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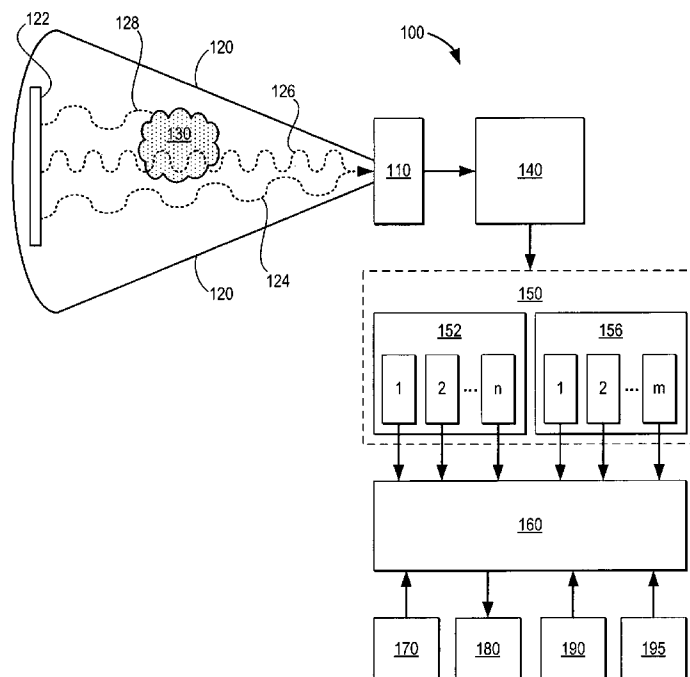


FIG. 1

(57) Abstract: Various embodiments are disclosed herein that facilitate the passive detection of analytes. In one embodiment, a chemical sensor system is provided, including an electromagnetic radiation collector configured to collect an electromagnetic radiation sample from a field of view, a reference spectrum analyzer configured to output a reference signal dependent upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within a reference spectral range, and an analytical spectrum analyzer configured to output an analytical signal dependant upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within an analytical spectral range, and a controller configured to receive the reference signal and the analytical signal, detect changes in the reference signal and analytical signals, and indicate a presence of an analyte when a change is detected in the analytical signal and no corresponding change is detected in the reference signal that exceeds a reference signal threshold.



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APPROACH FOR PASSIVELY DETECTING ANALYTES

BACKGROUND

[0001] Chemical sensors may be used to detect the presence of an analyte. Some chemical sensors may be configured to passively detect electromagnetic radiation that is naturally emitted or reflected by background targets. By analyzing the spectrum of collected radiation, these passive sensors can detect and identify chemicals without directly sampling or contacting the chemical or background target.

[0002] However, chemical sensors that passively detected electromagnetic radiation may be unsuitable for environments where the electromagnetic radiation background is changing with time or location. For example, some spectral variations in the electromagnetic radiation that is received by the sensor from time to time or from location to location as the sensor is moved may be introduced as a consequence of a changing electromagnetic radiation background rather than the presence of the analyte. As such, these passive chemical sensors may falsely indicate the presence of the analyte in response to a detected change in the electromagnetic radiation background that is instead caused by changing ambient light conditions or a changing field of view.

SUMMARY

[0003] Various embodiments are disclosed herein that facilitate the passive detection of analytes. For example, in one disclosed embodiment, a chemical sensor system is provided, comprising an electromagnetic radiation collector configured to collect an electromagnetic radiation sample from a field of view, a reference spectrum analyzer configured to output a reference signal dependent upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within a reference spectral range, and an analytical spectrum analyzer configured to output an analytical signal dependant upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within an analytical spectral range. The chemical sensor system also comprises a controller configured to receive the reference signal and the analytical signal, detect changes in the reference signal, detect changes in the analytical signal, and indicate a presence of an analyte when a change is detected in the analytical signal and no corresponding change is detected in the reference signal that exceeds a reference signal threshold.

[0004] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a schematic depiction of an embodiment of a passive chemical sensor system.

[0006] FIG. 2 depicts a first embodiment of a process flow that may be performed by the chemical sensor system of FIG. 1.

[0007] FIG. 3 depicts a second embodiment of a process flow that may be performed by the chemical sensor system of FIG. 1.

[0008] FIGS. 4 – 7 depict experimental test data that was obtained from an embodiment of the chemical sensor system.

[0009] FIG. 8 is a detailed depiction of an example embodiment of the chemical sensor system of FIG. 1.

DETAILED DESCRIPTION

[0010] Various embodiments for remotely detecting the presence of one or more chemicals are described. As a non-limiting example, remote detection will be described in the context of a passive chemical sensor system. However, it should be appreciated that the various concepts described herein may be applied to active remote sensors where suitable.

[0011] The passive chemical sensor system may receive electromagnetic radiation that is naturally emitted from or reflected by background targets such as ground cover, the atmosphere, or ambient lighting emitted by natural or artificial light sources, that reside within a particular field of view. Spectral variations in the electromagnetic radiation observed by the chemical sensor system may be introduced as a consequence of one or more chemicals being present in the field of view. However, some spectral variations may instead be introduced as a consequence of a changing electromagnetic radiation background.

[0012] As such, the embodiments described herein may be configured to detect the presence of one or more chemicals by discriminating between spectral variations that result from a changing electromagnetic background and spectral variations that result from the presence of one or more chemicals. As a non-limiting example, the chemical sensor system may be configured to detect electromagnetic radiation within a first spectral range that is influenced by the presence of one or more chemicals and a second spectral range that is less influenced by the presence of the chemicals. By observing changes within each of these spectral ranges, spectral variations in the electromagnetic radiation that result from the presence of these chemicals may be distinguished from changes in the electromagnetic radiation background.

[0013] Referring to FIG. 1, a schematic depiction of an embodiment of a chemical sensor system 100 is provided. Chemical sensor system 100 may include an electromagnetic radiation collector 110 configured to collect an electromagnetic radiation sample from a field of view, indicated schematically at 120, on behalf of one or more electromagnetic radiation detectors.

[0014] In various embodiments, chemical sensor system 100 may be configured to be mounted on a mobile vehicle or may be configured as a handheld device, whereby the field of view of collector 110 may change with time or from location to location. In other embodiments, chemical sensor system 100 may be mounted to a fixed location.

[0015] In some embodiments, collector 110 may include one or more lenses, apertures, and focusing mirrors, or any other suitable optical components. As a non-limiting example, collector 110 may utilize a common set of optical elements to provide an electromagnetic radiation sample to two or more electromagnetic radiation detectors. In other embodiments, collector 110 may utilize two or more sets of optical elements, whereby an electromagnetic radiation sample that is collected by a first set of optical elements may be provided to a first detector and an electromagnetic radiation sample that is collected by a second set of optical elements may be provided to a second detector.

[0016] Field of view 120 may include one or more targets 122 from which electromagnetic radiation may be emitted or reflected. As a non-limiting example, the field of view may be arranged along a nadir viewing line of sight, such as from an aerial vehicle. However, it should be appreciated that the field of view may be arranged along any suitable line of sight.

[0017] The electromagnetic radiation emitted or reflected by target 122 may include electromagnetic radiation of various wavelengths. For example, target 122 may emit or reflect electromagnetic radiation of a first wavelength indicated schematically at 124 and 128, and may also emit or reflect electromagnetic radiation of a second different wavelength indicated schematically at 126.

[0018] Where a chemical to be analyzed by the chemical sensor system (i.e. analyte) is present within the field of view, as indicated schematically at 130, a portion of the electromagnetic radiation emitted or reflected from target 122 may be absorbed by the analyte so that it is not received by collector 110. For example, as shown in FIG. 1, electromagnetic radiation 128 may be partially or fully absorbed by analyte 130, whereas electromagnetic radiation 126 of a different wavelength may not be absorbed by the analyte or may be absorbed to a lesser extent such that it is collected at collector 110.

[0019] As a non-limiting example, the analytes that may be detected by chemical sensor system 100 may include, but are not limited to: acetic acid, toxic industrial chemicals such as vinyl chloride, ammonia, or hydrogen fluoride, chloro-fluoro-carbons such as FM-200, or R20 volatile organic compounds such as acetone, isopropanol, methanol, or ethanol. It should be appreciated that the approaches described herein may be applied to the detection or identification of any suitable chemical or composition of matter.

[0020] At least some of these chemicals may absorb electromagnetic radiation of infrared wavelengths while one or more of the visible, ultraviolet, and near-infrared wavelengths may not be absorbed by these chemicals or may be absorbed to a lesser extent. The absorption of electromagnetic radiation by airborne or surface chemicals that are present within the field of view may depend on the particular absorption spectrum and concentration of each chemical. As such, the chemical sensor system may distinguish between spectral features associated with background targets and spectral features associated with the chemicals being detected by observing the electromagnetic radiation within at least two different spectral ranges.

[0021] In some examples, chemical sensor system 100 may include an optical distributor 140 configured to receive the electromagnetic radiation samples from collector 110 and distribute the electromagnetic radiation samples to a detector sub-system 150. Optical distributor 140 may include one or more optical elements that are configured to distribute electromagnetic radiation samples to one or more detectors of

detector sub-system 150. A non-limiting example of an optical distributor is described in greater detail with reference to FIG. 8.

[0022] Detector sub-system 150 may include a reference spectrum analyzer 152 configured to output one or more reference signals dependent upon an intensity or level of electromagnetic radiation detected in the electromagnetic radiation sample within a reference spectral range. The reference spectrum analyzer may include one or more channels indicated schematically as channel 1 through channel n. Each of channels 1 through n may define one or more specific wavelengths within the reference spectral range. In some examples, channels 1 through n may each include one or more wavelengths within the reference spectral range that are unique to the particular channel.

[0023] Each of channels 1 through n may be used by the reference spectrum analyzer to output a reference signal dependent upon a level of electromagnetic radiation detected in the electromagnetic radiation sample for the one or more wavelengths covered by the channel. In this way, the reference spectrum analyzer may output a plurality of different reference signals that each correspond to a unique portion of the reference spectral range. As will be described in greater detail herein, these channels may be provided by a combination of one or more electromagnetic radiation detectors and/or one or more associated filters.

[0024] Detector sub-system 150 may further include an analytical spectrum analyzer 156 configured to output one or more analytical signals dependent upon an intensity or level of electromagnetic radiation detected in the electromagnetic radiation sample within an analytical spectral range. The analytical spectrum analyzer may include one or more channels indicated schematically as channel 1 through channel m. Each of channels 1 through m may define one or more specific wavelengths within the analytical spectral range. In some examples, channels 1 through m may each include one or more wavelengths within the analytical spectral range that are unique to the particular channel.

[0025] Each of channels 1 through m may be used by the analytical spectrum analyzer to output an analytical signal dependent upon a level of electromagnetic radiation detected in the electromagnetic radiation sample for the one or more wavelengths covered by the channel. In this way, the analytical spectrum analyzer may output a plurality of different analytical signals that each correspond to a unique portion of the analytical spectral range. As will be described in greater detail herein,

these channels may be provided by a combination of one or more electromagnetic radiation detectors and/or one or more associated optical filters.

[0026] In at least some embodiments, the analytical spectral range may define a first spectral range in which one or more analytes absorb electromagnetic radiation, and the reference spectral range may define a second spectral range where electromagnetic radiation is not absorbed by the analytes or is absorbed to a lesser extent. In this way, at least two spectral ranges that respond differently to the presence of a particular analyte may define the analytical and reference spectral ranges. However, in other examples, additional spectral ranges may be utilized by the chemical sensor system, wherein each of the additional spectral ranges may be represented by one or more channels as previously described with reference to the analytical and reference spectral ranges.

[0027] In some examples, the analytical spectral range may include electromagnetic radiation of longer wavelength than the reference spectral range. For example, in at least one embodiment, the reference spectral range may comprise electromagnetic radiation between ultraviolet wavelengths of approximately 240 nm and infrared wavelengths up to approximately 3 μm , while the analytical spectral range may comprise electromagnetic radiation of infrared wavelengths that are longer than 3 μm .

[0028] As a first non-limiting example, the analytical spectral range may include one or more infrared wavelengths, and the reference spectral range may include one or more visible wavelengths. As another non-limiting example, the analytical spectral range may include one or more infrared wavelengths, and the reference spectral range includes one or more ultraviolet wavelengths. As yet another non-limiting example, the analytical spectral range may include one or more mid or far-infrared wavelengths, and the reference spectral range may include one or more near-infrared wavelengths. It should be appreciated that the analytical spectral range and the reference spectral range may define other spectral ranges that are suitable for the identification of a particular analyte.

[0029] Furthermore, it should be appreciated that in other examples, the analytical spectral range may include electromagnetic radiation of shorter wavelength than the reference spectral range. For example, where a particular chemical of interest absorbs shorter wavelengths and absorbs longer wavelengths to a lesser extent, the analytical spectral range may include the shorter wavelengths and the reference

spectral range may include the longer wavelengths. Therefore, in at least some examples, the reference spectral range for the identification of a first analyte may be used as an analytical spectral range for the identification of a second analyte. Similarly, an analytical spectral range for the identification of a first analyte may be used as a reference spectral range for the identification of a second analyte.

[0030] In some examples, analytical spectrum analyzer 156 and reference spectrum analyzer 152 may be provided by different filters of a common electromagnetic radiation detector. For example, a single photodiode (e.g. a silicon photodiode) or pyroelectric detector may be used as an electromagnetic radiation detector, whereby the reference spectrum analyzer 152 may further comprise one or more filters that are configured to pass electromagnetic radiation within the reference spectral range to the electromagnetic radiation detector, and the analytical spectrum analyzer may further comprise one or more filters configured to pass electromagnetic radiation within the analytical spectral range to the electromagnetic radiation detector. Furthermore, each channel of the reference and analytical spectrum analyzers may be provided by a suitable filter for passing electromagnetic radiation of the appropriate wavelengths to the detector. Alternatively, or additionally, filters may be provided that pass or exclude particular portions of the output signals that are generated by the electromagnetic radiation detector.

[0031] In other examples, the reference spectrum analyzer may comprise a first electromagnetic radiation detector configured to detect electromagnetic radiation within the reference spectral range, and the analytical spectrum analyzer may comprise a second electromagnetic radiation detector configured to detect electromagnetic radiation within the analytical spectral range. For example, in some embodiments, the first electromagnetic radiation detector of the reference spectrum analyzer may be a different type of detector than the second electromagnetic radiation detector of the analytical spectrum analyzer. As a non-limiting example, the electromagnetic radiation detector of the reference spectrum analyzer may comprise a silicon photodiode while the electromagnetic radiation detector of the analytical spectrum analyzer may comprise a pyroelectric detector. In other embodiments, the electromagnetic radiation detector of the reference spectrum analyzer may comprise the same or similar type of electromagnetic radiation detector as the analytical spectrum analyzer.

[0032] Furthermore, each channel of the reference spectrum analyzer may be provided by one or more filters for passing electromagnetic radiation of the appropriate wavelength to the first electromagnetic radiation detector while each channel of the analytical spectrum analyzer may be provided by one or more filters for passing electromagnetic radiation of the appropriate wavelength to the second electromagnetic radiation detector. Alternatively, or additionally, filters may be provided that pass or exclude particular portions of the output signals that are generated by the electromagnetic radiation detectors.

[0033] In yet other examples, the reference spectrum analyzer may comprise one or more electromagnetic radiation detectors configured to detect electromagnetic radiation within the reference spectral range, and the analytical spectrum analyzer may comprise one or more electromagnetic radiation detectors configured to detect electromagnetic radiation within the analytical spectral range. Where the reference or analytical spectrum analyzers include two or more electromagnetic radiation detectors, their respective channels may be provided by the different detectors and/or filters associated with each of the detectors.

[0034] As a non-limiting example, the reference spectrum analyzer may include three channels that are provided by three electromagnetic radiation detectors that are configured as silicon photodiodes. Each of the three photodiodes may be associated with a different one of a red, green, and blue bandpass filter and an infrared cut-off filter making the reference spectrum analyzer sensitive to variations in specific wavelengths of visible electromagnetic spectrum, but relatively insensitive to spectral variations caused by airborne or surface chemicals that primarily influence the electromagnetic radiation within the infrared spectra. Further, in some examples, each detector of the reference spectrum analyzer may include one of a red, green, or blue dichroic color filter to provide additional color discrimination. Continuing with the non-limiting example, the analytical spectrum analyzer may include eight discrete channels that are provided by eight different infrared electromagnetic radiation detectors. Each of the eight infrared detectors may be configured to detect a specific and unique portion of the analytical spectral range. In this way, the analytical spectrum analyzer may be configured to output at least eight different analytical signals responsive to the level of the electromagnetic radiation sample received by the detector sub-system for the particular wavelengths covered by each channel.

[0035] The filters described herein may be configured to pass electromagnetic radiation of one or more specific wavelengths while excluding or reducing the detection of electromagnetic radiation of other wavelengths. It should be appreciated that at least some of these filters may be provided as optical filters that are configured to influence the spectral characteristics of the electromagnetic radiation sample that is received by one or more detectors, while at least some of these filters may be provided as electrical or signal based filters that are configured to influence one or more of the various signals that may be outputted by the analytical and reference spectrum analyzers. By way of example, these filters may include one or more bandpass filters, cutoff filters, notch filters, long pass filters, short pass filters, diffraction elements, colored glass, gel, or plastic filters, and polarizing filters, among others and combinations thereof.

[0036] Furthermore, while the electromagnetic radiation detectors are described in the context of photodiodes or more specifically silicon photodiodes, it should be appreciated that any suitable quantity and/or type of electromagnetic radiation detector may be used, where appropriate. As such, the analytical spectrum analyzer and the reference spectrum analyzer should not be limited only to the example hardware implementations described herein, but may include any suitable number of detectors and/or filters that enable detector sub-system 150 to output one or more signals that are dependent upon the electromagnetic radiation detected in the electromagnetic radiation sample within any suitable spectral range or ranges.

[0037] Referring again to FIG. 1, chemical sensor system 100 may include a controller 160 that is communicatively coupled with detector sub-system 150 to enable the controller to receive one or more reference signals from the reference spectrum analyzer and one or more analytical signals from the analytical spectrum analyzer. In some examples, the controller may be located remotely from detector sub-system 150, whereby one or more of the reference signals and analytical signals may be received by the controller via wireless communication.

[0038] In some examples, controller 160 may be configured to process the signals received from the reference spectrum analyzer and the analytical spectrum analyzer simultaneously and in parallel to enable the detection and identification of one or more analytes even as the spectral content of the electromagnetic radiation background varies. Controller 160 may also be configured to process signals received from the detector sub-system and/or receive signals from the detector sub-system that

have been processed by any suitable technique, including amplification, modulation, and demodulation of one or more these signals.

[0039] As a non-limiting example, the controller may include an automatic ranging and amplification (ARA) board. As one example, the controller may be configured to compensate for a relatively wide range of electromagnetic radiation intensities that may be encountered by the reference spectrum analyzer when viewing terrains emitting or reflecting a variety of different electromagnetic radiation spectra. For example, different electromagnetic radiation emissive spectra may be caused by different surface configurations such as snow, water or vegetation, etc. and/or different ambient lighting conditions such as sun light, cloud cover, dusk and artificial light, etc.

[0040] Under some conditions, if the chemical sensor system used a single set of amplification circuits for each channel and if the amplification level was set for sensitive detection, then higher intensity (e.g. bright illumination) conditions may lead to saturation of some or all of the detectors. However, if the amplification level is instead set to avoid saturation by higher intensity sources, sensitivity when detecting lower intensity electromagnetic radiation may be reduced.

[0041] To address some of these issues, the ARA board may be configured to amplify one or more of the various analytical and reference signals received from detector sub-system. As a non-limiting example, the ARA board may include two or more gain stages for each channel of the chemical sensor system. Each of the gain stages may include a pre-set amplification range. When the output from a particular channel exceeds the amplification limit of a first amplifier, the controller may switch its output to the next amplification range. The ARA board may also provide signals to other components of the controller indicating the current gain level of each channel or detector. The gain level may be utilized by the controller to scale the raw signals that are outputted by the detector sub-system. In other examples, logarithmic or other suitable signal amplification schemes may be employed by the controller.

[0042] In some examples, the various analytical and reference signals that are received by the controller may be corrected for various instrumental effects, may be converted to a format suitable for further processing, and may be optionally recorded in memory. Accordingly, the controller may remove offsets and biases associated with each detector, filter, or channel of the reference and analytical spectrum analyzers. These signals may also be converted to a scaled output at the detector sub-system that appropriately accounts for the particular amplification scheme to be employed by the

controller, including fixed gain amplification, auto-ranging amplification, or logarithmic amplification, among others.

[0043] Furthermore, in some examples, the controller may adjust one or more of the various reference and analytical signals to account for one or more of temperature and humidity effects. Referring again to FIG. 1, controller 160 may be configured to receive an indication of one or more of temperature from a temperature sensor 190 and humidity from humidity sensor 195.

[0044] FIG. 2 depicts an example process flow that may be performed by the chemical sensor system. As one example, the process flow of FIG. 2 enables the controller to indicate the presence of one or more analytes and their respective quantities within the field of view in response to changes in the analytical signals when one or more of the reference signals received from the reference spectrum analyzer do not indicate a substantial change in the electromagnetic radiation background. Additionally, the process flow of FIG. 2 further enables the controller to update the reference and analytical backgrounds when the reference signals indicate a corresponding change in the electromagnetic radiation background that does not result from the presence of one or more of the analytes within the field of view of the collector.

[0045] Beginning for example at 208, a reference signal threshold and an analytical signal threshold may be assessed. For example, the controller may be configured to receive input signals from the detector sub-system and/or a user input device, and assess the reference and analytical signal thresholds in response to one or more inputs received from the detector-subsystem and/or the user input device. In some examples, the controller may assess a different reference signal threshold for each channel of the reference and analytical spectrum analyzers.

[0046] Referring also to FIG. 1, the controller may be configured to receive one or more user inputs via a user input device indicated schematically at 170. As one example, user input device 170 may include a keyboard, keypad, graphical user interface, selector switch, button, or other suitable device that enables a user to communicate with the controller. In some examples, user input device 170 may communicate with controller 160 by way of wireless communication. In this way, the user input device may enable a user to adjust one or more of the reference and analytical signal thresholds that are associated with the various channels of the detector sub-system.

[0047] As another example, the controller may assess one or more of the reference and analytical signal thresholds according to the various reference and analytical signals that are provided to the controller by the detector sub-system. For example, the controller may assess the reference and analytical signal thresholds for each channel responsive to the respective gain setting utilized by the channel. As yet another example, the controller may assess one or more of the reference and analytical signal thresholds according to an indication of temperature received from temperature sensor 190 and/or an indication of humidity received from humidity sensor 195. In each of these examples, the controller may reference a database, look-up table, map, or other suitable function stored in memory when assessing the reference and analytical signal thresholds.

[0048] At 210, an analytical background and a reference background may be identified. As one example, the controller may be configured to perform an initialization operation to identify the analytical background and reference background upon initiation of the chemical sensor system.

[0049] As a non-limiting example, during the initialization operation, the controller may obtain a time based average for each of the reference signals outputted by the various channels of the reference spectrum analyzer. This time based average may be performed over any suitable period. For example, a time based average of ten seconds may be used to obtain a reference background for each channel of the reference spectrum analyzer.

[0050] In some examples, the approach taken by the controller for obtaining the analytical backgrounds may be similar to the approach taken for obtaining the reference backgrounds. For example, during the initialization operation a time based average may be obtained for each of the analytical signals outputted by the various channels of the analytical spectrum analyzer. This time based average may be performed over any suitable period. For example, a time based average of ten seconds may be used to obtain an analytical background for each channel of the analytical spectrum analyzer.

[0051] In some examples, the controller may assume that the analytes to be detected by the chemical sensor system are not present in the field of view and that a clean or uncontaminated electromagnetic radiation background has been established during the initialization operation. It should be appreciated that other approaches may be used by the controller for identifying the reference and analytical backgrounds. As

one example, the time based average that was identified for each channel may be omitted. For example, the controller may alternatively identify the analytical and reference backgrounds from a single signal measurement of some or all of the channels.

[0052] After the initialization operation is performed, at 212, new analytical signals and reference signals may be received by the controller responsive to an electromagnetic radiation sample being received by the detector sub-system. For example, controller 160 may receive one or more analytical signals from one or more channels of analytical spectrum analyzer 152 and may receive one or more reference signals from one or more channels of reference spectrum analyzer 156.

[0053] At 214, the controller may monitor for changes in one or more of the reference signals. For example, changes in each reference signal may be detected relative to its corresponding reference background identified at 212. As a non-limiting example, a net normalized response (NNR) for each reference signal may be obtained by the controller on a channel-by-channel basis by determining a difference between the new reference signals received at 212 and the reference backgrounds identified at 210 (e.g., from a previously acquired time based average). The controller may then normalize the difference obtained for each channel, for example, by dividing the difference by the reference background of the same channel. In this way, an NNR may be obtained for each channel of the reference spectrum analyzer.

[0054] At 216, the controller may monitor for changes in one or more of the analytical signals. For example, changes in each analytical signal may be detected by the controller relative to its corresponding analytical background. As a non-limiting example, a NNR for each analytical signal may be obtained by the controller on a channel-by-channel basis by determining a difference between the new analytical signals received at 212 and the analytical backgrounds identified at 210 (e.g. from a previously acquired time based average). The controller may then normalize the difference obtained for each channel, for example, by dividing the difference by the analytical background of the same channel. In this way, an NNR may be obtained for each channel of the analytical spectrum analyzer.

[0055] At 218, if a change is detected in one or more of the analytical signals, the process flow may proceed to 220. As one example, the controller may compare on a channel-by-channel basis the change detected at 218 in one or more of the analytical signals to the corresponding analytical signal thresholds identified at 208. Where the

controller has utilized an NNR for each channel to detect a change in the analytical signals, the NNR for each channel may be compared to the analytical signal threshold to determine whether a sufficient change in the analytical signal has been detected. Alternatively, where the detected change in one or more of the analytical signals do not exceed their analytical threshold of the corresponding channel, the controller may judged the answer at 218 to be no. If the controller judged the answer to 218 to be no, the process flow may return to the start or any other suitable operation of the process flow. For example, the process flow may return to 212 where new reference and analytical signals may be received by the controller.

[0056] At 220, if a corresponding change is not detected in one or more of the reference signals that exceed one or more of the reference signal thresholds, then the process flow may proceed to 222. Conversely, where a corresponding change is detected in one or more of the reference signals that exceed one or more of the reference signal thresholds of the corresponding channel, then the process flow may proceed to 226. Where the controller has utilized an NNR for each channel to detect a change in the reference signals, the NNR for each channel may be compared to the reference signal threshold to determine whether a sufficient change in the reference signal threshold has been detected.

[0057] Where the controller has determined that a corresponding change in the reference signals has been detected, the controller may associate spectral variations within the reference spectral range with changes in the background electromagnetic radiation that are not caused by the presence of analytes in the field of view. In some examples, the controller may recognize changes in the electromagnetic radiation background responsive to the detected changes in the reference signals irrespective of the detected changes in the analytical signals. In this way, the controller may associate changes in the reference spectral range with changes in the background radiation that may be caused by one or more new targets entering the field of view, movement of targets within the field of view, and/or changing ambient light conditions within the field of view.

[0058] On the other hand, when changes are detected in one or more of the analytical signals without sufficient corresponding changes in one or more of the reference signals, the controller may attribute the detected changes in the analytical signals to the inclusion of one or more analytes within the field of view or the removal of one or more analytes from the field of view.

[0059] Referring also to 222, the controller may be configured to identify one or more of the analytes present in the field of view and in some embodiments, to quantify their respective concentrations within the field of view. As one example, the controller may be configured to perform detect changes in the analytical signals received from the various channels of the analytical sensor to reveal the identity of each analyte according the detected change in one or more of the analytical signals. For example, the controller may be configured to recognize analytes by observing a characteristic of the detected changes in some or all of the analytical signals obtained across the various channels of the analytical spectrum analyzer to identify one or more of the chemicals that are responsible for the detected change in electromagnetic radiation sample.

[0060] As one example, the controller may reference a chemical library or database stored in memory according to a detected change in one or more of the analytical signals. For example, the chemical database may be provided as a look-up table, map, or other suitable function for attributing a particular change in one or more of the channels to the presence of one or more analytes in the field of view. This database may optionally include interferences such as water vapor, for example, in addition to the previously described chemicals.

[0061] As a non-limiting example, the controller may be configured to determine a quantity of one or more of the identified analytes by estimating an optical density of each analyte according to the detected change in one or more of the analytical signals. For airborne analytes, the controller may identify or estimate an optical density of the chemical cloud along a line of sight within the field of view. The optical density of the chemical cloud may be defined as the product of the average concentration (C) of the analyte within the chemical cloud and the linear dimension (L) of the chemical cloud along a line-of-sight. For example, for each chemical signature stored in the chemical database, the controller may be configured to estimate an optical density that would produce the corresponding analytical signals that were received from the detector sub-system at 212. However, it should be appreciated that the controller may employ any other suitable technique to determine the quantity of the identified analytes.

[0062] At 224, the controller may be configured to indicate the presence of one or more of the analytes identified at 222 and their respective quantities according to the detected change in the analytical signals. As one example, the controller may be

configured to output the name of the chemicals identified as well as their estimated optical densities. For example, the controller may be configured to indicate the presence of the analytes and their corresponding quantities by one or more of a user perceivable visual or aural output.

[0063] Referring also to FIG. 1, the controller may be configured to communicate the visual and/or aural output to a user of the chemical sensor system via one or more suitable output devices indicated schematically at 180. These output devices may include any suitable device for communicating information to a user. For example, these output devices may include one or more of an indicator lamp, a graphical display, an alpha-numerical display, an audio speaker, etc. For example, the controller may be configured to issue an alarm, present a user-readable display, or provide other suitable output indicating the particular analytes identified by the controller and their respective quantities determined at 222.

[0064] In some examples, the controller may provide the indication to one or more of the user output devices by way of wireless communication. For example, the controller may be configured to communicate with one or more user output devices that are remotely located from the controller by way radio transmission, satellite transmission, or other suitable form of wireless communication. Further, in some examples, the indication provided to the user at 224 may include a recommendation for further action to be taken by the user. Further still, the controller may be configured to autonomously carry out specific actions in accordance with the analytes identified by the chemical sensor system.

[0065] Referring to the operation at 226, the reference background may be adjusted for one or more of the reference spectrum analyzer's channels according to one or more of the reference signals received by the controller. As one example, the controller may adjust the reference background on a channel-by-channel basis by resetting the reference background to a new value that is dependent upon the received reference signal for the channel. As described with reference to 210, the controller may utilize a time based average of the reference signals received at 212 to identify a new reference background for each channel. For example, the controller may store the reference signal of a particular channel in memory as the reference background for the channel.

[0066] Further, at 228, the analytical background may be adjusted on a channel-by-channel basis according to the analytical signal associated with each

channel. As one example, the controller may adjust the analytical background by resetting the analytical background to a new value that is dependent upon the analytical signal. As described with reference to 210, the controller may utilize a time based average of the analytical signals received at 212 to identify a new analytical background for each channel. For example, the controller may store the analytical signal of a particular channel in memory as the analytical background for the channel.

[0067] From 224 and 228, the process flow may return to the start or any other suitable operation of the process flow. For example, the process flow may return to 212 where new reference and analytical signals may be received by the controller.

[0068] FIG. 3 depicts a non-limiting example of a process flow that may be performed by the controller in accordance with the process flow of FIG. 2. In the particular example of FIG. 3, the controller may utilize a net normalized response (NNR) of the analytical and reference signals that are received by the controller. Additionally, a statistical figure such as a Mahalanobis distance may be used to enable the controller to detect the presence of an analyte in the field of view and identify that particular analyte from the chemical database stored in memory responsive to the analytical signals received from the analytical spectrum analyzer.

[0069] Beginning at 310, the controller may establish an NNR for each of the analytical spectrum analyzer channels and the reference spectrum analyzer channels. As one example, newly recorded, demodulated, and corrected outputs of the detector sub-system may be subtracted, channel-by-channel, from the analytical and reference backgrounds previously identified and recorded, for example at 210, by dividing the difference between the newly acquired analytical and reference signals from the analytical and reference background by background identified for that channel. The NNR of the individual channels of the analytical spectrum analyzer may be corrected to account for the temperature and emissivity effects of targets within the field of view. Also, The NNR of the individual channels of the analytical spectrum analyzer may be corrected to account for the humidity effects within the field of view as estimated by a humidity sensor such as sensor 195 of Fig. 1. An estimate of surface temperature, scene specific emissivity, and the emission from vapor in the field of view may be used to obtain a corrected NNR.

[0070] At 312 the controller may compare each new NNR for the reference signals received by the controller at 212 to a previously recorded reference signal NNR to determine whether a variation in the background electromagnetic radiation (e.g.,

caused by changing terrain or ambient light within the field of view) has occurred. An example of this approach was previously described with reference to 220. For example, if the NNR of any channel of the reference spectrum analyzer deviates from a previously determined NNR of the same channel by the reference signal threshold (e.g. by a user defined level), the analytical background for all channels of the analytical spectrum analyzer may be reset in accordance to operation 228 where the new analytical backgrounds may be recorded in memory at the controller.

[0071] At 314, the controller may compare the Mahalanobis distance of the newly acquired NNR of the various analytical spectrum analyzer channels to the Mahalanobis distance of the analytical backgrounds identified at 210. For example, where the analytical spectrum analyzer includes eight channels, the NNRs of newly acquired analytical signals and the analytical background each represent an eight component vector. When the length of this vector, as expressed by the Mahalanobis distance, exceeds the length of the vector associated with the analytical background and nominal fluctuations that are associated with noise, the controller may associate the variations in the electromagnetic radiation with the presence of a new chemical in the field of view when the electromagnetic variations in the NNRs associated with the reference signals remain within the limits set by the reference signal thresholds.

[0072] At 316, the optical density may be estimated for each chemical in the chemical database. For each chemical signature stored in the chemical database, the controller may estimate an optical density that is required to produce the observed NNR response vector of the newly acquired analytical signals.

[0073] At 318, the controller may calculate a simulated response vector for each chemical signature in the chemical database based on the optical density estimated at 316.

[0074] At 320, the controller may determine the Mahalanobis distance between the simulated and observed response vector. For each chemical signature stored in the chemical database, the Mahalanobis distance between the observed NNR response vector and the simulated response vector may be computed by the controller.

[0075] At 322, the controller may identify the chemical in the field of view. For example, chemical identification at 222 may be achieved by the controller selecting the chemical having the smallest Mahalanobis distance between the observed and simulated response vectors. The chemical sensor system may output the name or other indication of the identified chemical as indicated at 224. The estimated optical

density for this chemical may also be reported by the controller. For reliable identification, the Mahalanobis distance may be below the analytical signal threshold as judged at 218. Thus, if a Mahalanobis distance below the analytical threshold value is not observed, an “unknown chemical” identification may be optionally provided by the controller at 224 and a corresponding optical density may not be provided by the chemical sensor system.

[0076] It will be appreciated that other possible data reduction and processing schemes may be employed which utilize information from an analytical spectrum analyzer operating in a first spectral range and a reference spectrum analyzer operating in a second different spectral range. These schemes may include, but are not limited to, change of state analysis, threshold analysis, linear or non-linear regression analysis techniques, orthogonal subspace projection (OSP) techniques, principle components analysis (PCA), canonical discriminate analysis (CDA), logic or fuzzy-logic techniques, or artificial neural network (ANN) processing, among others.

[0077] In field deployments, the chemical sensor system may encounter an electromagnetic radiation background having varying spectral features, particularly where the chemical sensor system is mounted on a mobile vehicle or is configured as a handheld device. As previously described with reference to FIGS. 1 and 2, a reference spectrum analyzer may be used to identify the varying spectral features that result from the changing background electromagnetic radiation and separate them from spectral features that are unique to one or more analytes that are to be detected by analytical spectrum analyzer.

[0078] FIGS. 4 – 7 depict experimental test data that was obtained from the chemical sensor system. Specifically, the depicted data was collected in an experiment that was performed to test an example embodiment of chemical sensor system 100 in an environment where spectral features of the electromagnetic radiation sample occur as a consequence of a changing electromagnetic radiation background. For this experiment, the chemical sensor system was configured with an analytical spectrum analyzer that included eight channels operating within an infrared electromagnetic radiation spectral range and a reference spectrum analyzer that included three channels operating within the visible electromagnetic radiation spectral range across discrete red, green, and blue components.

[0079] To test the chemical sensor system, the electromagnetic radiation collector was orientated towards a first ground surface for a period of time, followed

by a rapid movement towards a second different ground surface, and then followed by an introduction of a chemical into the field of view of the collector.

[0080] FIG. 4 shows the time record of this experiment where the collector of the chemical sensor system was initially pointed towards a section of weathered asphalt and then re-orientated towards a section of new asphalt. The appearance of the two sections asphalt surfaces was visibly different.

[0081] The initial segment of FIG. 4 shows the calibrated radiance outputs of an analytical spectrum analyzer operating in the infrared range of the electromagnetic radiation background and marked in FIG. 4 as IR sensor, and the reference spectrum analyzer operating in the visible range and marked in FIG. 4 as RGB sensor, while facing the weathered asphalt surface. The measured temperature contrast when facing this segment was 14.7 K. Note that the reference signals outputted by the three channels of the reference spectrum analyzer are nearly identical during this period, and was identified to be a mere coincidence with no significant consequences.

[0082] At approximately 120 sec after the start of this experiment, the collector of the chemical sensor system was manually orientated to include the newly paved asphalt within its field of view. The measured temperature contrast when facing the newly paved asphalt was 16.9 K. Both the reference and analytical spectrum analyzers responded to this transition. Note that the analytical signal outputs of the analytical spectrum analyzer were increased, thereby confirming the measurement of the higher surface temperature of the new asphalt surface. However, since the controller was configured to attribute a substantial change in the reference signal outputs of the reference spectrum analyzer as an indication of a changing electromagnetic radiation background, such as the new ground target, the corresponding changes in the analytical signals outputted by the analytical spectrum analyzer were treated as a new electromagnetic radiation background, rather than an encounter with a new chemical.

[0083] Referring again to FIG. 4, the first vertical dotted line, immediately after re-orientation of the chemical sensor system occurred, marks when an adjustment (e.g. reset) of the reference background was triggered. The time lapsed between the two adjacent vertical dotted lines represents the delay between initiation of the reference background adjustment and the restart of the acquisition of a new electromagnetic radiation sample by the controller. This delay may be optionally imposed to avoid transient effects from being accumulated and averaged as part of the new reference background.

[0084] At approximately 180 sec from the start of this test, the sun emerged from behind a cloud. This resulted in a slight heating of the asphalt surface. Both the analytical and reference spectrum analyzers responded to the change in the electromagnetic radiation background caused by the changing ambient light conditions. The newly illuminated surface was treated by the controller as a new background target. This is indicated in FIG. 4 by the next pair of dotted vertical lines.

[0085] At approximately 250 sec from the start of the test, a gas cell was filled with a chemical: FM 200 at an optical density of 0.62 atm-cm within the field of view of the collector. The release of the FM 200 created an observable change in the analytical signal outputs of the analytical spectrum analyzer. However, since FM 200 has little or no spectral features in the visible range there were no corresponding changes in the reference signal outputs of the reference spectrum analyzer. Accordingly, the controller treated this event as a chemical release rather than a changing electromagnetic background and processed the data to identify the chemical.

[0086] FIG. 5 shows a Mahalanobis distance map corresponding to data accumulated after the release of the FM 200 (e.g. as represented by data segment of approximately 250 sec through approximately 300 sec) while using the data segment between approximately 200 and approximately 250 sec as the electromagnetic radiation background. Clearly, the chemical release, in this example, is well separated both from the electromagnetic radiation background and from the signatures of other chemicals stored in the controller's chemical database, thereby resulting in the detection and correct identification of the chemical.

[0087] Note that the Mahalanobis distance coordinate points associated with the electromagnetic radiation background are confined to the left of the vertical line marked "Detection Threshold". Of course as this line shifts towards the origin, the detectable optical density of any chemical release may be potentially reduced, thereby rendering the chemical sensor system to become more sensitive. Conversely, as this threshold shifts away from the origin, the sensitivity of the chemical sensor system may decline.

[0088] To illustrate, Figure 6 shows a new Mahalanobis distance map consisting of all points recorded after the sensor was shifted from the weathered asphalt to the new asphalt surface (approximately 120 sec through 300 sec). In this map, the electromagnetic radiation background data includes the periods both before and after the sun emerged from behind the cloud, and thus this electromagnetic

radiation background set covers a wider range. Clearly the “Detection Threshold” line shifted to the right, or away from the origin. Similarly, FIG. 7 shows the Mahalanobis distance map containing all data recorded during this test, including the data obtained while pointing the collector towards the weathered asphalt. Once again, the “Detection Threshold” shifted even further to the right.

[0089] As the data shows, FM-200 at an optical density of 0.62 atm-cm still could be detected and identified by the chemical sensor system. However, detection at that optical density may be very near the threshold. Clearly, the incorporation of the reference spectrum analyzer operating in the red, green, and blue portions of the reference spectral range as a supplement to the analytical sensor that operated in the infrared range results in a refinement of the background identification process and in effect enhances the sensitivity of the analytical spectrum analyzer.

[0090] FIG. 8 is schematic depiction of an example embodiment of the previously described chemical sensor system 100. In this particular example, chemical sensor system 800 includes an electromagnetic radiation collector comprising an aperture device 810 and a light gathering device 812, which collects and focuses an electromagnetic radiation sample 820 received from a field of view including one or more targets indicated at 122 and an analyte 130. The electromagnetic sample 820 may be redirected by an optical distributor including folding optical element 840 as indicated by axial ray 822. Optical element 840 may distribute the electromagnetic radiation sample so that its focal point is located at one or more electromagnetic radiation detectors. For example, a focal point of electromagnetic radiation sample 820 may be distributed by optical element 840 so that it is located at electromagnetic radiation detector 856A. The folding optical element 840 may include a mirror or other suitable optically reflective element, tilted at a reflection angle that is suitable to project axial ray 822 of electromagnetic radiation sample 820 from the on-axis focusing cone of the light gathering device 812.

[0091] Detector 856A may comprise a first electromagnetic radiation detector of a plurality of electromagnetic radiation detectors associated with an analytical spectrum analyzer. In this particular example, the analytical spectrum analyzer of chemical sensor system 800 comprises a total of eight electromagnetic radiation detectors 856A – 856H, each of which may detect a specific infrared component of the electromagnetic radiation spectra within an analytical spectral range of the analytical spectrum analyzer. Further, a reference spectrum analyzer of chemical sensor system

800 may be provided, which comprises a total of three electromagnetic radiation detectors 852A, 852B, and 852C. Each of detectors 852A, 852B, and 852C may respectively detect red, green, and blue components of the electromagnetic radiation spectra within a reference spectral range of the reference spectrum analyzer.

[0092] These detectors may comprise a detector array 850. In some embodiments, the detector array may include a plurality of detectors that are arranged in a ring pattern or other suitable pattern, such that, when folding optical element 840 is rotated about its axis, the focal point of the incoming electromagnetic radiation sample, and thus the image of the field of view, including targets 122 and analyte 130, move successively to each of the detectors of detector array 850. As one example, incoming radiation from the field of view is distributed to one or more detectors at a time until all detectors are exposed to the electromagnetic radiation sample after a complete revolution of the optical element or mirror.

[0093] Each detector may further include or may be associated with one or more filters. For example, as depicted schematically with reference to detector 856A, a filter assembly 858 may be disposed optically between the detector and folding optical element 840. Filter assembly 858 may include one or more of the previously described filters or optical elements. Each detector may include a respective filter assembly that includes one or more filters or optical elements. In some embodiments, at least some of these filter assemblies may include one or more different filters or optical elements than other filter assemblies of the various detectors.

[0094] Electromagnetic radiation detected by each of the detectors may be provided to controller 860 by an output signal as indicated schematically with reference to detector 856A. In this way, each of detectors 856A – 856H may provide a channel of the analytical spectrum analyzer and each of detectors 852A – 852C may provide a channel of the reference spectrum analyzer. Thus, in this particular embodiment, detector array 850 provides a total of eight channels in the analytical spectral range and three channels in the reference spectral range, although any suitable number of channels may be provided in other embodiments.

[0095] Controller 860 is depicted in this embodiment to include a demodulation device 862, a processor 864, and memory 866. Processor 864 may communicate with a driving device 842 to enable folding optical element 840 to direct the electromagnetic radiation sample onto one or more of the detectors. For example, as shown in FIG. 8, driving device 842 may cause folding optical element 840 to rotate

about its axis as indicated by arrow 844, thereby enabling folding optical element 840 to distribute the electromagnetic radiation sample to one or more of the detectors in accordance with a control signal received from controller 860. In other embodiments, driving device 842 may be instead configured to adjust the position of detector array 850 relative to folding optical element 840.

[0096] The output signals received from the various detectors in response to the electromagnetic radiation sample comprise the previously described analytical and reference signals. The demodulation device of controller 860 may demodulate these signals in synch with driving device 842, which may cause the folding optical element 840 to move relative to detector array 850 at a prescribed frequency. In some embodiments, a synchronization signal may be provided to demodulation device 862 by processor 864, where the synchronization signal indicates the frequency or rotation speed of folding optical element 840. As one example, demodulation device 862 may accomplish demodulation of the signals received from the various sensors by using one or more analog to digital (A/D) converters to monitor the "on" signal of a similar number of adjacent detectors, while another A/D converter may be used to monitor the "off" state of a non-illuminated detector. For example, two A/D converters may be used to monitor the on state of two adjacent detectors, since as the focal point location of the electromagnetic radiation sample is changed relative to the detector array, a portion of the focused radiation may fall on two adjacent detectors where the inter-detector spacing is less than the radiation beam size.

[0097] In some embodiments, these multiple A/D channels provided by the various detectors may be implemented with a single A/D converter with an input channel multiplexer. Samples of the detector signals may be taken while radiation is focused on them. The decision to monitor a particular detector may be based on the output of a stepper motor controller or an encoder. Reference samples, possibly acquired at a slower sample rate, may be obtained from a detector, typically immediately preceding exposure to focused radiation.

[0098] Processor 864 may receive the analytical and reference signals from detector array 850 and perform the previously described process flow to indicate the presence of an analyte, identify the analyte from a plurality of analytes stored in the chemical database, and identify the quantity or concentration (e.g. optical density) of the analyte within the field of view of the chemical sensor system. In performing this process flow, the processor may store and retrieve information from a computer

readable media such as memory 866. For example, the previously described process flow may be embodied in instructions that are stored at memory 866, where they may be accessed by processor 864 where appropriate. Further, the chemical database as previously described may be stored at memory 866 for reference by the processor. Processor 864 may provide user perceivable outputs to output device 880 in response to the identification and quantification of the analyte.

[0099] It should be appreciated that the chemical sensor system described herein may be used in any suitable scenario where remote chemical detection and identification is desired. Specifically, the chemical sensor system described herein may be used in situations where the field of view of the chemical sensor system may be changing over time. Possible applications of the chemical sensor system include, but are not limited to, deployment on manned or unmanned aerial or ground vehicles, unattended ground sensors, and handheld chemical detection devices, among others. Potential users of the chemical sensor system may include military personnel, first responders such as police, fire fighters, rescue workers, or HAZMAT teams. Additionally, it should be appreciated that certain aspects of the chemical sensor system may be packaged as an add-on component for other passive remote chemical sensors in order to increase their sensitivities to the environments where the electromagnetic radiation background may be changing with time.

[00100] It will be appreciated that the configurations and/or approaches described herein are exemplary in nature, and that these specific embodiments or examples are not to be considered in a limiting sense, because numerous variations are possible. Furthermore, the specific process flows or methods described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various acts illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of any of the above-described processes is not necessarily required to achieve the features and/or results of the exemplary embodiments described herein, but is provided for ease of illustration and description.

[00101] The subject matter of the present disclosure includes all novel and nonobvious combinations and subcombinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

CLAIMS:

1. A chemical sensor system, comprising:
 - an electromagnetic radiation collector configured to collect an electromagnetic radiation sample from a field of view;
 - a reference spectrum analyzer configured to output a reference signal dependent upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within a reference spectral range;
 - an analytical spectrum analyzer configured to output an analytical signal dependant upon a level of electromagnetic radiation detected in the electromagnetic radiation sample within an analytical spectral range; and
 - a controller configured to:
 - receive the reference signal and the analytical signal;
 - detect changes in the reference signal;
 - detect changes in the analytical signal; and
 - indicate a presence of an analyte when a change is detected in the analytical signal and no corresponding change is detected in the reference signal that exceeds a reference signal threshold.
2. The chemical sensor system of claim 1, wherein the analytical spectral range includes electromagnetic radiation of a longer wavelength than the reference spectral range.
3. The chemical sensor system of claim 2, wherein the analytical spectral range includes one or more infrared wavelengths; and wherein the reference spectral range includes one or more visible wavelengths.
4. The chemical sensor system of claim 2, wherein the analytical spectral range includes one or more infrared wavelengths; and wherein the reference spectral range includes one or more ultraviolet wavelengths.
5. The chemical sensor system of claim 2, wherein the analytical spectral range includes one or more infrared wavelengths; and wherein the reference spectral range includes one or more near-infrared wavelengths.

6. The chemical sensor system of claim 1, wherein the analytical spectral range defines a first spectral range in which the analyte absorbs electromagnetic radiation and wherein the reference spectral range defines a second spectral range in which the analyte does not substantially absorb electromagnetic radiation.
7. The chemical sensor system of claim 1, wherein the detected change in the reference signal is relative to a reference background and wherein the detected change in the analytical signal is relative to an analytical background.
8. The chemical sensor system of claim 7, wherein the controller is further configured to reset the reference background according to the reference signal and to reset the analytical background according to the analytical signal when the change in the reference signal is greater than the reference signal threshold.
9. The chemical sensor system of claim 1,
wherein the reference spectrum analyzer comprises a first filter assembly configured to pass electromagnetic radiation within the reference spectral range to an electromagnetic radiation detector; and
wherein the analytical spectrum analyzer comprises a second filter assembly configured to pass electromagnetic radiation within the analytical spectral range to the electromagnetic radiation detector.
10. The chemical sensor system of claim 9, wherein the first filter assembly includes at least a first filter and wherein the second filter assembly includes at least a second filter that is different than the first filter.
11. The chemical sensor system of claim 9, wherein the first filter assembly and the second filter assembly each include a plurality of filters.
12. The chemical sensor system of claim 1,
wherein the reference spectrum analyzer comprises a first electromagnetic radiation detector configured to detect electromagnetic radiation within the reference spectral range; and

wherein the analytical spectrum analyzer comprises a second electromagnetic radiation detector configured to detect electromagnetic radiation within the analytical spectral range.

13. The chemical sensor of claim 1, wherein the controller is further configured to identify the analyte from a chemical database stored in memory at the controller according to the detected change in the analytical signal when the change in the reference signal is less than a reference signal threshold.

14. The chemical sensor of claim 1, wherein the controller is further configured to indicate a quantity of the analyte according to the detected change in the analytical signal when the change in the reference signal is less than a reference signal threshold.

15. The chemical sensor system of claim 1, wherein the controller is further configured to receive a user input setting the reference signal threshold.

16. The chemical sensor system of claim 1, wherein the controller is further configured to set the reference signal threshold according to a condition of the field of view.

17. The chemical sensor system of claim 1, wherein the presence of the analyte is indicated by the controller by one or more of a user perceivable visual or aural output.

18. The chemical sensor system of claim 1, further comprising:
a temperature sensor configured to output a temperature signal dependent upon a temperature of the chemical sensor system; and

wherein the controller is further configured to:
receive the temperature signal from the temperature sensor; and
adjust, in response to the received temperature signal, one or more of:
the change in the analytical signal, the change in the reference signal, and the reference signal threshold.

19. The chemical sensor system of claim 1, further comprising:
a humidity sensor configured to output a humidity signal dependent upon a humidity detected at the chemical sensor system; and
wherein the controller is further configured to:
receive the humidity signal from the humidity sensor; and
adjust, in response to the received humidity signal, one or more of: the change in the analytical signal, the change in the reference signal, and the reference signal threshold.
20. The chemical sensor system of claim 1, wherein the chemical sensor system is configured as a handheld device.
21. The chemical sensor system of claim 1, wherein the chemical sensor system is configured to be mounted on a mobile vehicle.
22. The chemical sensor system of claim 1, wherein the chemical sensor system is configured to be mounted at a fixed location.
23. The chemical sensor system of claim 1, wherein the reference spectrum analyzer includes three electromagnetic radiation detectors configured to detect electromagnetic radiation within the reference spectral range and where the analytical spectrum analyzer includes eight electromagnetic radiation detectors configured to detect electromagnetic radiation within the analytical spectral range.
24. A method of passively detecting a chemical analyte, comprising:
receiving an electromagnetic radiation sample from a field of view;
generating a reference signal responsive to a characteristic of the electromagnetic radiation sample within a reference spectral range;
generating an analytical signal responsive to a characteristic of the electromagnetic radiation sample within an analytical spectral range;
identifying a change in the reference signal relative to a reference background;
identifying a change in the analytical signal relative to an analytical background;

indicating a presence of an analyte in response to the change identified in the analytical signal when the change identified in the reference signal is less than a reference signal threshold; and

resetting the reference background according to the reference signal and the analytical background according to the analytical signal when the change in the reference signal is greater than the reference signal threshold.

25. The method of claim 24, wherein the analytical spectral range includes electromagnetic radiation of a longer wavelength than the reference spectral range.

26. The method of claim 24, wherein the analytical spectral range defines a first spectral range in which the analyte absorbs electromagnetic radiation and wherein the reference spectral range defines a second spectral range in which the analyte absorbs less electromagnetic radiation than the first spectral range.

27. The method of claim 24, wherein said receiving the electromagnetic radiation sample from the field of view includes moving the field of view relative to a target to produce a transient electromagnetic radiation sample.

28. A mobile chemical sensor system, comprising:

an analytical spectrum analyzer configured to output an analytical signal responsive to an analytical band of an electromagnetic radiation sample, said analytical band comprising one or more infrared wavelengths;

a reference spectrum analyzer configured to output a reference signal responsive to a reference band of an electromagnetic radiation sample, said reference band comprising one or more shorter wavelengths than the analytical band;

an electromagnetic radiation collector configured to collect electromagnetic radiation samples from a field of view;

an optical distributor configured to receive the electromagnetic radiation samples from the collector and distribute the electromagnetic radiation samples to the analytical spectrum analyzer and the reference spectrum analyzer; and

a controller configured to:

receive the reference signal and the analytical signal;

detect changes in the reference signal relative to a reference background;

detect changes in the analytical signal relative to an analytical background;

indicate a presence of an analyte according to a detected change in the analytical signal when a detected change in the reference signal does not exceed a reference signal threshold; and

adjust the reference background according to the reference signal and adjust the analytical background according to the analytical signal when the detected change in the reference signal exceeds the reference threshold.

29. The mobile chemical sensor system of claim 28, wherein the optical distributor is configured to move between a first position that distributes an electromagnetic radiation sample to the analytical spectrum analyzer and a second position that distributes an electromagnetic radiation sample to the reference spectrum analyzer.

30. The mobile chemical sensor system of claim 28, wherein at least the electromagnetic radiation collector, the optical element, and the reference spectrum analyzer, and the analytical spectrum analyzer reside at a mobile vehicle; wherein the controller resides at a remote location from the mobile vehicle; and wherein the controller is configured to receive the analytical signal and reference signal by wireless communication.

31. The mobile chemical sensor system of claim 28, wherein the mobile chemical sensor system is configured as a handheld device.

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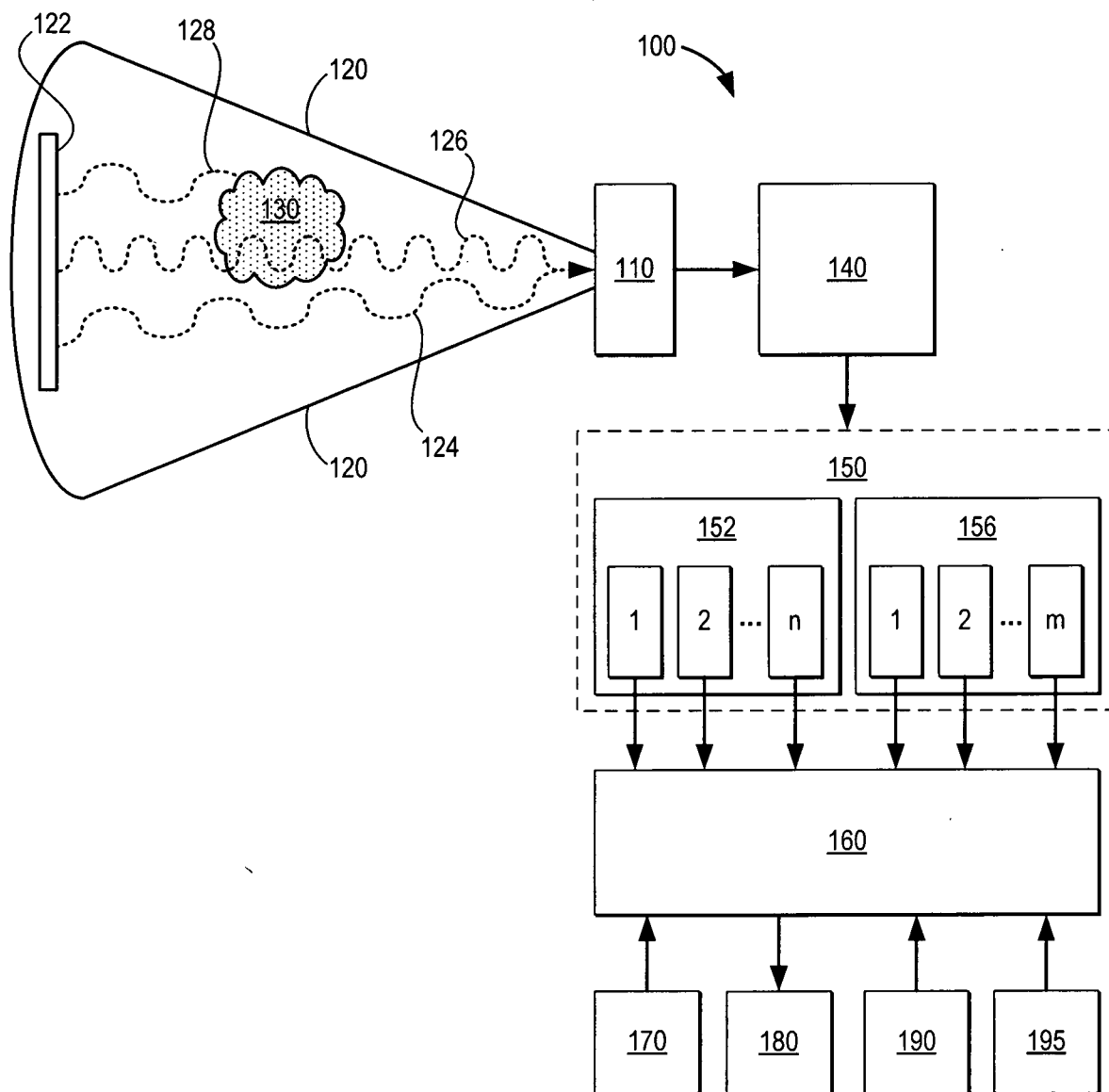


FIG. 1

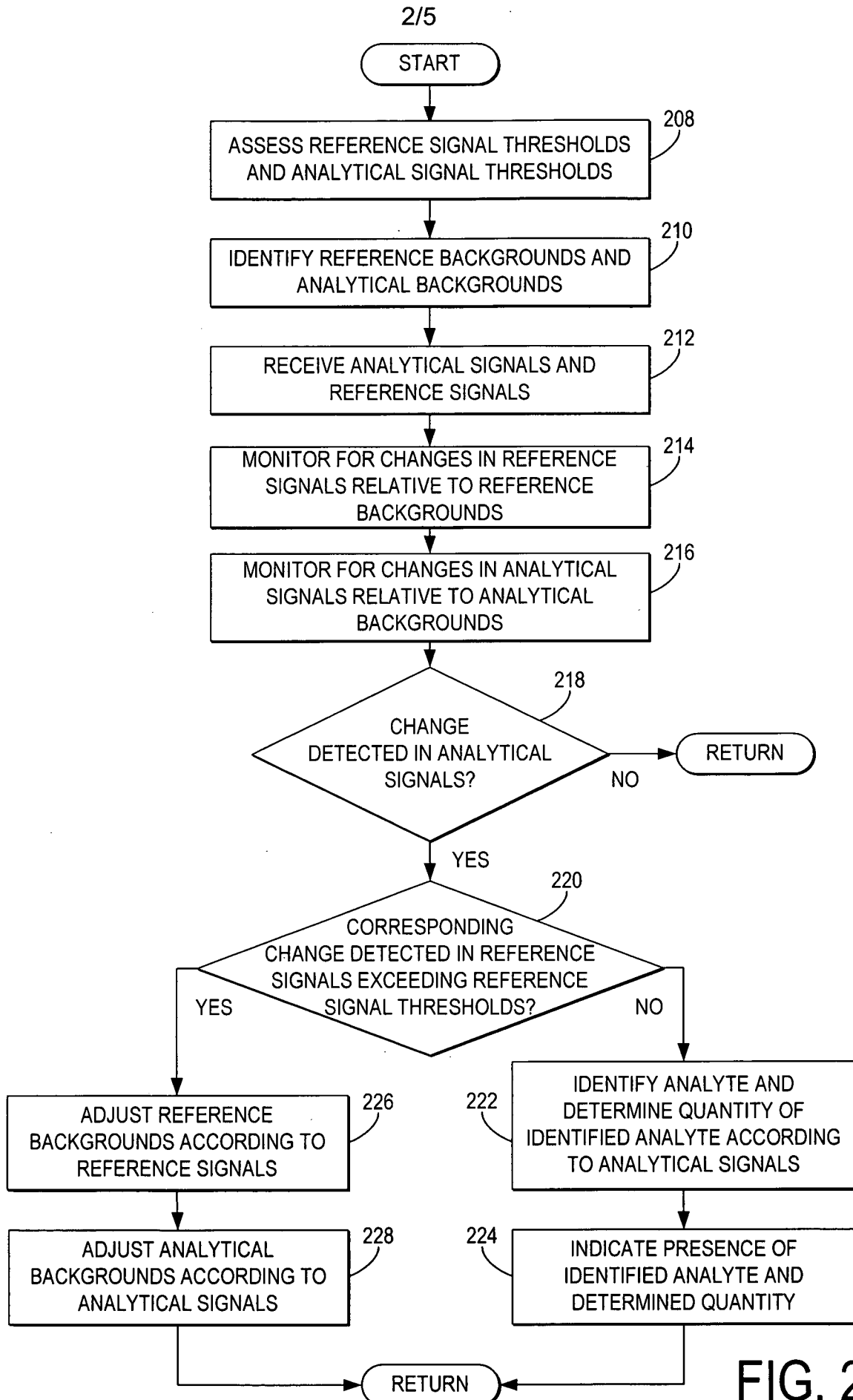


FIG. 2

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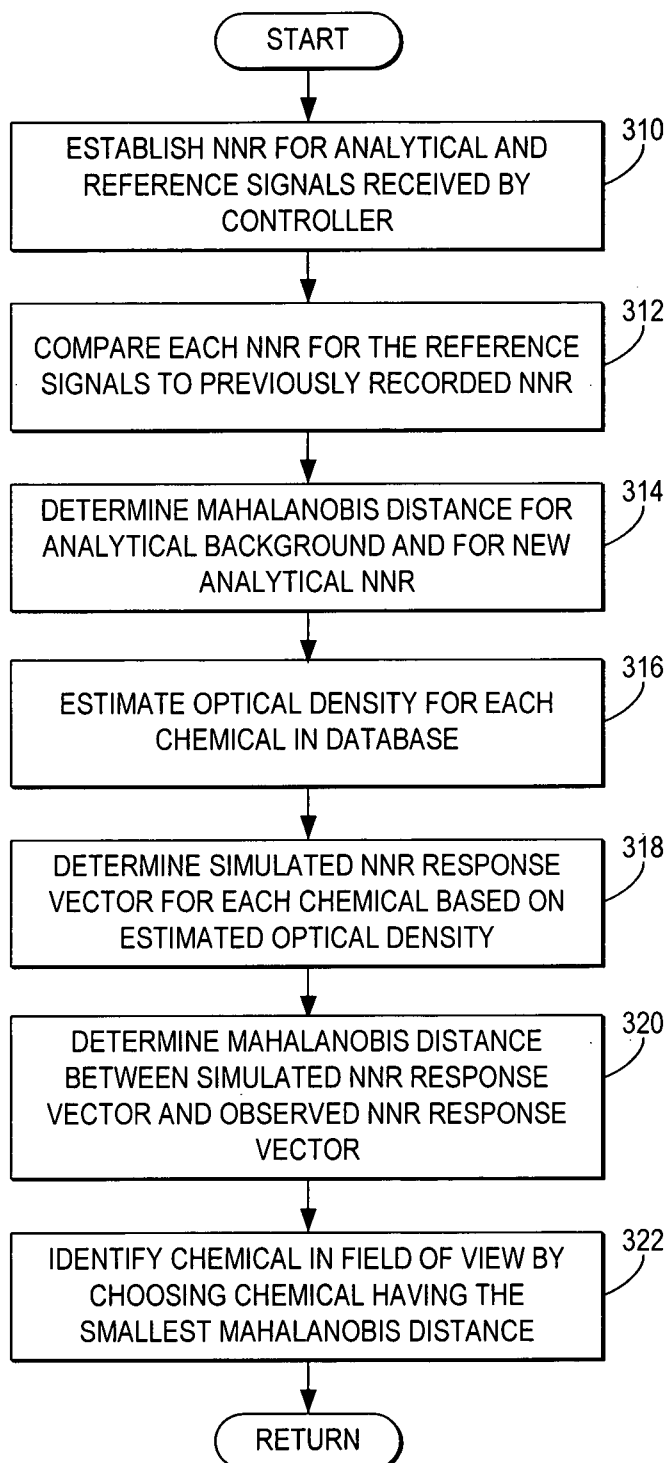


FIG. 3

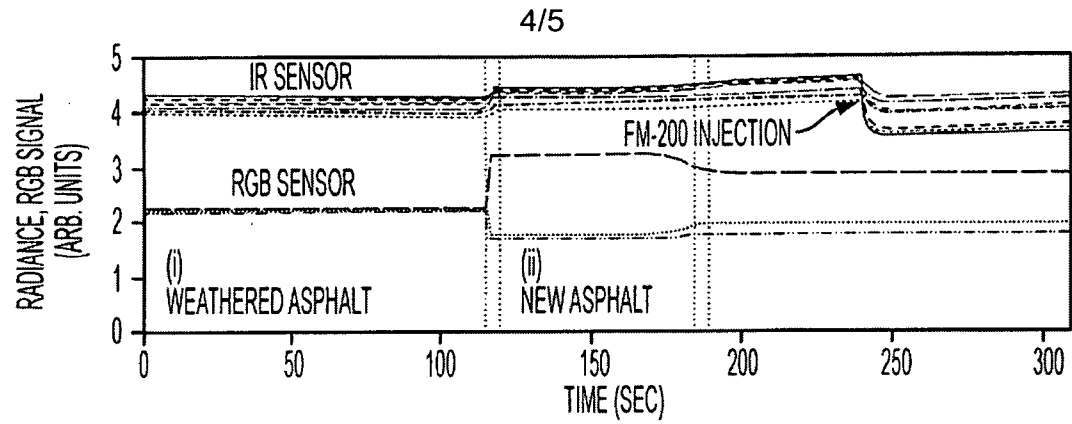


FIG. 4

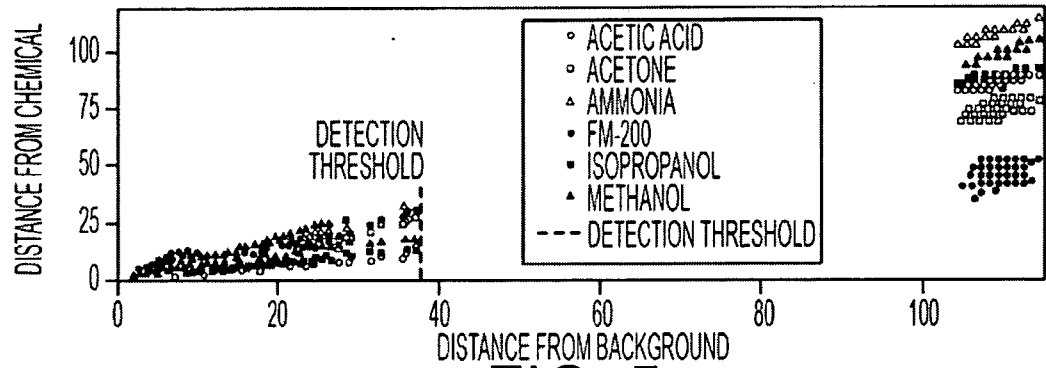


FIG. 5

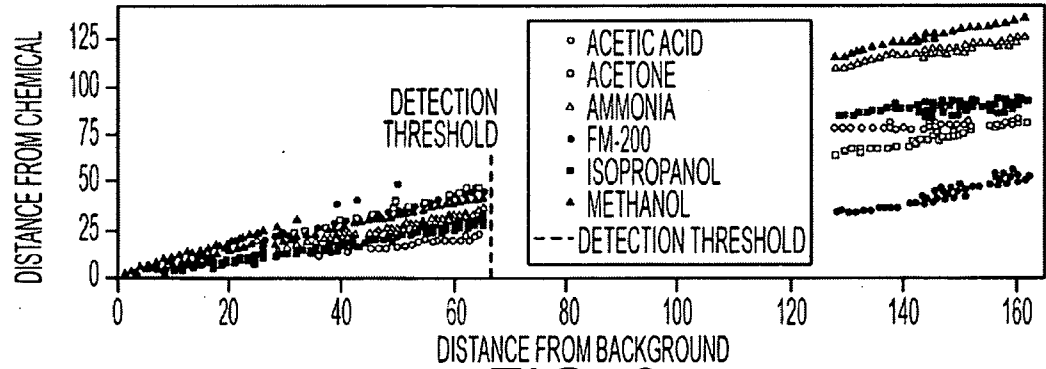


FIG. 6

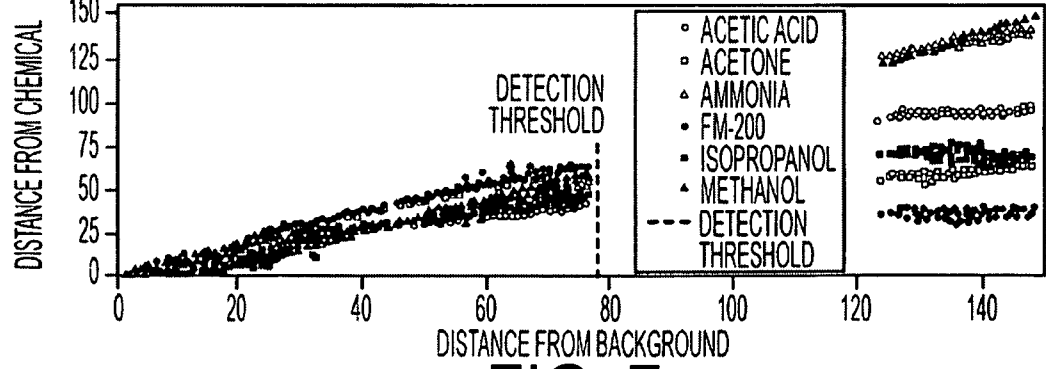


FIG. 7

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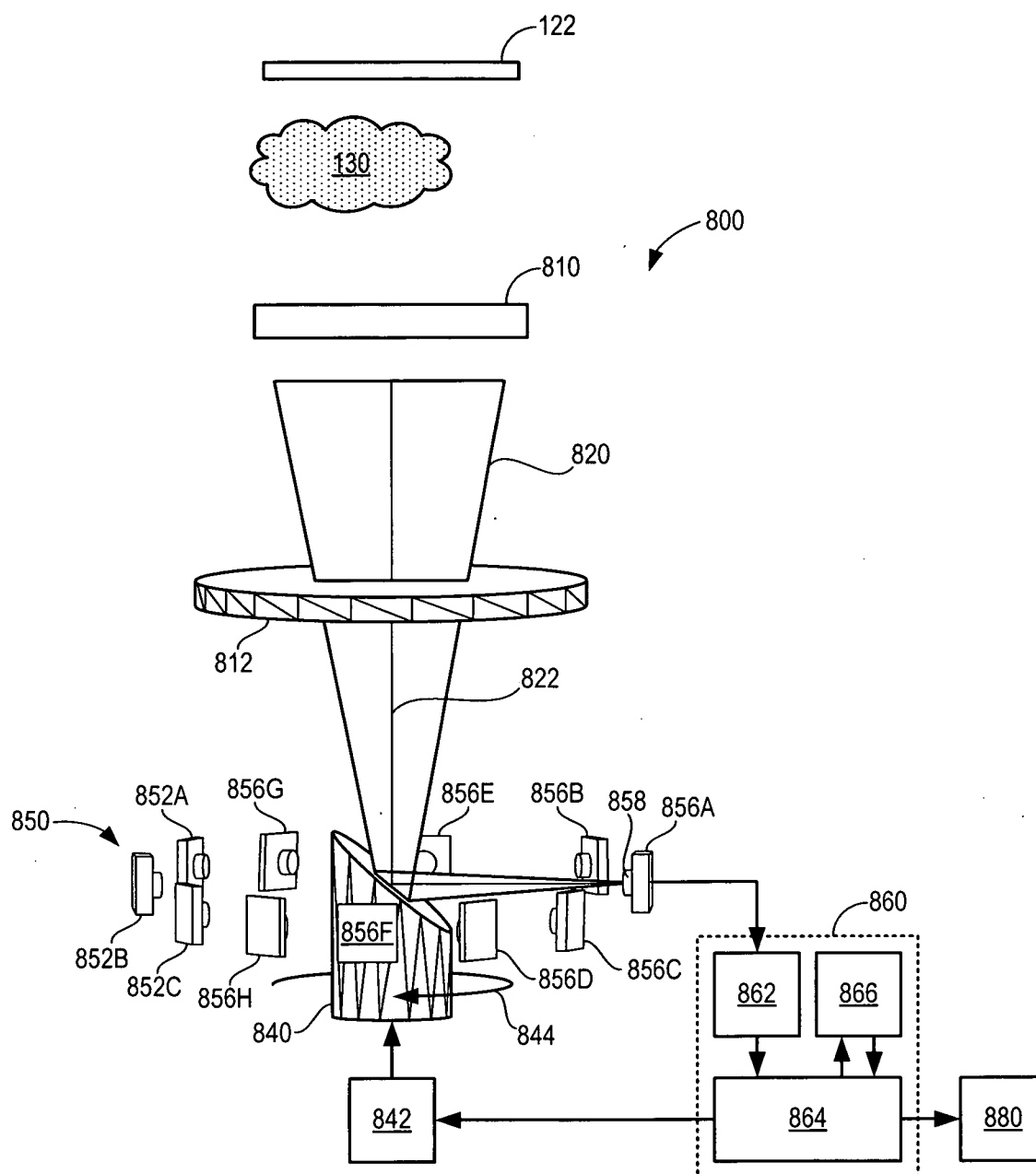


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 08/03198

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01J 19/00; G01N 33/53 (2008.04)

USPC - 435/5; 422/68.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - B01J 19/00; G01N 33/53 (2008.04)

USPC - 435/5; 422/68.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
US 6,853,452 B1; US 3,957,200; Remote detection of Volatile Organic Compounds by Passive Multispectral Infrared Imaging Measurements, Applied Spectroscopy, Volume 61, Number 4, 2007.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Google, Google Patents, PUBWEST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 6,853,452 B1 (Laufer) 08 February 2005 (08.02.2005) Entire Document especially col 11, ln 10-25, col 19, ln 43-48 and col 14, ln 1-25, col 11, ln 20-25 and col 26, ln 6, col 15, ln 45 to col 16, ln 12, claim 1-2, 7, 9, 25 and 52	1-12, 14 -18, 20-31 ----- 13, 19
Y	US 3,957,200 A (Young). 18 May 1976 (18.05.1976) entire document especially Abstract).	19
Y	Wabomba et al "Remote detection of Volatile Organic Compounds by Passive Multispectral Infrared Imaging Measurements", Applied Spectroscopy, Volume 61, Number 4, 2007. (Introduction Section paragraph 6).	13

☐ Further documents are listed in the continuation of Box C.



* Special categories of cited documents:

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Date of the actual completion of the international search

03 June 2008 (03.06.2008)

Date of mailing of the international search report

26 JUN 2008

Name and mailing address of the ISA/US

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