such as several hundred meters or farther. Noise from travelling the relatively long distance of optical fibers may significantly deteriorate the detected signals, causing reduction in the accuracy of measurements by sampler **216**.
[0044] In the example embodiment, sampler **216** may include a splitter **404** that split light **406** modulated by interferometer **212** and transmitted over fiber optic cable **218** into two groups **408** of rays. The light intensity of first group **408-1** and second group **408-2** may be the same or in a known proportion with one another. First group **408-1** of rays travel toward optical detector reference module **402**. Second group **408-2** of rays travel toward sampling module **220**. The frequency information in optical signals of groups **408-1**, **408-2** of rays are the same or approximately the same, where light in the groups **408-1**, **408-2** is modulated by interferometer **212** in the same manner. First group **408-1** is detected by optical detector reference module **402**. Second group **408-2** travels through sampling module **220** and is modified by the sample. The modified second group of rays are detected by optical detector signal module **304**. Optical detector reference module **402** and optical detector signal module **304** are both configured to convert incoming light into electrical signals. Conditioning amplifier **308** and ADC **306** may include two channels, where one channel is for processing output signals **410-***r* from optical detector reference module **402** and the other channel is for processing output signals **410-***s* from optical detector signal module **304**.
[0045] In the example embodiment, the output signals **410-***r* from optical detector reference module **402** include reference signals, which are optical signals before being modified by the sample. The output signals **410-***s* from optical detector signal module **304** include modified signals, which are optical signals modified by the sample. Accordingly, the differences between the two output signals **410-***r*, **410-***s* represent the optical signals modified by the sample, with noise introduced by optical fibers in fiber optic cable **218** being reduced or removed. Accordingly, accuracy of measurements by spectrometer system **200** and sampler **216** is increased.
[0046] FIG. **5** is a schematic diagram of another example spectrometer system **200-5**. In the

example embodiment, spectrometer system **200-5** includes a plurality of samplers **216**. Analyzer **202** further includes an optical output panel **502**. Optical output panel **502** may include a plurality of outlets each sized to receive a fiber optic cable **218**. Modulated light by interferometer **212** is provided to samples via fiber optic cables **218**. For example, N number of samplers **216-1**, . . . , **216-**N are included in spectrometer system **200**. N number of fiber optic cables **218-1**, . . . , **218-**N are also included, each fiber optic cable **218** being connected to a corresponding sampler **216**. The detected signals by samplers **216** are transmitted to analyzer **202** for further processing. Analyzer **202** further includes a sampler communication switch panel **504**, which includes a plurality of outlets each sized to receive a networking cable **238**. In some embodiments, communication between analyzer **202** and samplers **216** is wireless, where each sampler **216** may communicate with analyzer **202** in a specific wireless channel. In other embodiments, communication between analyzer **202** and samplers **216** is a combination of wired and wireless communication, where a given sampler **216** may communicate with analyzer **202** in a wired or wireless mode.

[0047] Synchronization between analyzer **202** and sampler **216** is provided by synchronizing analyzer computing device **230**, interferometer module **206**, and controllers **228** in samplers **216**. For example, clock signals are communicated among analyzer computing device **230**, interferometer electronic board **214**, and controllers **228**, and are used to synchronize interferometer **212** with samplers **216**.

[0048] In at least some known spectrometer systems, the analyzer is equipped with a fixed number of detector modules. A sampler is added or removed from the spectrometer system by connecting the interferometer with each of the samplers via a fiber optic cable and connecting each of the samplers with one of the outlets for the detector modules via another fiber optic cable. A number of detection modules are often unused, reducing the utility of the analyzer. Further, a user needs to choose an analyzer that has a number of detection modules being the same as or greater than the number of samplers, which often is unknown in advance or may change during operation, causing inconvenience or production delays to the user.

[0049] In contrast, spectrometer system **200-5** is flexible in the configuration while fully using the components in the system. Any number of samplers that is the same as or less than the number of outlets in analyzer **202** may be included in spectrometer system **200-5**. To add or remove a sampler **216**, the sampler **216** is plugged into or removed from analyzer **202** by connecting or disconnecting fiber optic cable **218** and communication with the sampler **216**.

[0050] FIG. **6** is a flow chart of an example method **600** of remotely acquiring data using a spectrometer system for detecting chemical compositions of a sample. In the example embodiment, method **600** includes transmitting **602**, to a sampler, light modulated by an interferometer of an analyzer in a spectrometer system. Example spectrometer systems, analyzers, and samplers are spectrometer systems **200**, analyzers **202**, and samplers **216** described herein. Sampler **216** is positioned remotely from analyzer **202**. Method **600** also includes positioning **604** a sample in a sampling module of the sampler and in an optical path of the modulated light. Method **600** further includes positioning **606** an optical detector of the sampler adjacent to the sampling module and in an optical path of light exiting from the sampling module. In addition, method **600** includes detecting **608**, by the optical detector, light modified by the sample. Further, method **600** includes transmitting **610**, via an interface module of the sampler, detected signals to the analyzer.

[0051] As used herein, the terms “processor” and “computer,” and related terms, e.g., “processing device,” “computing device,” and “controller” are not limited to just those integrated circuits referred to in the art as a computer, but broadly refers to a microcontroller, a microcomputer, an analog computer, a programmable logic controller (PLC), an application specific integrated circuit (ASIC), field programmable gate arrays (FPGA), and other programmable circuits, and these terms are used interchangeably herein. In the embodiments described herein, “memory” may include, but is not limited to, a computer-readable medium, such as a random-access memory (RAM), a computer-readable non-volatile medium, such as a flash memory. Alternatively, a floppy disk, a compact disc-read only memory (CD-ROM), a magneto-optical disk (MOD), and/or a digital versatile disc (DVD), and/or other optical media storage devices may also be used. Also, in the embodiments described herein, additional input channels may be, but are not limited to, computer peripherals associated with an operator interface such as a touchscreen, a mouse, and a keyboard. Alternatively, other computer peripherals may also be used that may include, for example, but not be limited to, a scanner. Furthermore, in the example embodiment, additional output channels may include, but not be limited to, an operator interface monitor or heads-up display. Some embodiments involve the use of one or more electronic or computing devices. Such devices typically include a processor, processing device, or controller, such as a general purpose central processing unit (CPU), a graphics processing unit (GPU), a microcontroller, a reduced instruction set computer (RISC) processor, an ASIC, a programmable logic controller (PLC), a field programmable gate array (FPGA), a digital signal processing (DSP) device, and/or any other circuit or processing device capable of executing the functions described herein. The methods disclosed herein may be encoded as executable instructions embodied in a computer readable medium, including, without limitation, a storage device and/or a memory device. Such instructions, when executed by a processing device, cause the processing device to perform at least a portion of the methods disclosed herein. The above examples are not intended to limit in any way the definition and/or meaning of the term processor and processing device.

[0052] At least one technical effect of the systems and methods described herein includes (a) reducing costs and increasing accuracy of measurements by positioning an optical detector adjacent to a sampling module in a sampler; (b) increasing accuracy of measurements by including an optical detector reference module to reduce noise caused by a fiber optic cable used for transmitting modulated light to the sampler; and (c) eliminating a separate synchronization cable between an interferometer and a detection module by synchronizing the interferometer with the optical detectors via software.

[0053] Example embodiments of spectrometer systems and methods are described above in detail. The systems and methods are not limited to the specific embodiments described herein but, rather, components of the systems and/or operations of the methods may be utilized independently and separately from other components and/or operations described herein. Further, the described components and/or operations may also be defined in, or used in combination with, other systems, methods, and/or devices, and are not limited to practice with only the systems described herein.

[0054] As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural elements or steps, unless such exclusion is explicitly recited. Furthermore, references to “example” or “one example” of the present disclosure are not intended to be interpreted as excluding the existence of additional examples that also incorporate the recited features. Further, to the extent that terms “includes,” “including,” “has,” “contains,” and variants thereof are used herein, such terms are intended to be inclusive in a manner similar to the term “comprises” as an open transition word without precluding any additional or other elements.

[0055] Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

[0056] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

Claims

1. A spectrometer system for remote data acquisition in detecting chemical compositions of a sample, the spectrometer system comprising: an analyzer comprising: an interferometer configured to modulate light; and a sampler positioned remotely from the analyzer and connected with the interferometer via a fiber optic cable, the fiber optic cable configured to transmit modulated light from the interferometer to the sampler, the sampler comprising: an optical detector positioned adjacent to a sampling module, wherein the sampling module is configured to receive a sample and configured to position the sample in an optical path of the modulated light, the optical detector configured to detect modified light by the sample; and an interface module configured to transmit detected signals by the optical detector to the analyzer.
2. The spectrometer system of claim 1, wherein the sampler further comprises: an optical detector reference module positioned in a different optical path of the modulated light from the sampling module and configured to detect the modulated light before being modified by the sample.
3. The spectrometer system of claim 2, wherein the sampler further comprises: a controller configured to remove noise caused by the fiber optic cable based on reference signals detected by the optical detector reference module.
4. The spectrometer system of claim 1, wherein the interferometer and the optical detector are synchronized via synchronization signals based on clock signals.
5. The spectrometer system of claim 4, wherein the synchronization signals are in a precision time protocol (PTP).
6. The spectrometer system of claim 4, wherein the clock signals comprise global positioning system (GPS) clock data.
7. The spectrometer system of claim 4, further comprising a networking cable coupled with the interface module and configured to transmit the synchronization signals.
8. The spectrometer system of claim 1, comprising a plurality of samplers, wherein each of the plurality of samplers is coupled with the analyzer and configured to transmit the signals detected by the each of the plurality of samplers to the analyzer.
9. The spectrometer system of claim 1, further comprising a networking cable configured to transmit electric power and digital signals.
10. The spectrometer system of claim 9, wherein the networking cable is configured to be used in a hazardous environment.
11. A method of remotely acquiring data using a spectrometer system for detecting chemical compositions of a sample, the method comprising: transmitting, to a sampler, light modulated by an interferometer of an analyzer in a spectrometer system, the sampler positioned remotely from the analyzer; positioning a sample in a sampling module and in an optical path of the modulated light; positioning an optical detector of the sampler adjacent to the sampling module and in an optical path of light exiting from the sampling module; detecting, by the optical detector, light modified by the sample; and transmitting, via an interface module of the sampler, detected signals to the analyzer.
12. The method of claim 11, wherein: positioning the optical detector further comprises: positioning an optical detector reference module in a different optical path of the modulated light from the sampling module; and splitting the modulated light transmitted from the interferometer into a first group of rays and a second group of rays, wherein the first group of rays travel toward the optical detector reference module, and the second group of rays travel toward the sampling module.
13. The method of claim 12, further comprising: removing noise caused by an fiber optic cable based on reference signals detected by the optical detector reference module, wherein the fiber optic cable connects the interferometer with the sampler and is configured to transmit the

modulated light from the interferometer to the sampler.

14. The method of claim 11, wherein detecting the light further comprises: synchronizing the interferometer and the optical detector via synchronization signals based on clock signals.

15. The method of claim 14, wherein the synchronization signals are in a precision time protocol (PTP).

16. The method of claim 14, wherein the clock signals include global positioning system (GPS) clock data.

17. The method of claim 11, wherein transmitting the detected signals further comprises: transmitting, via a networking cable, the detected signals to the analyzer.

18. The method of claim 17, wherein the networking cable is configured to transmit electric power and digital signals.

19. A sampler of a spectrometer system for detecting chemical compositions of a sample, the sampler comprising: an optical detector positioned adjacent to a sampling module and in an optical path of light exiting from the sampling module, wherein the sampling module is configured to receive a sample and configured to position the sample in an optical path of light modulated by an interferometer such that the modulated light travels through the sample and is modified by the sample, the optical detector configured to detect the modified light by the sample; and an interface module configured to transmit detected signals by the optical detector to an analyzer positioned remotely from the sampler.

20. The sampler of claim 19, wherein the optical detector further comprises an optical detector reference module positioned in a different optical path of the modulated light from the sampling module.