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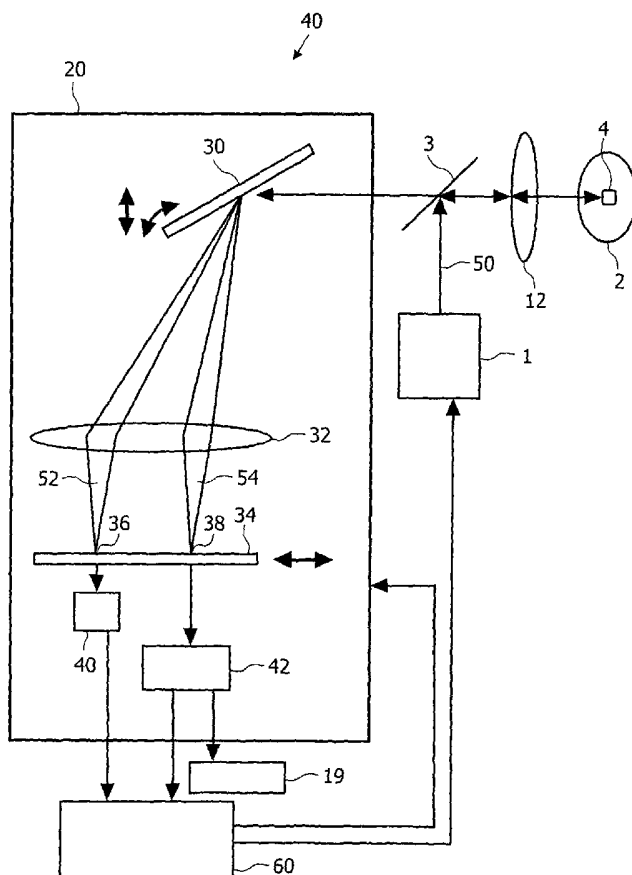
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(54) Title: AUTONOMOUS CALIBRATION FOR OPTICAL ANALYSIS SYSTEM



(57) Abstract: The present invention provides an autonomous calibration of a multivariate based spectroscopic system that is preferably implemented as a multivariate based spectrometer. The spectroscopic system is based on a multivariate optical element that provides a spectral weighting of an incident optical signal. Spectral weighting is performed on the basis of spatial separation of spectral components and subsequent spatial filtering by means of a spatial light modulator. Calibration of the spectroscopic system is based on a dedicated calibration segment of the spatial light modulator, whose position corresponds to a characteristic calibration or reference wavelength of the incident optical signal. Preferably, the calibration or reference wavelength is given by the wavelength of the excitation radiation generated by the optical source that serves to induce scattering processes in a volume of interest.



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Autonomous calibration for optical analysis system

The present invention relates to the field of optical spectroscopy.

5 Spectroscopic techniques are widely used for determination of the composition of a substance. By spectrally analyzing an optical signal, i.e. a spectroscopic optical signal, the concentration of a particular compound of the substance can be precisely determined. The concentration of a particular substance is typically given by an amplitude of a principal component of an optical signal.

10

In the prior art optical analysis system for determining an amplitude of a principal component of an optical signal are well known. The known optical analysis systems are typically part of a spectroscopic analysis system suited for, e.g., analyzing which compounds are comprised at which concentrations in a sample. It is well known that
15 light interacting with the sample carries away information about the compounds and their concentrations. The underlying physical processes are exploited in optical spectroscopic techniques in which light of a light source such as, e.g., a laser, a lamp or light emitting diode is directed to the sample for generating an optical signal which carries this information.

20

For example, light may be absorbed by the sample. Alternatively or in addition, light of a known wavelength may interact with the sample and thereby generate light at a different wavelength due to, e.g. a Raman process. The transmitted and/or generated light then constitutes the optical signal, which may also be referred to as the spectrum. The relative
25 intensity of the optical signal as function of the wavelength is then indicative for the compounds comprised in the sample and their concentrations.

To identify the compounds comprised in the sample and to determine their concentrations the optical signal has to be analyzed. In the known optical analysis system
30 the optical signal is analyzed by dedicated hardware comprising an optical filter. This optical filter has a transmission which depends on the wavelength, i.e. it is designed to

weight the optical signal by a spectral weighting function which is given by the wavelength dependent transmission. The spectral weighting function is chosen such that the total intensity of the weighted optical signal, i.e. of the light transmitted by the filter, is directly proportional to the concentration of a particular compound. Such an optical
5 filter is also denoted as multivariate optical element (MOE). This intensity can then be conveniently detected by a detector such as, e.g., a photodiode. For every compound a dedicated optical filter with a characteristic spectral weighting function is used. The optical filter may be, e.g., an interference filter having a transmission constituting the desired weighting function.

10

For a successful implementation of this analysis scheme it is essential to know the spectral weighting functions. They may be obtained, e.g., by performing a principal component analysis of a set comprising N spectra of N pure compounds of known concentration where N is an integer. Each spectrum comprises the intensity of the
15 corresponding optical signal at M different wavelengths where M is an integer as well. Typically, M is much larger than N . Each spectrum containing M intensities at corresponding M wavelengths constitutes an M dimensional vector whose M components are these intensities. These vectors are subjected to a linear-algebraic process known as singular value decomposition (SVD) which is at the heart of principal
20 component analysis and which is well understood in this art.

As a result of the SVD a set of N eigenvectors z_n with n being a positive integer smaller than $N+1$ is obtained. The eigenvectors z_n are linear combinations of the original N spectra and often referred to as principal components or principal component vectors.
25 Typically, the principal components are mutually orthogonal and determined as normalized vectors with $|z_n|=1$. Using the principal components z_n , the optical signal of a sample comprising the compounds of unknown concentration may be described by the combination of the normalized principal components multiplied by the appropriate scalar multipliers:

30

$$x_1z_1+x_2z_2+\dots+x_nz_n,$$

The scalar multipliers x_n with n being a positive integer smaller than $N+1$ may be considered the amplitudes of the principal components z_n in a given optical signal. Each multiplier x_n can be determined by treating the optical signal as a vector in the M dimensional wavelength space and calculating the direct product of this vector with a principal component vector z_n .

The result yields the amplitude x_n of the optical signal in the direction of the normalized eigenvector z_n . The amplitudes x_n correspond to the concentrations of the N compounds.

In known optical analysis systems the calculation of the direct product between the vector representing the optical signal and the eigenvector representing the principal component is implemented in the hardware of the optical analysis system by means of the optical filter. The optical filter has a transmittance such that it weighs the optical signal according to the components of the eigenvector representing the principal component, i.e. the principal component vector constitutes the spectral weighting function. The filtered optical signal can be detected by a detector which generates a signal with an amplitude proportional to the amplitude of the principal component and thus to the concentration of the corresponding compound.

Especially, when the optical analysis system is dedicated to determine the concentration of a single compound of a substance, like e.g. glucose concentration in blood, it is advantageous to make use of a corresponding optical filter, that is designed for the spectral weighting function of this particular compound. Such dedicated optical filters can be realized in a cost efficient way because they do not have to provide reconfigurable transmission or absorption properties. Optical analysis systems dedicated for determination of the concentration of a particular compound may therefore be implemented on the basis of a low-cost MOE, that can be implemented on the basis of a dispersive optical element, such as a prism or a grating and a corresponding optical filter providing a spatial transmission pattern.

Here, an optical signal received from a sample carrying spectral components being indicative of the composition of the sample is incident on the dispersive optical element. By means of the dispersive optical element, the incoming optical signal is spatially decomposed into various spectral components. Hence, the dispersive optical element
5 serves to spatially separate the spectral components of the incident optical signal. Preferably, the evolving spectrum spreads along a direction specified by the dispersive optical element. For example, the spectrum might spread along a first direction, e.g. horizontally.

10 Making use of a dedicated spatial transmission mask inserted into the optical path of the spectrum, dedicated spectral components of the evolving spectrum can be attenuated or even entirely blocked. Therefore, the spatial transmission mask has to provide a plurality of areas featuring different transmission properties. When the spectrum is spread in a horizontal direction, these areas of the spatial transmission mask have to be aligned
15 horizontally, thereby providing a uniform transmission in the vertical direction.

Additionally, by uniformly expanding the spectrum in a vertical direction, the spatial transmission mask might be divided in two, or more, sections being aligned in a vertical direction. Each section may then feature different spatial transmission patterns allowing
20 to simultaneously manipulate the spectrum in two, or more, different ways.

Consequently, when vertically divided in two sections, the upper section of the spatial transmission mask may effectively serve as a first spectral weighting function whereas the lower section of the spatial transmission mask may provide a second spectral
25 weighting function. By separately detecting these two differently manipulated spectra, positive and negative parts of a principal component can be separately detected, thus allowing for an effective and sufficient amount of information in order to determine an amplitude corresponding to the concentration of the dedicated compound. For example, by mutually subtracting positive and negative part of the spectral weighting function, a
30 signal being indicative of the compounds' concentration might be precisely derived.

Usage of dedicated spatial transmission masks in combination with dispersive optical elements effectively provides a low-cost implementation of an optical analysis system. However, because the spectral components of the received optical signal are spatially spread, the spatial transmission mask has to be properly aligned in order to provide accurate spectral attenuation of dedicated spectral components of the optical signal. The relative positioning of an evolving spectrum and the spatial transmission mask is rather critical and a slight displacement of either the spectrum or the transmission mask may seriously affect the result of the optical analysis. Therefore, an accurate and reliable calibration mechanism is required for spectroscopic analysis that is based on multivariate optical analysis of an optical signal.

The present invention aims to provide calibration of an optical analysis system without implementation of a light source that is dedicated for calibration. In contrast the invention aims to provide calibration on the basis of a spectroscopic optical signal.

The present invention provides a spectroscopic system for determining a principal component of an optical signal comprising return radiation from a volume of interest. The spectroscopic system comprises a light source for generating an excitation radiation. The excitation radiation is adapted to be transmitted into the volume of interest. The spectroscopic system further comprises an objective for collecting return radiation from the volume of interest. It therefore serves to collect the optical signal that returns as e.g. scattered radiation from the volume of interest. The spectroscopic system further comprises a dispersive optical element for spatially separating the spectral components of the return radiation in a first direction and spatial light manipulation means for modulating the spectral components of the return radiation. The spatial light manipulation means further have a reference segment at a first position. This reference segment is at least partially transparent for the excitation radiation, i.e. the reference segment is at least partially transparent for radiation that has substantially the same wavelength as the excitation radiation that is transmitted into the volume of interest. The

spectroscopic system further comprises at least a first detector for detecting radiation that is transmitted through the reference segment of the spatial light manipulation means. Finally, the spectroscopic system further comprises a control unit that is adapted to calibrate the spectroscopic system on the basis of radiation that is detected by means of
5 the at least first detector.

The dispersive optical element in combination with the spatial light manipulation means represent a multivariate optical element (MOE). Typically, the spatial light manipulation means comprise a spatial transmission pattern for selectively blocking or attenuating
10 various spectral components of the optical signal. In this way a spectral weighting function can be effectively realized that in turn allows to determine the concentration of a dedicated compound inside the volume of interest. The position of the spatial light manipulation means with respect to a dispersed spectrum of the optical signal provided by the dispersive optical element is rather critical and has a severe impact on the spectral
15 filtering provided by the MOE.

Additionally, not only the relative position of a spatially dispersed spectrum and a spatial transmission mask but also the light emission characteristics of the light source that may depend on temperature may have a critical impact on the calibration of the optical
20 analysis system.

The reference segment of the spatial light manipulation means serves as an effective means for calibrating the optical analysis system. Preferably, a calibration is performed on the basis of radiation that is transmitted through the reference segment of the spatial
25 light manipulation means and that is detected by means of the at least first detector. In particular, the magnitude of the light intensity being detected by means of the at least first detector gives a sufficient indication whether the spectroscopic system is accurately calibrated. In case that the magnitude of detected light intensity indicates an inaccurate calibration, the control unit serves to calibrate the spectroscopic system in a plurality of
30 different ways until the light intensity that is transmitted through the reference segment

of the spatial light manipulation means indicates accurate calibration, i.e. accurate alignment of the optical paths of the optical analysis system.

According to a preferred embodiment of the invention, the reference segment comprises
5 a slit aperture and the first position substantially corresponds to the wavelength of the excitation radiation. Hence, the reference segment is implemented as a slit aperture at a position on the spatial light manipulation means that corresponds to the wavelength of the excitation radiation. In this way the excitation radiation serves as a reference for calibration of the optical analysis system. Typically, the excitation radiation features a
10 narrow spectral band that is suitable to induce various scattering processes when focused into the volume of interest. For example, the wavelength of the excitation radiation may be in the infrared (IR) or in the near infrared (NIR) spectral range. When focused into the volume of interest, numerous scattering processes either of elastic or inelastic type may occur.

15 The return radiation emanating from the volume of interest may therefore comprise inelastically as well as elastically scattered components. For example, back-scattered inelastic components of the return radiation may have been subject to Raman scattering processes whereas elastically scattered components of the return radiation may stem
20 from Rayleigh scattering leaving the wavelength of the back-scattered components substantially unaffected with respect to the incident excitation radiation. In typical spectroscopic scenarios only a minor portion of the return radiation has become subject to an inelastic scattering process, such like a Stokes or Anti-Stokes scattering process. Therefore, only a minor portion of the return radiation is frequency shifted with respect
25 to the excitation radiation. The spectrum of the return radiation therefore inevitably features a peak at the wavelength of the excitation radiation.

The invention effectively exploits the existence of the excitation radiation's peak in the spectrum of the return radiation. The inherent existence of this excitation peak therefore
30 effectively provides a reference line in the spectrum.

By detecting an intensity of light being transmitted through the reference segment of the spatial light manipulation means and comparing the detected light intensity with a corresponding intensity that has been detected for an accurately calibrated optical analysis system, reliable information about accurate or inaccurate calibration of the optical analysis system can be obtained. Alternatively, when a reference intensity value of an accurately calibrated spectroscopic system is not available, the control unit may calibrate the spectroscopic system in a plurality of different ways until the light intensity that is transmitted through the reference segment of the spatial light manipulation means reaches, for instance, a maximum value.

In this way the excitation radiation that is inherently present in the spectrum of the optical signal can be effectively exploited for calibration of the optical analysis system. Hence, no external or no additional calibration light source has to be implemented into the optical analysis system. By effectively replacing such a calibration light source by means of the excitation radiation, a potential misalignment of a calibration light source leading to a dramatic falsification of the results of the spectroscopic system is intrinsically prevented.

According to a further preferred embodiment of the invention, the control unit is adapted to ~~translate the spatial light manipulation means along the first direction. In this way a~~ misalignment of the spatial light manipulation means that may be either implemented as a fixed spatial light transmission pattern or a reconfigurable spatial light modulator (SLM), can be effectively compensated. Preferably, the spatial light manipulation means are mounted on a servo driven translation stage that can be controlled by means of the control unit.

According to a further preferred embodiment of the invention, the control unit is adapted to control the light source in order to modify the wavelength of the excitation radiation. In this way the control unit may tune the wavelength of the light source that generates

the excitation radiation. Typically, this light source is implemented as a laser light source emitting in the NIR range. Due to varying external conditions, e.g. varying temperature, the wavelength of the emitted excitation radiation might become subject to a remarkable drift or offset. This may have dramatic consequences for the scattering processes
5 induced by the excitation radiation inside the volume of interest. In such a case, the spectrum of the return radiation might be shifted correspondingly and/or the efficiency of the spectroscopic process may decrease.

Additionally, the intensity being transmitted through the reference segment of the spatial
10 light manipulation means may no longer correspond to the expected maximum intensity that can be measured when the spectroscopic system is correctly calibrated. Hence, in response to a detection of a decrease of intensity being transmitted through the reference segment, the control unit may stepwise modify the calibration of a laser light source in order to compensate, for instance, a temperature based offset of the excitation light
15 source.

According to a further preferred embodiment of the invention, the control unit is further adapted to rotate or to translate the dispersive optical element. In this way a position mismatch of the spectrum evolving from the dispersive optical element and the spatial
20 light manipulation means can be compensated. Preferably, the dispersive optical element ~~is mechanically coupled to a rotation and/or translation stage that can be electrically~~ controlled by means of the control unit.

According to a further preferred embodiment of the invention, the spatial light
25 manipulation means are implemented as modifiable spatial light manipulation means. In this embodiment the control unit is further adapted to modify the spatial light manipulation means, i.e. to modify the spatial light transmission pattern of the spatial light manipulation means. For example the spatial light manipulation means can be implemented on the basis of a liquid crystal (LC-cell) in combination with an
30 arrangement of crossed polarizers.

The LC-cell is preferably electrically controllable and provides manipulation of the spatially dispersed spectrum. In this embodiment calibration of the spectroscopic system can be realized by a modification of the spatial light manipulation means. Instead of
5 shifting the spatial light manipulation means itself, here, the spatial light transmission pattern of the spatial light modulator can be shifted along the first direction, i.e. in the direction of the spatial separation of the spectral components of the return radiation by keeping the position of the spatial light modulator constant. Implementing the spatial light manipulation means as spatial light modulator also requires realizing the reference
10 segment in a reconfigurable way. Hence, reconfiguration of the spatial light modulator equally refers to reconfiguration of the spatial light transmission mask as well as to a modification of the position of the reference segment.

Consequently, the spectroscopic system can be calibrated by means of the control unit in
15 a plurality of different ways, either by translating the spatial light manipulation means, by modifying or reconfiguring the spatial light manipulation means, by rotating or translating the dispersive optical element or by calibrating or tuning the light source that generates the excitation radiation. Calibration of the spectroscopic system may be performed on the basis of a single one or on the basis of several ones of the above
20 described calibration techniques. For example, calibration of the spectroscopic system ~~can be performed by tuning the laser light source in combination with a translation of the~~ spatial light manipulation means. The various calibration techniques may either be performed simultaneously or sequentially or in any other arbitrary order.

25 According to a further preferred embodiment of the invention, the at least first detector further comprises a segmented detector that has at least two separate detector segments that are separated along the first direction. like e.g. a split detector. In this way a misalignment of the spatial light manipulation means can be directly classified. Whenever a detector segment detects a transmitted intensity that is larger than the intensity
30 detected by the other detector segment, this gives a clear indication that the spatial light

manipulation means are improperly positioned within the optical analysis system.

Depending on the arrangement of the two detector segments, also the direction of the spatial light manipulation means' misplacement can be determined. This allows for a faster calibration of the optical analysis system.

5

According to a further preferred embodiment of the invention, the at least first detector is directly integrated into the spatial light manipulation means at the first position. The at least first detector is either rigidly attached behind the slit aperture of the spatial light manipulation means or when available in an appropriate size, the detector itself may
10 represent the slit aperture. In both cases no further optical components are required to transmit or to focus the light that has been transmitted through the reference segment onto the at least first detector.

In another aspect the invention provides a method of calibrating a spectroscopic system
15 that has a light source for generating an excitation radiation and an objective for collecting return radiation from a volume of interest. The return radiation is generated on the basis of scattering processes induced by the excitation radiation inside the volume of interest. The spectroscopic system further has a dispersive optical element for spatially separating spectral components of the return radiation in a first direction and spatial light
20 manipulation means for modulating the spectral components of the return radiation. The method of calibrating of the spectroscopic system comprises detecting radiation that is transmitted through a reference segment of the light manipulation means by means of an at least first detector. The reference segment is at least partially transparent for the excitation radiation and is located at a first position on the spatial light manipulation
25 means. The method of calibrating further comprises calibrating the spectroscopic system on the basis of radiation being detected by means of the at least first detector.

According to a preferred embodiment, calibrating of the spectroscopic system comprises maximizing of radiation being transmitted through the reference segment. The reference
30 segment and in particular the first position specifying the lateral position of the reference

segment on the spatial light manipulation means corresponds to the position of the spectral line of the excitation radiation. Hence, the wavelength of the excitation radiation serves as a reference for the calibration of the optical analysis system. Since the return radiation and hence the optical signal that is subject to spectroscopic analysis intrinsically
5 has a spectral component that corresponds to the wavelength of the excitation radiation, no additional light source for calibrating the spectroscopic system is required. In this way erroneous calibration that is due to insufficient positioning or insufficient alignment of the calibrating light source is not present.

10 According to a further preferred embodiment of the invention, calibrating of the spectroscopic system either comprises translating the spatial light manipulation means along the first direction and/or modifying the wavelength of the excitation radiation by means of the controlling the light source, and/or rotating and/or translating the dispersive optical element and/or reconfiguring a spatial transmission pattern of the spatial light
15 manipulation means.

In still another aspect, the invention provides a computer program product for calibrating an optical analysis system. The spectroscopic system has a light source for generating an excitation radiation and means for transmitting the excitation radiation into
20 the volume of interest. The spectroscopic system further has an objective for collecting return radiation from the volume of interest, a dispersive optical element for spatially separating spectral components of the return radiation in a first direction and spatial light manipulation means for modulating the spectral components of the return radiation. The computer program product comprises computer program means that are adapted to
25 store a first output signal of an at least first detector. The first output signal is generated in response to detect a radiation being transmitted through a reference segment of the spatial light manipulation means.

30 The computer program means are further adapted to store a second output signal of the

at least first detector after a modification of the position of the spatial light manipulation means along the first direction and/or after a modification of the wavelength of the excitation radiation and/or after a modification of the orientation and/or position of the dispersive optical element and/or after a reconfiguration of a spatial transmission pattern
5 of the spatial light manipulation means.

The computer program means are further adapted to compare the first and second output signal of the at least first detector and to repeatedly calibrate the spectroscopic system until the output signal of the detector is indicative of, for instance, a maximum of
10 transmitted radiation.

Further it is to be noted, that any reference signs in the claims are not to be construed as limiting the scope of the present invention.

15 In the following preferred embodiments of the invention will be described in detail by making reference to the drawings in which:

Figure 1 is a schematic diagram of an embodiment of a blood analysis system,

20 Figures 2a and 2b are spectra of the optical signal generated from blood in the skin
~~and from a sample comprising one analyte in a solution,~~

Figure 3 is a spectral weighting function implemented in a multivariate optical element,

25

Figure 4 schematically illustrates a block diagram of the optical analysis system,

Figure 5 schematically illustrates a block diagram of possible detector configurations,

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Figure 6 shows a perspective illustration of the spatial light modulating mask and a corresponding detector,

Figure 7 shows a flowchart of calibrating the optical analysis system.

5

In the embodiment shown in figure 1 the spectroscopic system is schematically illustrated. The spectroscopic system has an optical analysis system 20 for determining an amplitude of a principal component of an optical signal. The spectroscopic system further has a light source 1 for providing light for illuminating a sample 2 comprising a substance having a concentration and thereby generating the principal component. The
10 amplitude of the principal component relates to the concentration of the substance. The light source 1 is a laser such as a gas laser, a dye laser and/or a solid state laser such as a semiconductor or diode laser.

15 The optical analysis system 20 is part of a blood analysis system 22. The blood analysis system further comprises a computational element 19 for determining the amplitude of the principal component, hence for determining the composition of the compound. The sample 2 comprises skin with blood vessels. The substance may be one or more of the following analytes: glucose, lactate, cholesterol, oxy-hemoglobin and/or desoxy-
20 hemoglobin, glycohemoglobin (HbA1c), hematocrit, cholesterol (total, HDL, LDL), triglycerides, urea, albumin, creatinin, oxygenation, pH, bicarbonate and many others. The concentrations of these substances is to be determined in a non-invasive way using optical spectroscopy. To this end the light provided by the light source 1 is sent to a beam splitter 3 which reflects the light provided by the light source towards the blood
25 vessels in the skin. The light may be focused on the blood vessel using an objective 12. The light may be focused in the blood vessel by using an imaging and analysis system as described in the international patent application WO 02/057759.

By interaction of the light provided by the light source 1 with the blood in the blood
30 vessel an optical signal is generated due to Raman scattering and fluorescence. The

optical signal thus generated may be collected by the objective 12 and sent to the dichroic mirror 3. The optical signal has a different wavelength than the light provided by the light source 1. The dichroic mirror is constructed such that it transmits at least a portion of the optical signal.

5

A spectrum 100 of the optical signal generated in this way is shown in figure 2A. The spectrum comprises a relatively broad fluorescence background (FBG) 102 and relatively narrow Raman bands (RB) 104, 106, 108. The x-axis of figure 2A denotes the wavelength shift with respect to the 785 nm of the excitation by light source 1 in wave
10 numbers, the y-axis of figure 2A denotes the intensity in arbitrary units. The x-axis corresponds to zero intensity. The wavelength and the intensity of the Raman bands, i.e. the position and the height, is indicative for the type of analyte as is shown in the example of figure 2B for the analyte glucose which was dissolved in a concentration of 80 mMol in water. The solid line 110 of figure 2B shows the spectrum of both glucose
15 and water, the dashed line 112 of figure 2B shows the difference between the spectrum of glucose in water and the spectrum of water without glucose. The amplitude of the spectrum with these bands is indicative for the concentration of the analyte.

Because blood comprises many compounds each having a certain spectrum which may
20 be as complex as that of figure 2B, the analysis of the spectrum of the optical signal is ~~relatively complicated. The optical signal is sent to the spectroscopic system 20~~ according to the invention where the optical signal is analyzed by a MOE which weighs the optical signal by a weighting function shown e.g. schematically in figure 3. The weighting function of figure 3 is designed for glucose in blood. It comprises a positive
25 part P and a negative part N. The positive part P and the negative part N each comprise in this example more than one spectral band.

Here and in the remainder of this application the distance between a focusing member and another optical element is defined as the distance along the optical axis between the
30 main plane of the focusing member and the main plane of the other optical element.

A computational element 19 shown in figure 1 is arranged to calculate the difference between the positive and negative signal. This difference is proportional to the amplitude of the principal component of the optical signal. The amplitude of the principal
5 component relates to the concentration of the substance, i.e. of the analyte. The relation between the amplitude and the concentration may be a linear dependence.

Figure 4 schematically illustrates a block diagram of the blood analysis system 22 and the optical analysis system 20 in a more detailed way. Here, the optical analysis system 20 is
10 shown as an integral part of the blood analysis system 22. However, the invention is by no means restricted to blood analysis but may be universally applied to various spectroscopic operational areas. In the illustrated embodiment, the optical analysis system 20 has a dispersive optical element 30, a lens 32, a spatial light transmission mask 34 and two detectors 40, 42. The output of the two detectors 40, 42 is coupled into a
15 control unit 60 that is in turn adapted to manipulate the path of the optical beams inside the optical analysis system 20 as well as to calibrate or to tune the light source 1.

The light source 1 is preferably implemented as a laser light source operating in the near infrared spectral range. The light source produces an optical beam of excitation radiation
20 50 that is directed towards the beam splitter 3. The arrangement of beam splitter 3 and objective lens 12 serves to focus the excitation radiation 50 into the volume of interest 4 of the biological sample 2. Inside the volume of interest the excitation radiation typically induces a variety of scattering processes. In particular inelastic scattering processes, like Stokes or Anti-Stokes scattering processes lead to a Raman spectrum that allows for
25 spectral analysis for determination of the composition of the volume of interest 4. Typically, a part of the Raman spectrum is back-scattered and re-enters the objective lens 12 in a counter propagating way with respect to the excitation radiation 50. The collected return radiation is then transmitted through the beam splitter 3 and becomes incident on the dispersive optical element 30.

The dispersive optical element 30 can be implemented by e.g. a transmission or reflection grating, a prism or any other dispersive element that provides spatial separation of spectral components of an incident light beam. The dispersive element 30 provides spatial separation of the spectral components of the incident return radiation in the horizontal direction, as shown in figure 4. The lens 32 provides focusing of the various spectral components 52, 54 of the return radiation to different positions on the spatial light transmission mask 34. Depending on the light transmission pattern of the spatial light transmission mask 34, the various spectral components of the return radiation are selective attenuated or even blocked. In this way a spectral weighting function as required for multivariate optical analysis can be effectively realized.

For an accurate and reliable determination of a concentration of a particular compound of the volume of interest 4, the relative position between the evolving spectrum and the spatial light transmission mask 34 is of high relevance. Already a slight mismatch between the position of the spectrum and the horizontal alignment of the transmission mask 34 may lead to an insufficient result of the optical and spectral analysis of the return radiation.

The transmission mask 34 comprises a slit 36 at a first position that serves as a reference segment. When properly aligned the position of the reference segment 36 corresponds to the position of the spectral component 52 of the return radiation. This spectral component 52 serves as a reference line in the spectrum. Preferably, the reference line is determined by the wavelength of the excitation radiation 50. Typically, the spectrum not only comprises spectral components from inelastic but also from elastic scattering processes that leave the wavelength of the optical radiation substantially unaffected during a scattering process. Moreover, elastically scattered radiation may even represent a major portion of the return radiation. The slit 36 is therefore highly transmissive for the wavelength of the excitation radiation. Hence, radiation that is transmitted through the slit 36 is detected by means of the detector 40 that is adapted to generate a calibration signal that is fed into the control unit 60.

Slit 38 of the transmission mask 34 is located at a different horizontal position compared to slit 36. It therefore serves to attenuate and/or to transmit a spectral component of the return radiation featuring a different wavelength than the excitation radiation 50.

- 5 Typically, the transmission mask 34 comprises a plurality of slits 38 that are located at different horizontal locations on the transmission mask 34. The slits 36, 38 might be implemented as slit apertures. Additionally, they might be combined with neutral density filters for selectively attenuating different spectral components of the return radiation to various degrees.

10

- The transmission mask 34 can be implemented as a fixed transmission mask providing a single spatial transmission pattern. In such a case the optical analysis is dedicated for determining the concentration of a single particular compound in the volume of interest 4. Various compounds or analytes in the volume of interest 4 might be investigated and spectrally analyzed by replacing the transmission mask 34 by another compound specific transmission mask that is dedicated for multivariate optical analysis of a different compound.
- 15

- Alternatively, the transmission mask 34 might be implemented as a reconfigurable transmission mask. This can for example be realized by implementing the transmission mask 34 on the basis of a liquid crystal cell in combination with a crossed polarizer arrangement.
- 20

- Detector 42 serves to detect radiation that has been transmitted through the transmission mask 34. Preferably, some kind of focusing means is placed between transmission mask 34 and detector 42 in order to collect a plurality of transmitted spectral components onto the detector 42. Hence, detector 42 generates an output signal in response to detect a plurality of transmitted spectral components. The output signal of detector 42 is therefore directly indicative of the concentration of a particular compound that can be calculated by means of the computational element 19.
- 25
- 30

The calibration signal generated by means of detector 40 is provided to the control unit 60 that in turn is adapted to manipulate the horizontal position of the transmission mask 34, to shift or to rotate the dispersive optical element 30 or to tune the light source 1.

- 5 Whenever the light intensity detected by detector 40 does not correspond to an intensity that is expected for an accurate calibration of the optical analysis system, the control unit may successively modify the position or orientation of the optical components 30, 34 or may tune the light source 1 until the intensity detected by detector 40 corresponds to an expected value. Additionally, the control unit 60 may perform a position scan of
10 transmission mask 34 in order to maximize the light intensity detected by detector 40.

In this way the intrinsically present excitation radiation component of the collected return radiation can be effectively exploited for calibration of the optical analysis system
20.

15

- Figure 5 shows an alternative arrangement of the two detectors 40, 42 with respect to the spatial light transmission mask 34. Here, detector 40 that is adapted for detection of the calibration signal 52 is positioned directly behind the slit 36 of the transmission mask 34. In this way no additional optical means, like lenses are required for directing the
20 transmitted radiation onto the detector 40. Additionally, by mechanically fixing or ~~mechanically coupling detector 40 to the transmission mask 34, the detector 40 follows~~ any movement of the transmission mask 34.

- Moreover, figure 5 also depicts a collection lens 56 that serves to focus transmitted
25 spectral components of the return radiation 54 onto the detector 42 for multivariate optical analysis.

- Figure 6 shows a perspective illustration of the transmission mask 34 and the detector 40. The transmission mask 34 features three slit apertures 36, 38, 39 that serve to
30 transmit a corresponding spectral component of the return radiation. In particular, slit

aperture 36 serves as reference segment of the transmission mask 34 and is therefore horizontally positioned in such a way that it provides transmission of an excitation radiation spectral component of the return radiation 52.

- 5 Detector 40 is implemented as a split detector that has at least two detection segments 62, 64. In this way the detector 40 not only allows to determine whether the optical analysis system is not properly calibrated but also provides information of a type of positional mismatch between the spatial distribution of the spectrum and the transmission mask 34. For example, when the two detection segments 62, 64 of the detector 40
10 detect equal transmitted intensity, this gives a clear indication that the optical analysis system is accurately calibrated. Whenever one of the two detection segments 62, 64 detects a larger intensity than the other one, information whether the transmission mask 34 has to be shifted to the left or to the right is directly obtained. In this way a calibration of the optical analysis system can be performed in a less time intensive way,
15 i.e. a scan for a maximum of transmitted intensity has in principle only to be performed along one direction.

Figure 7 illustrates a flowchart for performing the inventive calibration method making use of e.g. a photodiode as detector 40. In a first step 700 radiation that is transmitted
20 through the reference segment 36 is detected. This detected light intensity is stored in a subsequent step 702 as intensity I_x . When no reference intensity is stored in the control unit that allows to determine whether the measured intensity I_x corresponds to the maximum intensity, thereby indicating that the optical analysis system is accurately calibrated, in a subsequent step 704 a system parameter of the optical analysis system is
25 modified. Modification of a system parameter typically refers to translating of the spatial transmission mask 34, translating or rotating of the dispersive optical element 30, tuning or calibrating of the laser light source 1 and reconfiguring of the spatial light transmission pattern of the transmission mask 34.

- 30 Modification of these system parameters either corresponds to a successive modification

- of a single system parameter or to simultaneous or combined modification of a variety of system parameters. After or during modification of those system parameters performed in step 704 radiation that is transmitted through the reference segment is repeatedly detected in step 706. A corresponding intensity referred to as I_{x+1} is stored in step 708.
- 5 Thereafter, the detected light intensities I_x and I_{x+1} are compared in step 710. Comparison of the two light intensities that correspond to slightly different calibration configurations of the optical analysis system typically refers to a comparison of their absolute value.
- 10 In case that the successively detected intensity of I_{x+1} is larger than the previously detected intensity I_x the method continues with step 714 where intensity I_x is replaced by the recently detected intensity I_{x+1} . In this way the intensity I_x principally refers to a temporary maximum detected intensity. After step 714 the method returns to step 704 where again a system parameter of the optical analysis system is modified.
- 15 In the other case, where the recently detected intensity I_{x+1} is not larger than the previously detected intensity I_x , after step 710 the method continues with step 712, where the last modification performed in step 704 is undone. In this case the modification of a system parameter performed in 704 did not lead to an improvement of
- 20 the optical analysis system's calibration. Therefore, the performed modification is ~~cancelled. After this canceling performed in step 712 the method returns to step 704,~~ where another system parameter is preferably subject to modification.
- In this way the optical analysis system is iteratively and constantly calibrated by means of
- 25 seeking for a maximum of transmitted intensity of the reference spectral component.
- Consequently, the invention provides an autonomous calibration of a multivariate based spectrometer. By making use of the excitation radiation as calibration or reference line in the obtained spectrum, no additional light source for calibration of the optical analysis
- 30 system is needed.

LIST OF REFERENCE NUMERALS

	1	light source
	2	sample
5	3	beam splitter
	4	volume of interest
	12	objective
	19	computational element
	20	optical analysis system
10	22	blood analysis system
	30	dispersive element
	32	lens
	34	spatial light transmission mask
	36	slit
15	38	slit
	40	detector
	42	detector
	50	excitation radiation
	52	return radiation
20	54	return radiation
	56	lens
	60	control unit
	62	detection segment
	64	detection segment
25		

CLAIMS

1. A spectroscopic system for determining a principal component of an optical signal, the optical signal comprising return radiation from a volume of interest (4), the spectroscopic system comprising:
- a light source (1) for generating an excitation radiation, the excitation radiation
5 (50) being adapted to be transmitted into the volume of interest,
 - an objective (12) for collecting return radiation from the volume of interest,
 - a dispersive optical element (30) for spatially separating spectral components of the return radiation in a first direction,
 - spatial light manipulation means (34) for modulating the spectral components of
10 the return radiation, the spatial light manipulation means further having a reference segment (36) at a first position, the reference segment being at least partially transparent for the excitation radiation,
 - at least a first detector (40) for detecting radiation being transmitted through the reference segment,
 - 15 - a control unit (60) being adapted to calibrate the optical analysis system on the basis of the radiation being detected by means of the at least first detector.
2. The spectroscopic system according to claim 1, wherein the reference segment (36) comprises a slit aperture and the first position substantially corresponds to the
20 wavelength of the excitation radiation.
3. The spectroscopic system according to claim 1, wherein the control unit (60) is adapted to translate the spatial light manipulation means (34) along the first direction.
- 25 4. The spectroscopic system according to claim 1, wherein the control unit (60) is adapted to control the light source (1) in order to modify the wavelength of the excitation radiation (50).

- 24 -

5. The spectroscopic system according to claim 1, wherein the control unit (60) is adapted to rotate or to translate the dispersive optical element (30).
6. The spectroscopic system according to claim 1, wherein the spatial light manipulation means (34) are modifiable, the control unit (60) being further adapted to modify the spatial light manipulation means.
7. The spectroscopic system according to claim 1, wherein the at least first detector (40) comprises a segmented detector having at least two detector segments (62, 64) being separated along the first direction.
8. The spectroscopic system according to claim 1, wherein the at least first detector (40) being integrated into the spatial light manipulation means (34) at the first position.
9. A method of calibrating a spectroscopic system having a light source (1) for generating an excitation radiation (50) being adapted to be transmitted into a volume of interest (4), an objective (12) for collecting return radiation from the volume of interest, a dispersive optical element (30) for spatially separating spectral components of the return radiation in a first direction and spatial light manipulation means (34) for modulating the spectral components of the return radiation, the method of calibrating comprising the steps of:
- detecting radiation being transmitted through a reference segment (36) of the spatial light manipulation means by means of an at least first detector (40), the reference segment being at least partially transparent for the excitation radiation and being located at a first position on the spatial light manipulation means,
 - calibrating the spectroscopic system on the basis of radiation being detected by means of the at least first light detector.
10. The method according to claim 9, wherein calibrating of the spectroscopic system

- 25 -

comprising maximizing the radiation being transmitted through the reference segment.

11. The method according to claim 9, wherein calibrating of the spectroscopic system further comprising the steps of:

- 5 - translating the spatial light manipulation means along the first direction, and/or
- modifying the wavelength of the excitation radiation by means of controlling the light source, and/or
- rotating and/or translating the dispersive optical element, and/or
- reconfiguring a spatial transmission pattern of the spatial light manipulation
- 10 means.

12. A computer program product for calibrating a spectroscopic system, the spectroscopic system having a light source (1) for generating an excitation radiation (50) being adapted to be transmitted into a volume of interest (4), an objective (12) for

15 collecting return radiation from the volume of interest, a dispersive optical element (30) for spatially separating spectral components of the return radiation in a first direction and spatial light manipulation means (34) for modulating the spectral components of the return radiation, the computer program product comprising computer program means being adapted to:

- 20 (a) store a first output signal of an at least first detector (40), the first output signal being generated in response to detect a radiation being transmitted through a reference segment (36) of the spatial light manipulation means,
- (b) store a second output signal of the at least first detector after a modification of the position of the spatial light manipulation means along the first direction and/or
- 25 after a modification of the wavelength of the excitation radiation and/or after a modification of the orientation and/or position of the dispersive optical element and/or after a reconfiguration of a spatial transmission pattern of the spatial light manipulation means,

- 26 -

- (c) compare the first and second output signal of the at least first detector,
- (d) repeat steps (a) to (c) until the output signal is indicative of a maximum of radiation being detected by means of the at least first detector.

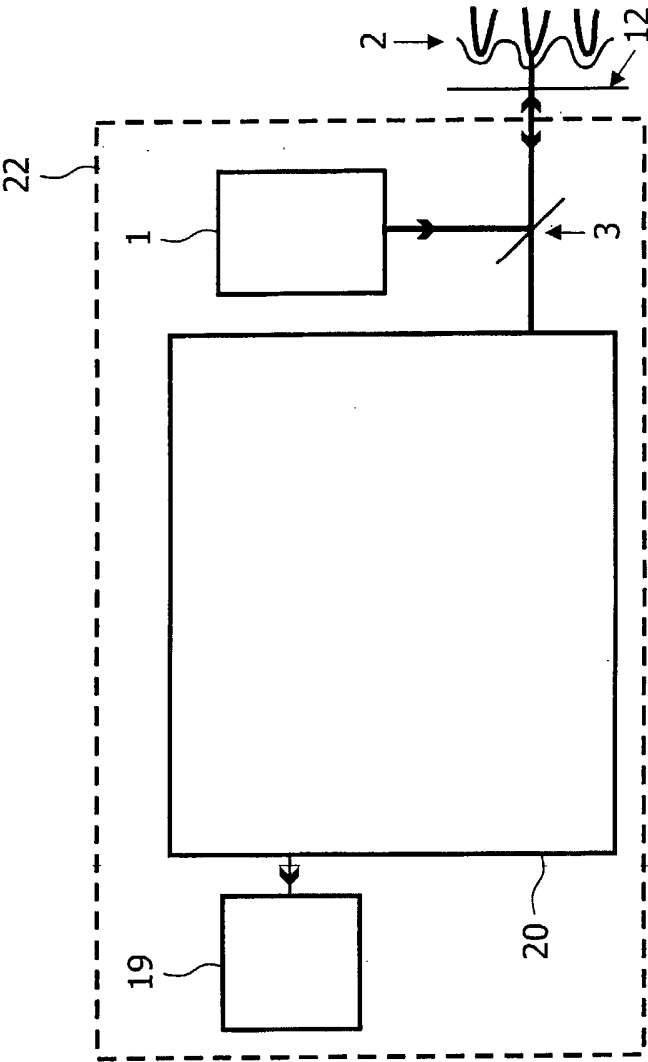


FIG.1

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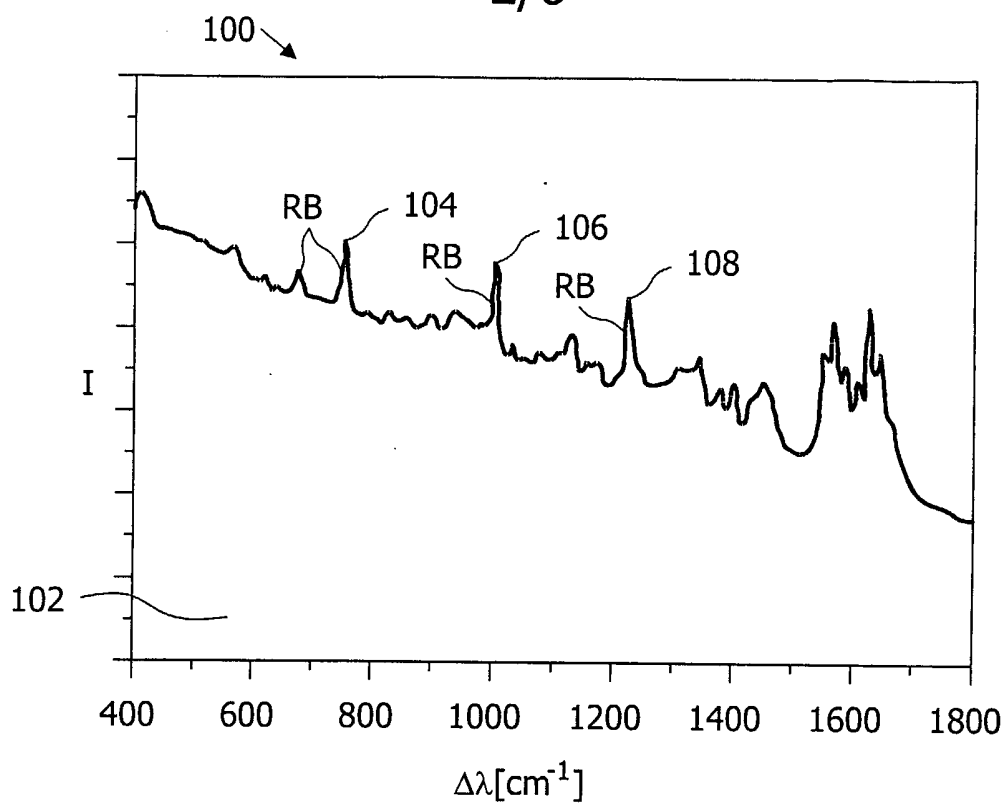


FIG.2A

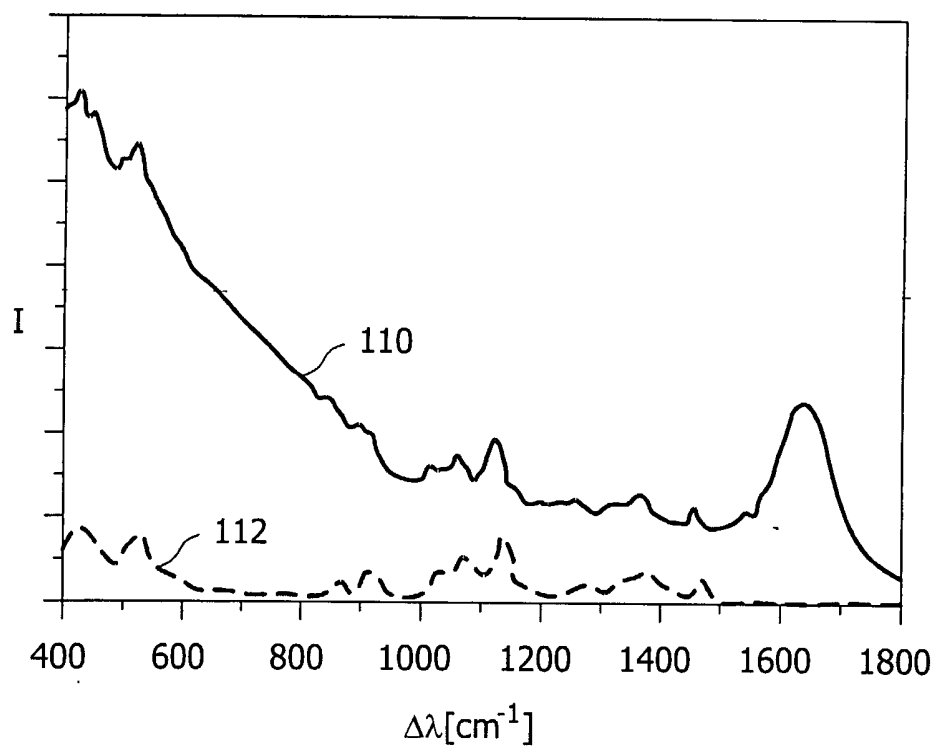


FIG.2B

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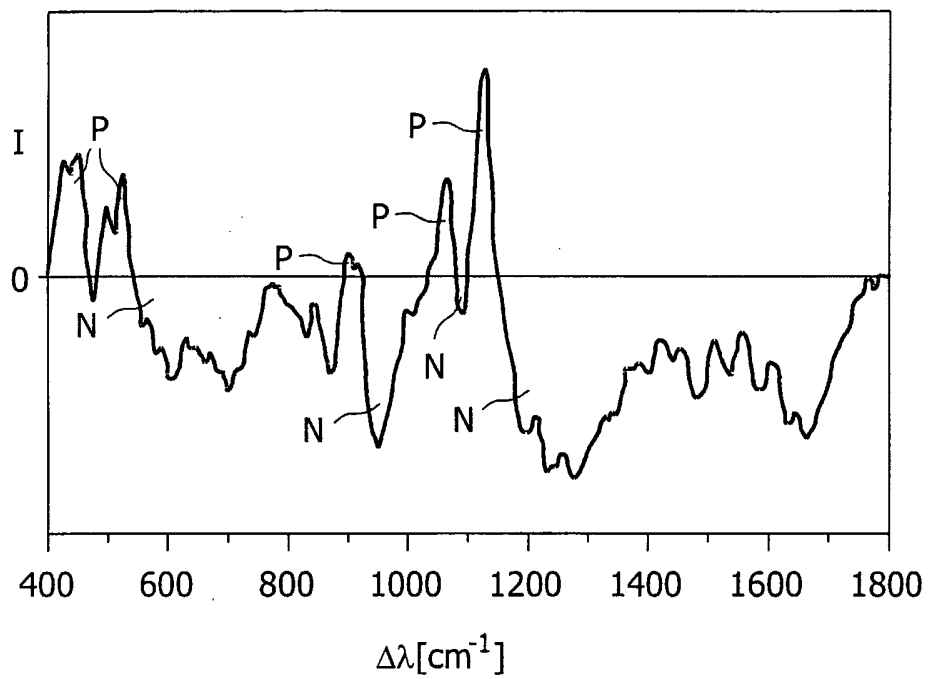


FIG.3

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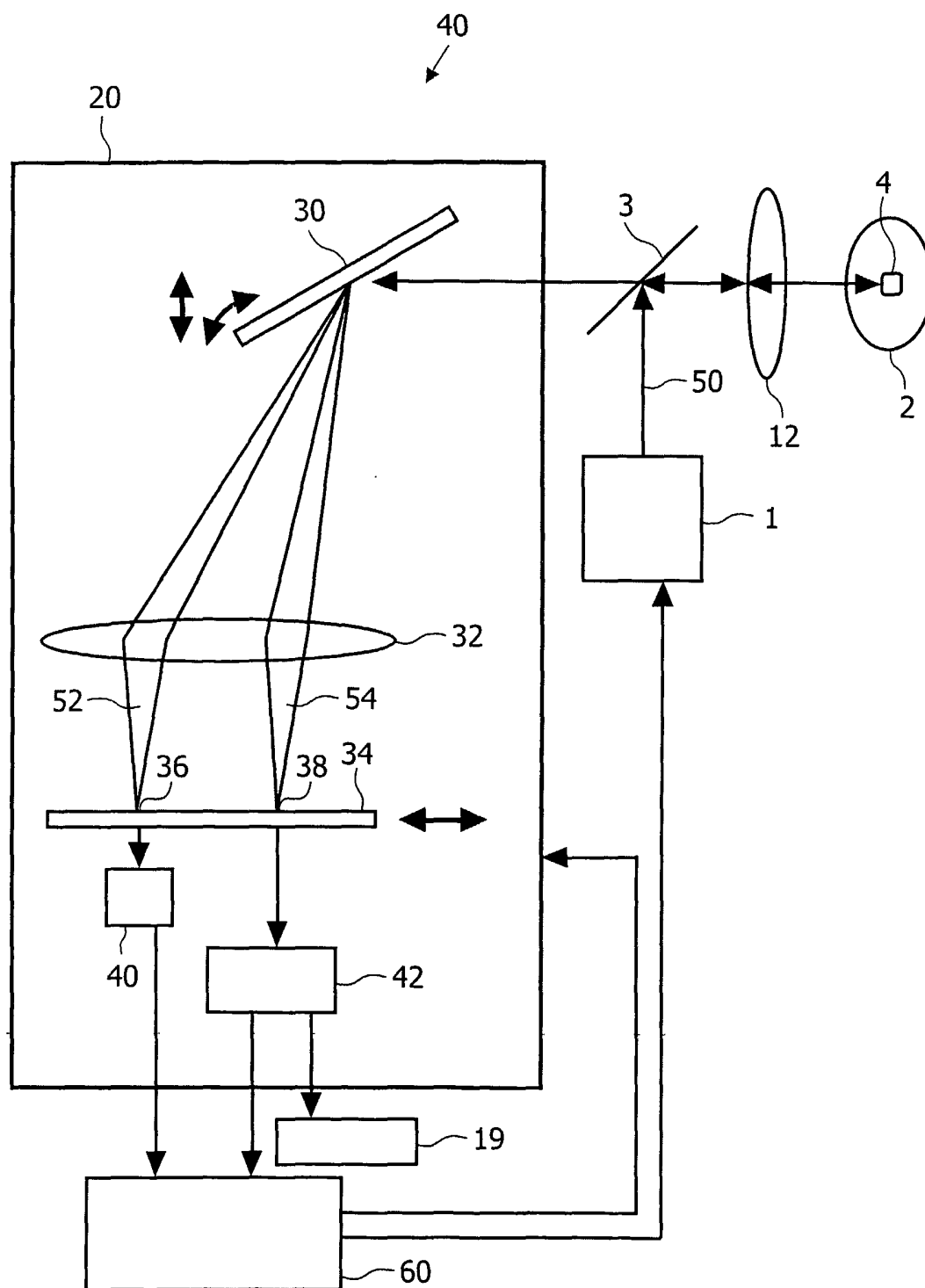


FIG.4

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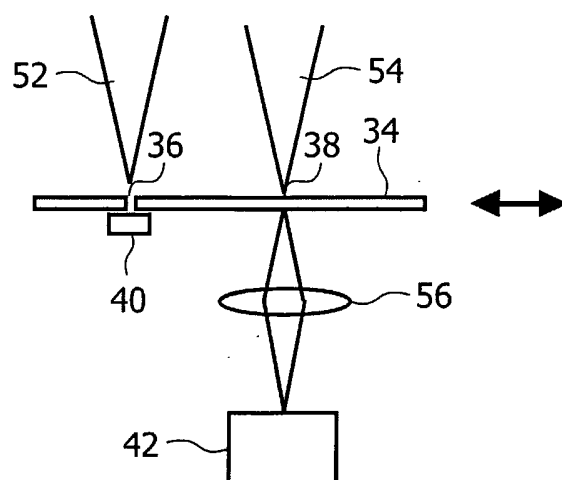


FIG.5

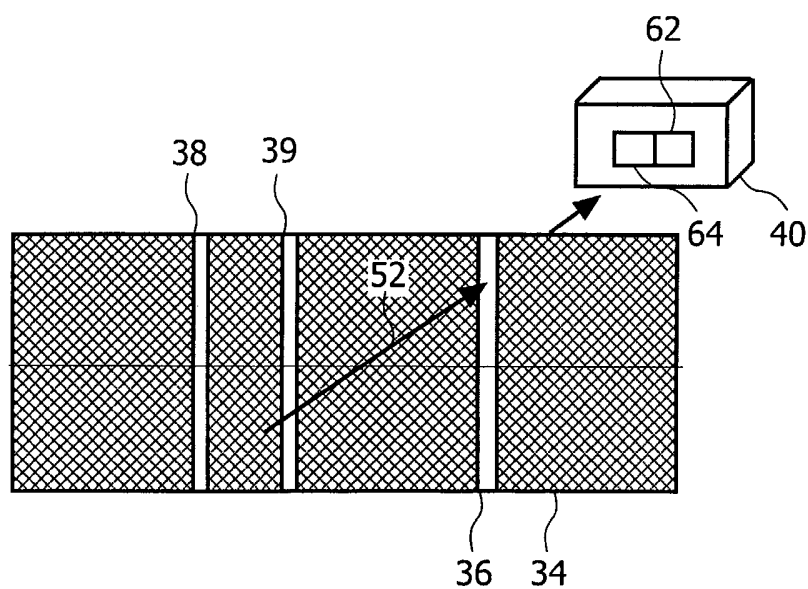


FIG.6

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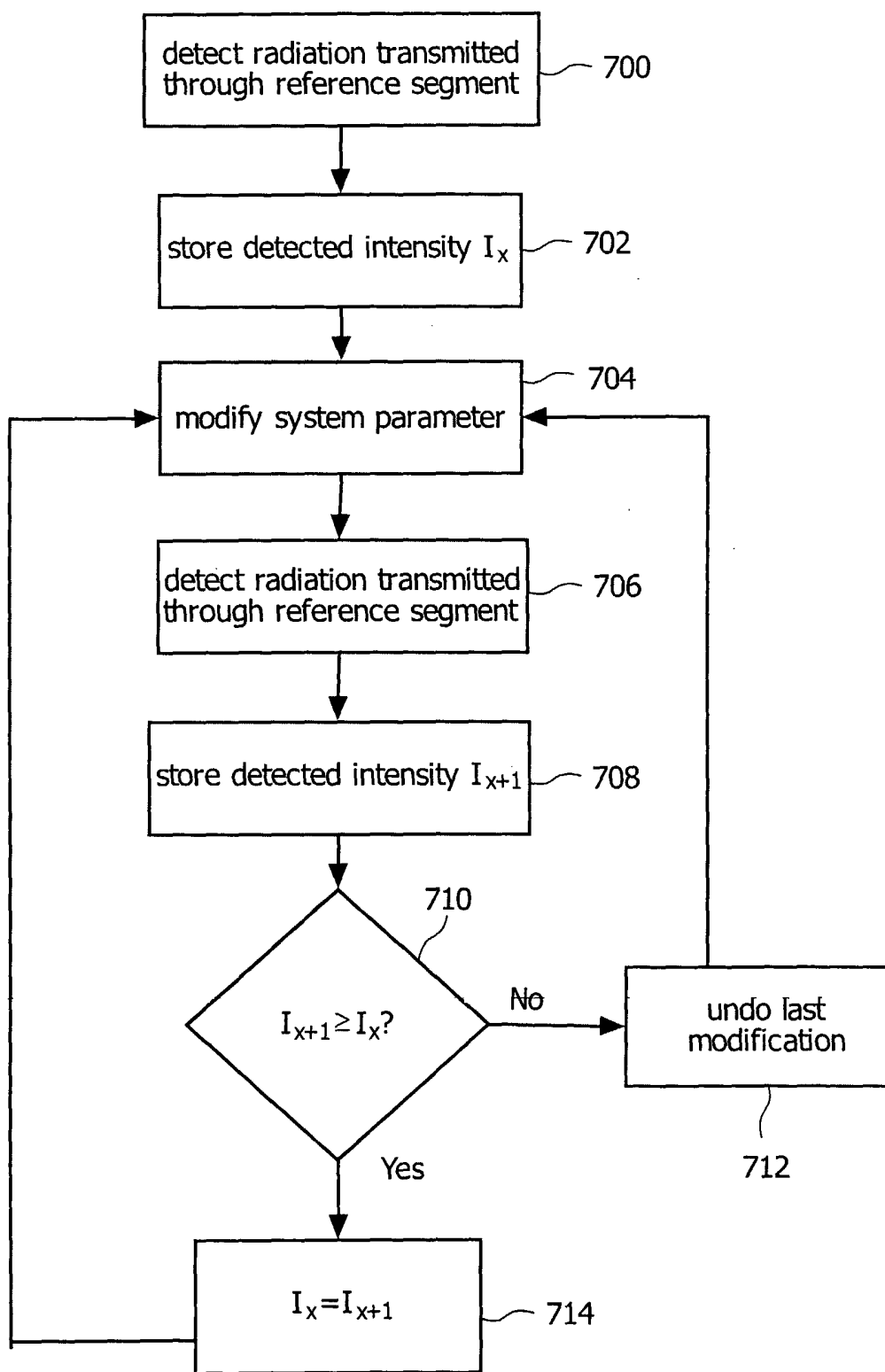


FIG.7

INTERNATIONAL SEARCH REPORT

Inter. Appl. No.
PC 17 182005/052558

A. CLASSIFICATION OF SUBJECT MATTER
G01J3/36 G01J3/04

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)
G01J G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	JP 61 266925 A (TOKYO RIKAI KIKAI KK) 26 November 1986 (1986-11-26) abstract figures 1,2	1,2,4, 7-9
X	US 5 504 575 A (STAFFORD ET AL) 2 April 1996 (1996-04-02) abstract column 2, line 55 - column 5, line 35 column 7, line 18 - line 30 figures 1-4	1,4,9
Y	----- -/--	2,3,5-8, 10-12

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

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PCT/IB2005/052558

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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